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DuPont Chambers Works Waste Minimization Project

Chambers Works – Deepwater, New Jersey

May, 1993

This report is being presented to the United States in satisfaction of the pollution prevention requirements of Section V of the Consent Decree in *U. S. v. DuPont*, Docket Number: 91cv768(JFG)

Inquiries concerning the information contained
in this report should be directed to:

C. S. Hoffman, Jr.
DuPont
Chambers Works
Deepwater, NJ 08023

Foreword

In May of 1993, the EPA and DuPont completed a joint two-year project to identify waste reduction options at the DuPont Chambers Works chemical site in Deepwater, New Jersey. This report describes the proceedings and results of that project. It has been published in hope of providing useful information about methodologies for waste reduction programs in the process industries, and about implementing specific waste reduction options on various chemical processes.

The DuPont waste minimization methodology, one of the methodologies examined in this report, was established in support of the company's commitment to specific environmental goals:

- to reduce hazardous waste by 35% from 1990 to 2000. The company has already reduced hazardous waste by 35% from 1982 to 1990.
- to reduce toxic emissions to the air (from U.S. sites) by 60% from 1987 to 1993.
- to reduce emissions of the EPA's special list of 17 hazardous chemicals by 50% from 1987 to 1995.

DuPont has also committed to goals for reducing or eliminating CFC production, energy consumption, carcinogenic air emissions, and toxic discharges to landfill. To meet these commitments, the company is attempting to incorporate waste reduction into its everyday working culture. As DuPont CEO Edgar Woolard has said, "we have to put behind us the notion that the inevitability of some waste generation therefore makes any waste acceptable."

This report is divided into five sections.

Section 1: Executive summary. An overview of the entire project.

Section 2: Project Methodology. A description of the scope and goals of the project, its participants, and the methodology used to conduct waste minimization assessments on 15 processes at the Chambers Works site.

Section 3: Case Studies. Fifteen waste minimization assessment reports.

Section 4: Methodology Critique. An overview, comparison, and critique of the EPA and DuPont methodologies for waste reduction programs. Also discussed is the Responsible Care® program of the Chemical Manufacturer's Association (CMA), an important influence upon the DuPont methodology.

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SECTION **1**

Executive Summary

This report describes the proceedings and results of the EPA/DuPont Chambers Works Waste Minimization Project. The report is divided into five sections:

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Section 2: The EPA/DuPont Chambers Works Waste Minimization Project. A description of the scope and goals of the project, its participants, and the methodology used to conduct waste minimization assessments for 15 processes at the Chambers Works site.

*Section 3: **Case Studies***. Fifteen waste minimization assessment reports.

*Section 4: **Methodology Critique***. An overview, comparison, and critique of the EPA and DuPont methodologies for waste reduction programs. Also discussed is the Responsible Care® program of the Chemical Manufacturer's Association (CMA), an important influence upon the DuPont methodology.

*Section 5: **Technology Exchange***. A summary of implementation options generated by the 15 assessments and a post-assessment search of the technical literature.

Project Methodology

The joint waste minimization project of the EPA and DuPont had three primary goals:

- to identify methods for the actual reduction or prevention of pollution for specific chemical processes at the Chambers Works site,
- to generate useful technical information about methodologies and technologies for reducing pollution which may help the EPA assist companies implementing pollution prevention/waste minimization programs, and
- to evaluate and identify potentially useful refinements to the EPA and DuPont methodologies for analyzing and reducing pollution and/or waste generating activities.

Project Scope

The Chambers Works Waste Minimization Project involved about 150 people at the site who devoted more than 12,000 person-hours to the project. A brief history of the project is provided below:

- May 1991: Creation of the EPA/DuPont project team
- May 1991–June 1992: Selection of 15 waste streams for inclusion in the project
- June 1992–August 1992: Area preparation
- August 1992–November 1992: Assessment phase

Waste Stream Selection

Five processes each were selected from three categories:

Category 3: Processes for which no recent waste minimization and/or pollution prevention assessment analysis has been performed.

Category 2: Processes which have shown little or no progress in waste minimization or pollution prevention.

Category 1: Processes which have shown significant progress in waste minimization or pollution prevention.

In choosing the 15 waste streams, it was the intent of the EPA/DuPont project team to develop a group of assessments that are diverse in terms of process type, mode of operation (i.e., batch or continuous), waste type, disposal media, and relative success in identifying good waste reduction options.

Assessment Methodology

The assessments typically involved the following steps:

- *Assessment team formation*. The project team worked with management to form multidisciplinary assessment teams for the 15 assessments.
- *Area preparation*. Each assessment began with data collection and an inspection of the process area.
- *Option generation*. For seven of the 15 assessments, brainstorming sessions were convened to generate waste reduction options.
- *Option screening*. The assessment teams for five assessments applied the weighted-sum method to screen and prioritize options.
- *Feasibility evaluation*. Economic evaluations determined the net present values (NPV) and internal rates of return (IRR) for waste reduction options.

Assessment Results

To date, seven of the 15 processes have implemented waste reduction options. Without those implementations, their wastes would have totaled 4,004,000 lbs per year. They now total 1,075,000 lbs per year, a reduction of 73%. The total capital requirement for these seven processes was $3,085,000.

The other eight processes are now in various stages of implementing waste reduction projects. Their combined waste streams total 4,934,000 lbs per year. The assessments identified options that could reduce this number by 34% to 3,250,000 lbs. Total capital cost for implementing the waste reductions is $3,600,000. A brief follow-up note will be provided to the EPA in one year to summarize the implementation status for these eight processes.

If the recommended options for all 15 case studies are implemented, and if they achieve the predicted waste reductions, then DuPont will save $14,900,000 per year (using the DuPont methodology for economic evaluations). These savings are itemized below:

- $1,645,000 in waste disposal costs (treatment, handling, packaging, transportation, etc.)
- $2,185,000 from improved product recovery (reduced raw materials consumption, reduced utilities use, etc.)
- $11,070,000 from such process improvement benefits as increased uptime, increased capacity, improved quality, etc.

Case Studies

In choosing the 15 waste streams, it was the intent of the EPA/DuPont project team to develop a group of assessments that are diverse in terms of process type, mode of operation (i.e., batch or continuous), waste type, disposal media, and relative success in identifying good waste reduction options.

The 15 case studies (assessment reports) describe waste streams, the processes that generate them, the incentives for reducing the wastes, the waste reduction options generated by members of assessment teams, the technical and economic evaluations of the best options, and the key learnings for other waste reduction efforts.

The 15 assessments are summarized below.

Category 3:

Case Study 1: Specialty Alcohols
A reduction in product impurities permits elimination of waste from a product wash step.

Case Study 2: Organic Salt Process
A waste reduction effort extends its scope to an "upstream process" for possible source reductions.

Case Study 3: Nitroaromatics
Improved flow control is the key to waste reduction in this distillation process.

Case Study 4: Diphenol Ether Process
Balancing the potential for waste reduction with operational safety.

Case Study 5: CAP Purification
Viable waste reductions are difficult to identify in old processes.

Category 2

Case Study 6: Polymer Vessel Washout
High-pressure water cleaning eliminates the use of a hazardous solvent.

Case Study 7: Reusable Tote Bins
Returnable product containers eliminate 55-gallon drums.

Case Study 8: Monomer Production
A reaction/distillation process achieves waste reduction through better process control.

CASE STUDY 9: CAP ISOMERS PROCESS
Switching from batch to continuous feeding of a chemical stabilizer reduces waste in a distillation process.

CASE STUDY 10: WIPED FILM EVAPORATOR
Existing technology for reducing waste through increased product recovery.

Category 1

CASE STUDY 11: SPECIALTY SURFACTANT
A partnership between customer and manufacturer leads to the elimination of CFC from a surfactant product.

CASE STUDY 12: CAC PROCESS
Involving people from all disciplines in waste reduction effort is a key factor in eliminating a waste stream.

CASE STUDY 13: SOLVENT EMISSIONS
Upgrading the filtration system for recovering a metal catalyst has eliminated solvent emissions.

CASE STUDY 14: SAC PROCESS
Improvements in raw material quality open the door to substantial waste reductions.

CASE STUDY 15: DISTILLATION TRAIN
Relaxing cross-contamination limits in a multiproduct process helps reduce waste.

The accumulated experience of the 15 assessments yielded a number of key learnings for waste reductions in the process industries:

- It is important to consider all business objectives when trying to minimize waste. Waste reduction is often interrelated with such other business objectives as quality improvement, increased yield, increased capacity, shorter cycle time, etc.
- The effective elimination or reduction of a waste stream can often proceed in a series of small improvements, rather than in the implementation of a single solution. Waste reductions in one part of a process often produce opportunities for further reductions in other parts of the process.
- There is sometimes a trade-off between the safe operation of a process and pollution prevention.
- Recycling solutions still have their place, but only after all practical source reductions have been made.
- Waste reductions will increasingly involve collaboration between producers and customers.
- Waste minimization assessments need not be confined to the process area. They can be performed by the sales force to explore opportunities offered by "green" marketing.
- Many waste reductions can be identified and implemented by line workers. Operators and mechanics should be included on waste assessment teams.
- Equipment startups and shutdowns are a major source of waste.
- Quality need not be sacrificed to achieve waste reductions.
- Improved process control can often result in dramatic waste reductions.

Methodology Critique

Most waste reduction methodologies consist of the same basic steps:

- Chartering
- Waste stream selection
- Assessment phase
- Implementation
- Auditing

What distinguishes a methodology in terms of success or failure is the tools they provide for assessment teams at the process level. Tools are methods for accomplishing the tasks prescribed by a methodology.

The recent publication of the EPA's *Facility Pollution Prevention Guide* represents a major upgrade to the methodology. It places additional emphasis on the management of a continuous waste reduction program.

An important strength of the new methodology is its recognition that pollution prevention requires the participation from all levels of the organization. It contains well-articulated prescriptions around management commitment.

The *Pollution Prevention Guide* prescribes flexibility in the choice of assessment tools to suit local circumstances. But the DuPont members of the Chambers Works project team believe that the tools featured by the Guide in dedicated chapters and appendixes exhibit a bias toward formal and rigorous tools. Such featured methods as the total cost assessment, life cycle analysis, and weighted-sum rating and ranking all have simpler counterparts. The DuPont team members feel that the more rigorous tools work best when applied to very complex problems with many factors to consider. But most problems addressed at the process area level are amenable to quicker, less formal methods.

An upgraded methodology might combine the strengths of the EPA chartering tasks with the flexibility at the process level of the DuPont method. Documentation supporting such a methodology could present a variety of tools, describe how they are applied, provide clear examples, and include helpful forms or checklists.

Waste Reduction Opportunities for Organic Chemical Processes

The waste reduction options generated during the 15 assessments of the Chambers Works Waste Minimization Project represent a body of practical experience that can benefit others throughout the chemical processing industries. These options are compiled here and grouped by four waste stream types.

1. Solvent Wash Waste

Cleaning of equipment is one of the most common areas of waste generation. Three of the 15 assessments focused on solvent waste reduction.

2. Solvent Waste (other than wash waste)

Solvents are commonly used in the chemical industry as carriers to dissolve and dilute reactants or products, or as washing agents to wash out impurities from products. Five of the 15 assessments focused on solvent waste minimization.

3. Waste from Reaction Byproducts

Most processes that involve chemical reactions also involve side reactions which produce byproducts. The costs associated with the byproducts consist not only of the increasing disposal costs, but also the cost of raw materials and product yield. Six of the 15 assessments focused on reduction of byproducts.

4. Tar Waste

In many distillation processes, tar wastes accumulate in the bottoms of distillation columns. The Chambers Works project encountered three major contributors to tar waste:

- Reaction byproducts or impurities in the product crude.
- Thermal decomposition or polymerization within the column reboiler.
- The presence of such additives as stabilizers or inhibitors within the product crude.

Six of the 15 assessments focused on reduction of tar wastes.

SECTION 2

Project Methodology

This section describes the joint waste minimization project of the EPA and DuPont. The project, which lasted from May 1991 to May 1993, had three primary goals:

- To identify methods for the actual reduction or prevention of pollution for specific chemical processes at the Chambers Works site.
- To generate useful technical information about methodologies and technologies for reducing pollution which may help the EPA assist companies implementing pollution prevention/waste minimization programs.
- To evaluate and identify potentially useful refinements to the EPA and DuPont methodologies for analyzing and reducing pollution and/or waste generating activities.

Under the leadership of an EPA/DuPont project team, waste minimization assessments were performed for 15 industrial processes at the DuPont Chambers Works chemical site in Deepwater, New Jersey. Individual assessment teams from each process applied the EPA and DuPont methodologies to identify and evaluate ideas for reducing waste.

The Chambers Works Site

The Chambers Works site, one of the largest in DuPont, employs nearly 3,000 people and produces more than 600 different chemicals. The site contains five operating areas and an R&D group. Each of the operating areas contain several production facilities which in turn can contain several processes. Chambers Works generates about 1,000 waste streams to various media, including air, water, and land.

Chambers Works has an ongoing waste reduction program. Between 1990 and 1991, this program achieved a number of important reductions in wastes generated by on-site processes:

- Dissolved organics in wastewater reduced by 9.5%
- Wastes sent to off-site treatment or disposal facilities reduced by 35.3%
- Wastes incinerated on-site reduced by 7.9%
- Wastes sent to secure landfill reduced by 45.6%

Most, but not all, of the wastes generated at Chambers Works are treated at one of three on-site disposal facilities. These facilities are:

- *A wastewater treatment plant.* This facility treats all Chambers Works wastewater streams, as well as wastewater streams from other companies.
- *An incineration facility.* The incinerator disposes of the site's liquid waste that is unsuitable for wastewater treatment. Exceptions include some streams that contain valuable materials (e.g., precious metal catalysts) which Chambers Works is not equipped to recover. Those streams are sent to outside reclamation facilities.
- *A secure landfill.* The landfill receives the site's solid hazardous waste.

Project Scope

The Chambers Works Waste Minimization Project evolved from a consent order entered in May, 1991. Project planning was prescribed by the terms of the consent order. The project involved about 150 people at the site who devoted more than 12,000 person-hours to the project. The 15 assessments identified 4.6 million pounds of waste reductions, three million of which have already been implemented. A brief history of the project is provided below:

- May 1991: Creation of the EPA/DuPont project team
- May 1991–June 1992: Selection of 15 waste streams for inclusion in the project
- June 1992–August 1992: Area preparation (information gathering, creation of assessment teams)
- August 1992–November 1992: Assessment phase (waste minimization assessments performed)

The EPA/DuPont Project Team

In May of 1991, an EPA/DuPont project team was formed to implement the Chambers Works project. The team consisted of EPA personnel from Region 2 headquarters in New York, from various EPA headquarters offices in Washington, DC, and from the Risk Reduction Engineering Laboratory in Cincinnati. The DuPont members were four chemical and environmental engineers from the R&D organization at Chambers Works.

Waste Stream Selection

In choosing the 15 waste streams, it was the intent of the EPA/DuPont Project Team to develop a group of assessments that are diverse in terms of process type, mode of operation (i.e., batch or continuous), waste type, disposal media, and relative success in identifying good waste reduction options.

Waste stream selection began with the DuPont project team members leading a plant-wide effort to prioritize the waste streams generated at Chambers Works. They began by collecting waste information, including a list of waste streams and their volumes in pounds. The project team then organized five brainstorming sessions with key people from each operational area. These meetings produced a first cut of 168 waste steams. The project team then reduced this list to thirty candidates based on the following two sets of criteria: waste stream classification and EPA selection criteria.

From the preliminary list of 30, the EPA team members selected the final 15 waste streams.

Waste Stream Classification

One of the criteria for selecting processes for this study is that five would have to be selected from each of three categories:

Category 3: Processes for which no recent waste minimization and/or pollution prevention assessment analysis has been performed.

Category 2: Processes which have shown little or no progress in waste minimization or pollution prevention.

Category 1: Processes which have shown significant progress in waste minimization or pollution prevention.

The 15 waste streams eventually chosen for this project satisfied the classification criteria at the time of their inclusion on the candidate list of 30. But before the assessment phase began, the processes that generated three of the Category 2 streams began or committed to implementations that would eliminate or greatly reduce the wastes. In essence, they became Category 1 waste streams. This is not surprising given the definition of Category 2 wastes; the facilities that generated them were already at work to reduce them.

One of the processes generating Category 3 wastes also implemented a project which eliminated the waste entirely.

EPA Selection Criteria

The EPA specified a number of additional criteria to guide DuPont in the selection of the 30 candidate processes. EPA provided these criteria to ensure a variety of candidate processes from which to choose the 15. This in turn would allow DuPont to assess a well-rounded set of processes to provide as many different examples to industry as possible.

The EPA selection criteria were:

- Only ongoing processes at Chambers Works could be considered.
- The process must produce either a high-volume waste stream, or a waste stream containing high concentrations of hazardous constituents.
- At least one process from each Chambers Works operating area must be selected.
- A process could not be rejected because it is unique or proprietary.
- The selected candidates would include both batch and continuous processes.
- Prioritizing waste streams to select processes would proceed in accordance with the process outlined by the EPA methodology.

In addition, the selected processes should meet as many as possible of the following criteria:

- Candidate processes should either use or release one of the chemicals on the EPA "list of 17", or else meet all other project-specific criteria.

- The processes should have the potential for pollution prevention technology transfer to the EPA or other companies.
- The selected processes should be of types for which little or no technical information for pollution prevention is readily available.
- The selected candidates should include processes that release waste to a variety of media: air, land, and water.

These criteria may not necessarily lead other plants to choose the best streams for waste reduction opportunities. However, EPA believes that they helped to identify 15 Chambers Works processes which had both high potential for waste reductions and for providing a good breadth of technical information for technology transfer.

Final Selection
In February of 1992, EPA project team members arrived at Chambers Works to inspect the facilities that generated the 30 candidate waste streams and to attend process overview sessions. The information they received during their visit guided their selection of the final 15 waste streams.

Assessment Methodology

The assessments were performed using the EPA and DuPont methodologies for waste reduction, and typically involved the following steps:

- Assessment team formation
- Area preparation
- Option generation
- Option screening
- Feasibility evaluation

For Category 1 assessments, option generation, screening, and evaluation were performed retrospectively. The assessment teams did not try to generate new options, but tried simply to compile the options that had been considered and reconstruct whatever prioritization of the options had been performed.

Three Category 2 and one Category 3 processes identified successful waste reductions or eliminations before the start of the project's assessment phase. Therefore, like the Category 1 assessments, option generation, screening, and evaluation were performed retrospectively.

Two of the Category 2 processes and all of the Category 3 processes performed all of the assessment steps as prescribed by the EPA methodology.

Assessment Team Formation
The project team worked with management at the five operating areas to form assessment teams for the chosen facilities. Assessment teams varied in size from four to 12 members. They tended to be smaller at those facilities which had already implemented successful waste reductions. They tended to be larger in a few cases where the scopes of the assessments expanded to include other related processes at Chambers Works.

A conscious effort was made to include multidisciplinary representation on the assessment teams. Teams typically included an area supervisor, chemists, engineers, operators, and technicians. All of the teams included at least one, and as many as three, participants from outside the process area to provide objective input. A description of assessment team dynamics is included in Section 4 of this report. In general, the project team found that multidisciplinary participation, and especially the inclusion of line workers on the teams, enhanced the number and quality of the options generated.

Area Preparation

All of the assessments began with data collection and area inspection.

Data collection

For each assessment, the project team collected such process data as operating procedures, flow rates, raw material and product specifications, records of process changes or experimental trials, process costs, etc. Where material balances were not available, the project team created them using the collected process data.

Information about the waste stream was also collected. This included waste stream composition, amounts, disposal media, disposal costs, and such special costs as transportation, handling, and packaging.

Data collection typically took one project team member from four to eight hours, depending on the availability of information and the complexity of the process.

Area inspection

Area inspections were performed for all 15 assessments. These usually began with a meeting of project team members, outside members of the assessment team, and people from the process area. At these meetings, the process operations and material balances were reviewed. Then the participants toured the area. The meeting and inspection together typically took about two hours.

The site inspections were useful for giving outsiders on the assessment team a good understanding of the process in a short time. It also provided an opportunity to talk with process operators and other people who work at the process area.

Option Generation

For the seven assessments in which the EPA methodology was applied, brainstorming sessions were convened to generate waste reduction options. At these meetings, the assessment teams proposed ideas for reducing the target waste stream. Team members were encouraged to suggest ideas regardless of whether they seemed practical at the moment. Scribes captured suggestions and recorded them on cause-and-effect "fishbone" charts. The fishbone charts enabled options to be grouped into such categories as "chemistry", "equipment modification", "new technology", etc. The brainstorming sessions lasted from two to four hours, and generated about 10 to 20 options each.

For the eight retrospective assessments (i.e., assessments on processes which had already begun or completed implementations), no attempt was made to generate additional options. Instead, the assessment teams attempted merely to identify and evaluate the options that had been considered.

Option Screening

The EPA methodology offers several tools for screening options which vary in complexity from simple voting by the assessment team to the more rigorous weighted-sum ranking and weighting. Of the seven assessments which followed the full EPA methodology, five used weighted-sum ranking and weighting to screen the options; the other two used simple voting.

Table 2-1. Selected Criteria with Relative Weights for Five Assessments

	CAP Purification	Nitroaromatics	Organic Salt Process	Diphenol Ether Process	Monomer Production
Reduce Safety Hazards	10	1	10	10	10
Reduce Treatment/Disposal Costs	8	1	1C	-	1
Reduce Waste Quantity	10	1	10	10	5
Effect on Product Quality	5	1	10	10	10
Chance of Success	10	1	10	10	8
Fit Corporate Goals	8	1	8	8	-
Enhance Consumer Relations	8	1	5	8	10
Enhance Community Relations	8	1	5	8	8
Reduce Hazardous Toxicity	3	1	4	4	5
Reduce Raw Mat'l Costs	8	1	10	10	8
Low Capital Costs	8	1	10	7	8
Low O&M Costs	8	1	8	7	8
Short Implementation Period	5	1	7	7	6
Ease of Implementation	8	1	6	6	8
Success Within DuPont	9	1	2	-	-
Success Outside DuPont	-	1	1	-	-
Production Not Disrupted	4	1	3	3	10
Permit Requirements	8	1	[illegible]	1	-
Enhance Employee Relations	7	1	1	-	8
Source Reduction	10	1	-	5	6
Best Available Technology	-	1	-	3	-

In those assessments using the weighted-sum method, follow-up meetings were held after the brainstorming sessions. The meetings began with an open discussion of the options. Sometimes, a team concluded that an option did not really reduce waste and removed it from the list. At other times, interdependent options were combined into a single option, or general options were divided into several more specific options.

After the team agreed on the final option list, they generated a set of criteria against which to evaluate the options. Generally, the criteria prescribed by the EPA methodology were adopted as a starting point. Other criteria were often added to reflect company-specific or process-specific concerns. Table 2–1 shows the criteria and relative weights for the five waste streams that underwent formal ranking and weighting.

After the criteria were adopted, each one was assigned a weight, usually between 0 and 10, to signify its relative importance. In some cases, the teams felt that a criterion was not important to a process, or was adequately covered by another criterion. They therefore assigned a value of "0", essentially removing the criterion from the list.

After the weights were established, each option was rated according to how well it fulfilled each criterion with a number from 0 to 10. Multiplying the weight by the rating provided a score for that criterion, and the sum of all the scores of all the criteria yielded the option's overall score.

One assessment team, for the nitroaromatics process, adopted a simplified method in which they assigned a weight of "1" to all criteria. They then assigned ratings of –1, 0, or +1 according to how well an option satisfied each criterion.

Each assessment team was allowed to assign their own weights to the criteria. Not surprisingly, the weights varied from assessment to assessment. The project team did not suggest common weights for all assessments because this would not have met process-specific needs. For example, the criterion "short implementation time" may be less important where demand for a product is soft. One thing that all teams seemed to have in common is that the criteria "safety" and "probability of success" were always more decisive than their assigned weights. A low score for safety was not the same as a similar score for another criterion. If an option ranked high in all criteria except safety or probability of success, it stood no chance of being considered for implementation.

Feasibility Evaluation

Technical evaluations for the top options were performed by the project team with input from the assessment teams. No formal method was used for performing most technical evaluations. The project team found that the discussions of each option during the ranking and weighting sessions usually determined an option's practicality, safety, and effectiveness in reducing waste. Some of the top options require plant or lab trials to determine their technical feasibility.

The most difficult part of the feasibility evaluation was the economic analysis. This required estimates of equipment cost, installation cost, the amount of waste reduction, cost savings to the process, and economic return. For all options that had not already been estimated by the individual facilities, the project team performed the evaluations.

CALCULATING NPV AND IRR

DuPont uses net present value (NPV) and internal rate of return (IRR) as metrics for comparing the relative values of waste reduction options. The NPV is the value to DuPont of an option over time expressed in today's after-tax dollars. The value of future cash flows are discounted to today's dollars using a given discount rate. All NPV calculations in this report use a discount rate of 12%. The IRR is the discount rate at which the NPV of a given option would equal zero.

The DuPont and EPA methodologies offer similar tools for performing economic feasibility evaluations. Both offer a simple payback calculation for projects with low capital costs. Both recommend a calculation of NPV which incorporates expanded time horizons, long-term indicators, and allocation of costs by area. The DuPont methodology offers a short-cut formula to quickly calculate NPV based on a set of assumptions. Otherwise, NPV is usually calculated using computerized spreadsheets.

One point on which the DuPont and EPA methodologies differ is how to handle waste disposal costs. DuPont calculates only the direct cost of waste disposal. But there are other costs associated with waste disposal such as indirect costs, liability costs, and such "soft" costs as community relations. Process engineers make subjective decisions about how these other costs add to or offset the results of an NPV calculation. But the EPA recommends that dollar values be assigned to these other costs and that they be included in the NPV calculation.

For the Chambers Works project, NPVs were calculated in two ways to permit a comparison of the two methodologies. The NPVs labeled "DuPont Method" in the assessment reports use only the direct cost of waste disposal in the calculation. The NPVs labeled "EPA Method" were calculated using dollar values assigned for indirect costs, liability costs, and soft costs. In both cases, the calculations of NPV and IRR were based on a number of assumptions, some of which are listed below:

- a time span of 10 years
- U.S. tax and depreciation rates
- a 4% inflation rate for all cash flows
- startup costs at 10% of investment
- 40% of permanent investment spent in first year, 60% spent in second year, and start-up at the beginning of the third year
- achievement of 50% of the costs and revenues in the first year of operation
- the only terminal value of a project is its working capital liquidation
- calculation made at beginning of year zero
- end-of-year cash flows

When applying the EPA method to calculate NPV, the project team constructed a computerized spreadsheet to estimate the value of each variable in the calculation. These included costs associated with investment, revenue, costs savings, working capital, and one-time charges.

A short-cut method for calculating NPV for quick evaluation of multiple options has been developed by DuPont. This formula is mathematically equivalent to the EPA methodology as long as the assumptions given above are made.

$$NPV(12\%) = (-.91)*I + (-3.3)*(C-R) + (-.50)*WC + (-.54)*OTC$$

where: I = Investment
C = Cost
R = Revenue
WC = Working capital
OTC = One-time charges

In this formula, the assumptions determine the values of the coefficients (the numbers within parentheses). Changing the assumptions would require a change in the coefficient values.

Calculating the investment for an option required an understanding of the impact the option will have upon operating procedures and equipment. At times, the project team used computer modeling to determine this impact. Estimates for equipment costs were aided by the availability of an in-house database of such costs, vendor information, and trade books. These estimates also had to include costs associated with the installation of equipment, such as piping, instrumentation, contingency, escalation, etc.

Estimating changes in operating costs required data for the annual generation of waste, waste disposal media, disposal costs, and any applicable special waste costs such as transportation, handling, and packaging. Operating costs include raw materials, utilities, and labor. The economic evaluations in this report also considered cost savings which are triggered by waste reduction options, but are not directly related to waste reduction. These include improved equipment uptime, increased productivity, faster product changeovers in multiproduct facilities, improved quality, and reduced working capital.

Many options claimed additional product recovery as a benefit. Estimating the value of the additional product depended on whether the generating process was "sold out" (i.e., every pound of product had an immediate buyer) or had slack demand. In slack-demand processes, production can be reduced by an amount equivalent to the amount of product recovered. Thus, the value of additional product recovery equals the variable cost of producing the equivalent amount of new product. In the sold-out processes, there would be no production decrease since every available pound of product is quickly sold. Thus, the value of the recovered product equals its selling price less any additional selling costs.

Many options require laboratory or plant trials to demonstrate their technical feasibility. The cost of these trials were handled as one-time charges and include the cost of engineering, chemists, lab time, etc.

EPA METHOD VS. DUPONT METHOD

The DuPont method calculates only real changes in cash flow resulting from a project. The method recognizes that the economic evaluation is not always the chief determinant of whether a waste reduction option gets approval for implementation. So-called "soft costs" are also considered. But no attempt is made to place a dollar value on these costs.

Examples of such costs are safety, occupational health, and community relations. Soft costs can cause an economically acceptable option to be rejected, or an economically marginal option to be approved. In one of the case studies included in this report, a waste reduction option which had a negative NPV was implemented because of the soft cost of regulatory compliance. Another of the case studies reports implementation of a negative-NPV option because the implementation would enhance customer relations. Conversely, several assessments identified cost-effective options that were rejected because of negative soft costs, i.e., they would compromise safety.

The EPA method suggests a "total cost assessment", which considers four elements:

- extended time horizon
- use of long-term indicators
- allocation of costs by area
- expanded cost inventory

All of these elements are accounted for in the DuPont methodology except for the expanded cost inventory. This element attempts to place dollar values on what DuPont would regard as soft costs. Such intangibles as enhanced public image are quantified and included in the NPV calculation. For the 15 assessments, NPVs and IRRs that were calculated by the EPA method include an allowance for future liability and full disposal costs. But they don't include the intangible benefits as these were judged to be too difficult to estimate.

Another difference between the EPA and DuPont methods is in the way waste disposal costs are estimated. Most of the waste streams in this report are disposed on-site at one of the Chambers Works disposal facilities. The accounting system at Chambers Works charges a process the full fixed and variable costs for the waste it generates. This is the allocation of cost by area recommended by the EPA's total cost assessment. However, the DuPont methodology for calculating disposal cost savings uses only the actual cost saved by DuPont, i.e., the variable costs of waste disposal. The fixed costs associated with the on-site treatment facilities do not significantly decrease with smaller waste volume. These costs are redistributed among the remaining users. In other words, the on-site treatment cost used by a process in economic evaluations is lower than the cost actually paid by the process for waste treatment.

To some extent, the existence of on-site treatment facilities does tend to reduce the incentive for waste reduction when economics are calculated using the DuPont methodology. For marginal cases, an NPV using the full cost of disposal is often calculated in addition to the variable cost-only NPV. In these instances the direct-cost NPV is the primary evaluation tool and the full-cost NPV is considered as a soft benefit. In those cases where waste is disposed off site, the NPV calculated by the DuPont and EPA methodologies are the same.

For most of the 15 assessments, the DuPont and EPA economics did not differ greatly. Discounting of future cash flows diminished the differences between the two calculations, especially for economically attractive options. In fact, disposal costs represented only a small portion (about 11%) of the savings in most cases. Savings from such process improvements as shorter cycle times, yield increases, reduced raw material costs, etc. were usually decisive. The value of these savings is exactly the same whether one uses the EPA or the DuPont method of calculating NPV.

Assessment Results

To date, seven of the 15 processes have implemented waste reduction options. Without those implementations, their wastes would have totaled 4,004,000 lbs per year. They now total 1,075,000 lbs per year, a reduction of 73%. The total capital requirement for these seven processes was $3,085,000. The largest capital project required $2,200,000, while some projects required no capital money at all. The total NPV for the waste reductions was $15,574,000 (using the DuPont methodology). They all had positive economic returns, except for one implementation that was regulatory driven. Economic returns for the implementations tended to be very high because most of them provided benefits other than waste minimization, such as increased yield, productivity, reduced cycle time, etc. All seven implementations achieved source reductions, although some combined source reductions with recycling as well.

The other eight processes are now in various stages of implementing waste reduction projects. Their combined waste streams total 4,934,000 lbs per year. The assessments identified options that could reduce this number by 34% to 3,250,000 lbs. Only one of the eight processes identified an option that would completely eliminate the waste stream. The others identified reductions ranging from

21% to 50%. Total capital cost for implementing the waste reductions is $3,600,000. All eight of the processes identified options with positive economic returns for a total NPV of $23,681,000 (using the DuPont methodology). Most of the processes have begun implementations, but several have placed their implementations on hold pending commitment of resources. A brief follow-up note will be provided to the EPA in one year to summarize the implementation status for these eight processes.

If the recommended options for all 15 case studies are implemented, and if they achieve the predicted waste reductions, then DuPont will save $14,900,000 per year (using the DuPont methodology). These savings are itemized below:

- $1,645,000 in waste disposal costs (treatment, handling, packaging, transportation, etc.)
- $2,185,000 from improved product recovery (reduced raw materials consumption, reduced utilities use, etc.).
- $11,070,000 from such process improvement benefits as increased uptime, increased capacity, improved quality, etc.

Not all waste minimization assessments identify cost-effective waste reductions. The high rate of return for the assessments in this project are probably due to the EPA methodology criteria by which the waste streams were selected. These criteria select waste streams in part for their waste minimization potential, weeding out the streams that are less likely to be reducible. The criteria also tend to select large waste streams which offer more pounds of waste reduction per dollar of capital spending.

When large streams contain valuable products, the value of recovering the product often exceeds the cost of disposal. In fact, disposal costs represented only a small fraction of the savings for many of the assessments in this project. Most of the savings come from other process improvements that result from the waste reduction option, such as improved yield, quality, cycle time, and productivity.

SECTION **3**

Case Studies

This section presents the assessment reports for the 15 waste streams that comprised the Chambers Works project. The reports describe the wastes and the processes that produce them, the incentives for reducing the wastes, the waste reduction options that were generated by assessment teams, the technical and economic evaluations of the best options, and key learnings for other waste reduction efforts.

In each report, only the best waste reduction options are described in any detail. The full list of generated options are presented in tables, along with the pros and cons of each. The economic evaluations of the best options are also summarized in tables.

Before reading these reports, be sure to review Section 2: Project Methodology for a description of the methods used for option generation and screening, and for performing the technical and economic feasibility analyses. Section 2 also describes the selection and classification of the waste streams included in the project, and the formation of assessment teams and the tasks they performed.

The reports provide economic and waste reduction totals for individual assessments. The combined totals for all 15 assessments are presented in Section 2.

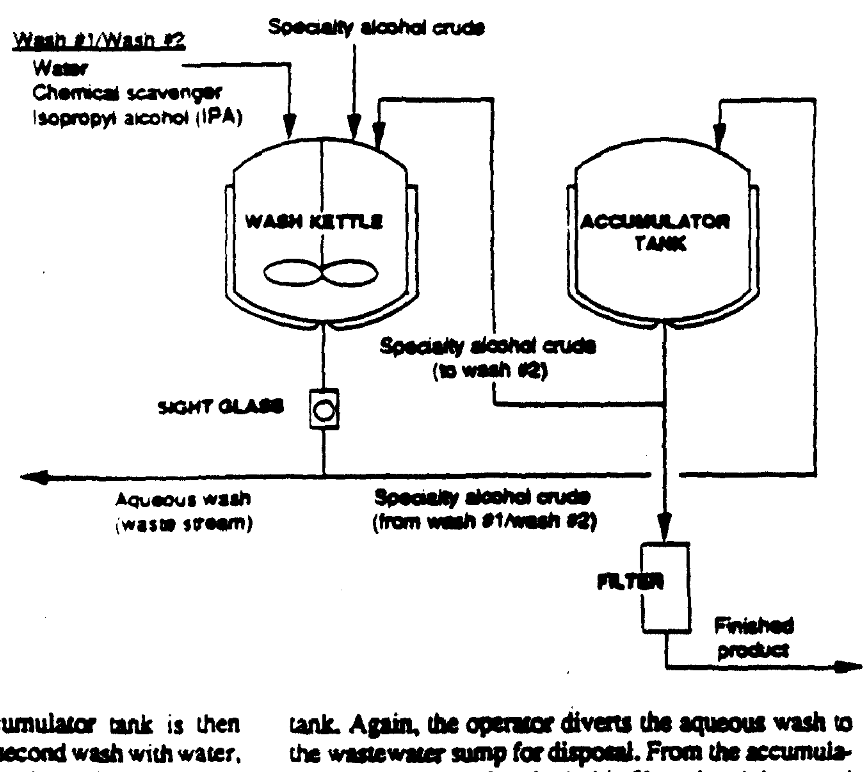
Case Study 1: Specialty Alcohols

A reduction in product impurities permits elimination of waste from a product wash step

Abstract

This case study describes a successful effort to eliminate a waste stream generated by washing a specialty alcohol product of impurities and residual acidity. Improvements in the purity of the crude product have enabled the business to explore ways of neutralizing the residual acidity and eliminating the wash step entirely. This effort began not as a waste minimization project, but as part of an overall process improvement program. Acid neutralization will replace washing because it attains most of the goals of the program, of which waste minimization is but one. This study highlights the importance of considering all business objectives when trying to minimize waste. Waste minimization is often interrelated with such other business objectives as quality improvements, increased capacity, and reduced cycle times. This assessment also demonstrates how improvements in one area of a process can produce opportunities for improvement in other areas.

A batch of alcohol crude enters the wash kettle and is mixed with water, chemical scavenging agents, and isopropyl alcohol (IPA). The mixture is agitated and then allowed to settle. The specialty alcohol product separates from the wash and settles to the bottom of the kettle. The mixture is then drained from the bottom of the kettle through a sight glass monitored by an operator. The settled product leaves the kettle bottom first and is sent to an accumulator tank. When the operator sees that the product layer has drained and the aqueous wash has started to exit the kettle, he/she diverts the flow from the accumulator tank to a sump for disposal.



The product layer in the accumulator tank is then returned to the wash kettle for a second wash with water, scavengers, and IPA. Again, the mixture is agitated and then allowed to settle. The kettle is drained, with the specialty alcohol product going to the accumulator tank. Again, the operator diverts the aqueous wash to the wastewater sump for disposal. From the accumulator tank, the specialty alcohol is filtered and drummed for shipment as final product.

Figure 3–1. Specialty Alcohols Wash Process

Background

DuPont produces several specialty alcohols at its Chambers Works site. When manufactured, these alcohols contain residual acidity which must be removed before the product can be sold. Historically, the crude alcohol also contained halogenated impurities. These corrosive compounds shortened the service life of process equipment and were responsible for high maintenance costs. But over the years, an ongoing process improvement program has steadily reduced these impurities. Today, the amount of impurities in the alcohol crude is low enough that further processing is not required except to remove the residual acidity.

In the mid-1970s, the Chambers Works plant implemented a process that washes residual acidity and impurities out of the alcohol crude. The process, illustrated in Figure 3–1, consists of washing the crude twice in aqueous solutions containing inorganic chemical "scavengers", which removed residual acidity and impurities. Isopropyl alcohol (IPA) is added to the solutions to assist the separation of the alcohol product from the wash water at the end of each wash.

The used wash water is sent to the on-site wastewater treatment plant for disposal. With the exception of a small amount of alcohol product that leaves the process as a yield loss, IPA is the only organic component of this waste stream.

The improved purity of the alcohol crude presented a good opportunity for a dramatic waste reduction. The only purpose now served by the wash process is to remove residual acidity from the crude. So a method for neutralizing the crude with a chemical agent was developed. This neutralization option will be implemented in early 1993, and will completely eliminate the wash process and its attendant waste.

The improved purity of the alcohol crude and the resulting elimination of the wash process originated not from a dedicated waste minimization effort, but from an ongoing process improvement program that has waste minimization as just one of its goals. The other goals are improved quality, shorter cycle times, reduction of inventories, etc. Nevertheless, a formal waste minimization assessment was undertaken to generate additional options and to compare them against acid neutralization. At an informal review of these options, the assessment team agreed that acid neutralization was clearly the best and only option for reducing wastes and satisfying other process improvement goals.

The process improvement program implemented acid neutralization for a variety of reasons:

- *Process simplification*. Acid neutralization frees the washing equipment for other uses. It simplifies operating procedures and enhances process flexibility.
- *Reduction in raw material costs*. This includes the cost of IPA and the chemical scavengers used in the wash process.
- *Waste reduction*. Acid neutralization reduces disposal costs by eliminating the need for treatment at the wastewater treatment plant.
- *Improved product yield*. The small amounts of alcohol product that were lost in the wash water are now saved.
- *Increased capacity*. The elimination of the wash process removes a significant bottleneck in the production of specialty alcohols.

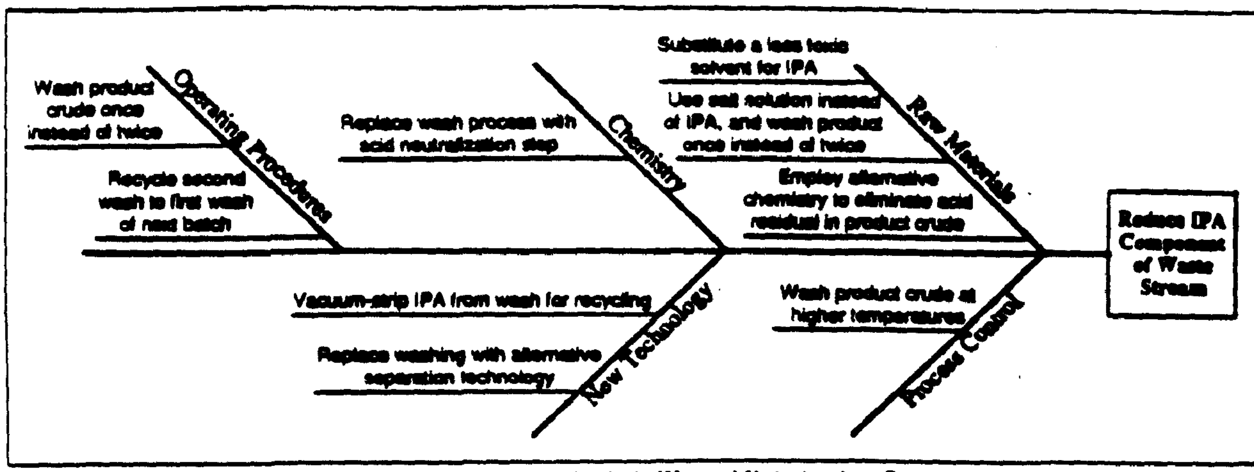


Figure 3–2. Specialty Alcohols Waste Minimization Options

Description of Waste Stream

A typical analysis of the waste stream resulting from the specialty alcohol wash process would reveal:

Water	93.6%
IPA	5.1%
Alcohol (product)	0.7%
Inorganic chemicals	0.6%

Excluding water, IPA accounts for 80% (by weight) of the waste stream, and 94% of the total organic content (TOC). At present, the wash process produces 0.15 lbs.of waste TOC for every pound of specialty alcohol produced. This waste stream is sent to the on-site wastewater treatment plant for disposal.

Costs associated with this waste stream include the replacement cost of the IPA and chemical scavengers, the yield loss represented by the specialty alcohol component, and the wastewater treatment cost.

Previous Waste Minimization Efforts

A series of small process changes over the course of 15 years gradually reduced impurities in the specialty alcohol crude. These changes were driven by a desire to improve product quality. The possibility that impurities had been reduced enough to eliminate the solvent wash was not explored during this period because the wash step was still thought to be necessary for good quality.

In 1991, a process improvement team identified elimination of the wash step as an option for simplifying the process. A subsequent laboratory study, completed in mid-1992, determined that washes were not needed for removing impurities, and that neutralizing the residual acid in the alcohol was all that was required.

Aside from continuous improvement in the purity of specialty alcohol crude, there has been no previous effort to reduce waste from the specialty alcohols wash process.

Waste Minimization Options

The specialty alcohols assessment team met in a brainstorming session and generated nine possible options for reducing waste. They recorded their ideas by constructing a cause-and-effect "fishbone" chart, shown in Figure 3–2. Given the clear superiority of the acid neutralization option, the assessment team did not perform formal weighting and

Table 3–1. Ranked Summary of Specialty Alcohols Waste Minimization Options

Option	Pros	Cons
1. Replace wash process with acid neutralization step.	• Elimination of the waste stream • Attainment of other process improvement goals	
2. Substitute a less toxic solvent for IPA.	• Substitution of waste IPA with a less toxic substance	• Alternative solvent is undefined • Alternative solvent would pose disposal problems of its own • No real reduction in the amount of waste produced
3. Use salt solution instead of IPA, and wash product once instead of twice.	• Reduction of TOC load in waste stream by about 94%	• Uncertain whether salt facilitates separation as well as IPA • Would not attain other process improvement goals
4. Employ alternative chemistry to eliminate acid residual in product crude.	• Elimination of the waste stream	• Alternative chemistry is undefined • High research cost • High capital cost • Long implementation time
5. Wash product crude once instead of twice.	• Reduction of the IPA component of the waste stream by half	• Would not attain other process improvement goals
6. Recycle second wash to first wash of next batch.	• Reduction of the IPA component of the waste stream by half	• Would not attain other process improvement goals
7. Wash product crude at higher temperatures.	• Elimination or reduction of IPA component of waste stream	• Uncertain chance of success • Would not attain other process improvement goals
8. Vacuum-strip IPA from wash for recycling.	• Elimination of IPA component of waste stream	• Not a source reduction • High research cost • High capital cost • Long implementation time
9. Replace washing with alternative separation technology.	• Elimination of waste stream	• Uncertain chance of success • High research cost • High capital cost • Long implementation time

ranking using the weighted-sum method. The acid neutralization option satisfied all of the process improvement program goals, including complete source reduction of organic waste from the wash process. Table 3–1 summarizes the assessment team's informal evaluation of each option.

Technical and Economic Feasibility

Technical Evaluation

The acid neutralization option had been chosen before this waste minimization assessment. But the assessment provided a method for testing the validity of this option against

Table 3–2. Economic Summary of Top Specialty Alcohols Waste Minimization Option

Option	Waste Reduction	Capital Cost	EPA Method NPV (12%)	EPA Method IRR	DuPont Method NPV (12%)	DuPont Method IRR	Implementation Time
Replace wash process with acid neutralization step	100%	$40,000	$725,000	182%	$272,000	93%	1 year
Comments: For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation" in Section 2: *Project Methodology.*							

other options generated by the interdisciplinary assessment team.

Because acid neutralization offered a complete source reduction of waste with little capital cost, all options that prescribed variations on the present washing method were quickly eliminated. Options that prescribed changes in reaction chemistry or separation technology were poorly defined, and could not be implemented without significant research and capital expenditures, and long development times. This left acid neutralization as the only option worthy of an economic evaluation. It not only provided a complete source reduction of waste, but also met all of the other process improvement goals.

Economic Evaluation

The results of the economic analysis are presented in Table 3–2. The analysis considered such environmental cost savings as yield improvement, wastewater treatment costs, and replacement costs for the wash solutions. Also considered were cost savings from the attainment of process improvement goals such as shortened cycle times and lower maintenance costs.

The majority of the cost savings from implementing acid neutralization resulted from eliminating the waste stream. But adding the process improvement benefits significantly enhanced the attractiveness of this option. It's conceivable that marginal waste reduction options for other processes could become justifiable if they were evaluated on the basis of both waste minimization and process improvement results.

Barriers to Implementation

The Chambers Works site expects to implement the acid neutralization option in early 1993. There are no perceived barriers to implementation.

Opportunities for Others

This case study, like others in this series, highlights the importance of considering all business objectives when trying to minimize waste. There were many incentives for change in addition to waste minimization, and the combination of these incentives led to a successful effort. Waste reductions are often interrelated with other goals of a process improvement program, and solutions which satisfy all of these goals are solutions that are likely to be implemented.

The specialty alcohols experience also demonstrates how improvements made in one area of the process can produce opportunities in other areas. The elimination of the wash process was made possible by improving product purity over a period of years. Significantly, some time had passed between the attainment of virtually impurity-free production and the realization that the wash process might no longer be necessary. It's important for process improvement teams to periodically reevaluate the entire manufacturing process as continuous improvements are implemented.

Case Study 2: Organic Salt Process

A waste reduction effort extends its scope to an upstream process for possible source reductions

Abstract

This report describes a waste minimization assessment performed for a process that neutralizes and purifies an acidic crude to recover an organic salt. The assessment revealed opportunities for waste reduction not only in the purification process itself, but also in the upstream process that produces the crude. Several options that combine source reductions with recycling were adopted for implementation. Some of these options have broad application throughout the process industries.

Background

The DuPont Chambers Works site produces an organic salt used in the textile industry. The salt is produced in two separate processes (illustrated in Figure 3–3) at the site. The first process makes an acidic crude (called "crude acid") through a series of reactions. A reactant in one of the reactions is methanol, and excess amounts of it are required to achieve a high-yield crude acid.

In the second process, the crude acid is neutralized with an alkaline compound, and then cooled to allow organic salt crystals to form. These crystals are filtered out, and the remaining process stream is sent to a distillation column where the excess methanol is recovered. The remaining waste from the distillation column is sent to the on-site wastewater treatment plant for disposal.

This waste minimization assessment began as an attempt to reduce waste from the process for neutralizing and purifying the organic salt. But the assessment team found opportunities for waste reduction in the crude acid process as well. The most promising waste minimization candidates were found to be:

- a source reduction through the minimization of a byproduct generated in the process that makes the crude,
- a source reduction through improved recovery of product in the purification process,
- and improved recycling of a process reactant through elimination of wastes caused by equipment startups and shutdowns.

Implementation of these options would result in an estimated waste reduction of 25%.

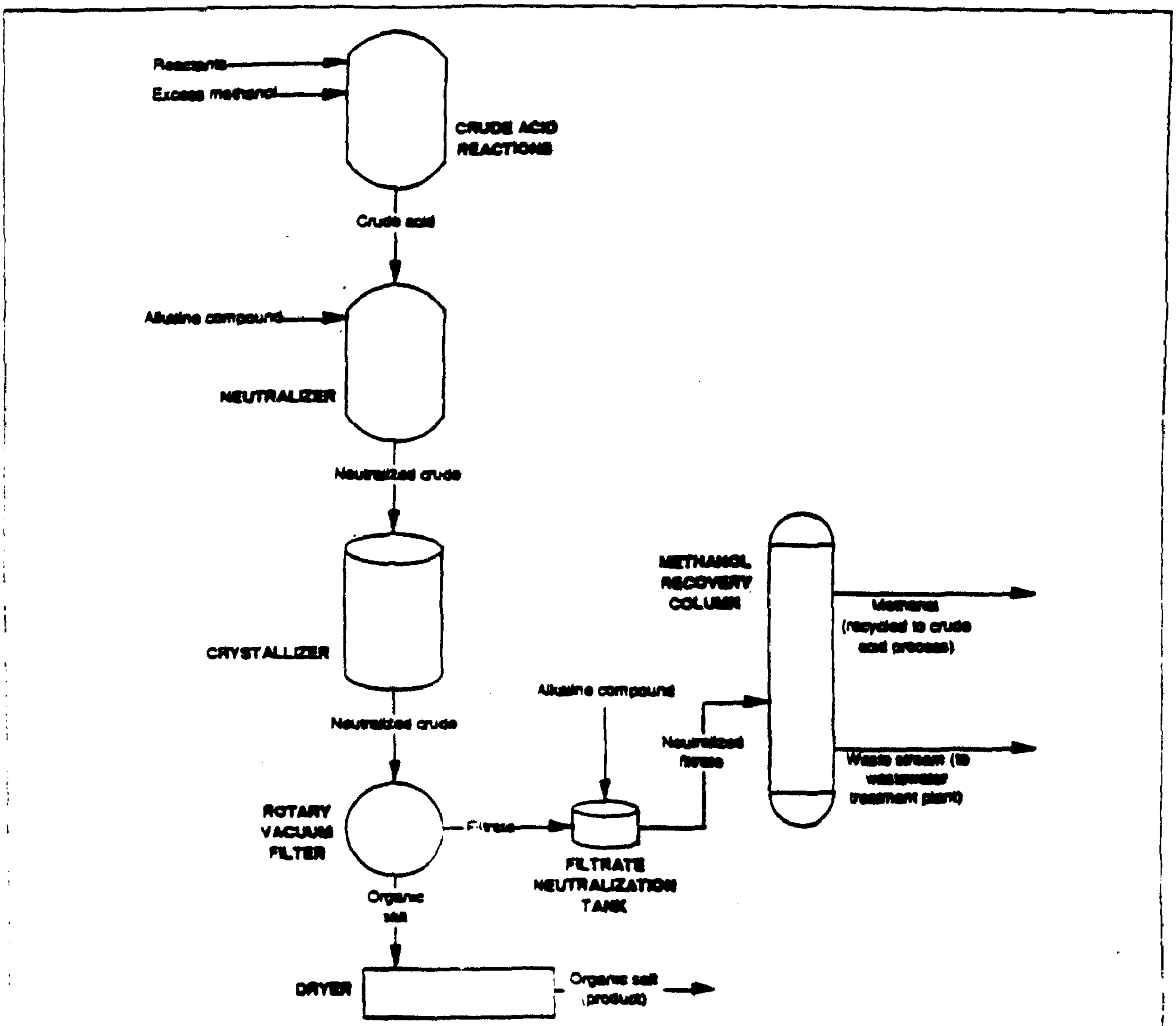
Description of Waste Stream

A typical analysis of the waste stream leaving the methanol recovery column would reveal:

Water	88.0%
Reaction byproducts	8.3%
Organic salt (product)	2.2%
Alkaline compound	1.0%
Methanol	0.5%

The amount of waste from this process has been constant for several years and equals 0.14 lbs of nonaqueous waste for every pound of organic salt produced.

Costs associated with this waste stream include the yield loss represented by the unrecovered organic salt, replacement cost of unrecovered methanol, and the costs of treating the stream at the wastewater treatment plant.



A series of reactions produces the crude acid which is processed into saleable organic salt. One of the reactants is methanol, and excess amounts of it are required to force one of the reactions to completion.

The crude acid is then fed into a neutralizer, where it is mixed with an alkaline compound and heated. From the neutralizer, the crude passes on to a crystallizer which cools the mixture, causing organic salt crystals to form. The crystal-bearing mixture then passes on to a rotary vacuum filter. Here the organic salt crystals collect in the outer part of the filter, forming a solid "filter cake". The remaining liquid, called the "filtrate", consists of methanol, byproducts, and uncrystallized organic salt.

The acidic filtrate exits the rotary filter and enters a neutralizing tank, where it is mixed with an alkaline compound to protect the downstream process equipment. From the neutralizing tank, the filtrate is sent to the methanol recovery column. There the filtrate is heated, causing the methanol to boil off and exit the process from the top of the column. The distilled methanol is collected and recycled back to the crude acid process. The remaining liquid exits the column bottom and is sent to the on-site wastewater treatment plant for disposal.

Figure 3–3. Organic Salt Process

Previous Waste Minimization Efforts

There are three waste minimization projects now being implemented in the organic salt process:

- *Optimize the reactant ratio in the crude acid process to reduce byproduct formation.* The reaction that produces the crude acid is the source of the byproducts in the waste stream.
- *Recirculate the column bottoms stream back to the methanol recovery column during startup.* During startup of the methanol recovery column, before the column has reached its operating temperature for optimum takeoff of methanol product, some methanol leaves with the column bottoms and is diverted to the wastewater treatment plant. A project is now under way to recirculate the column bottoms to a holding tank until the column has reached its operating temperature. The material in the holding tank would then be reintroduced to the column for normal methanol recovery. Successful implementation of this project would reduce the amount of methanol in the waste stream.
- *Install chiller to reduce the temperatures within the crystallizer.* Lower crystallizer temperatures will increase the amount of organic salt that crystallizes out from the crude acid. Successful implementation of this project will reduce the organic salt content of the waste stream.

These three projects were begun in an effort to increase process productivity by improving product yield and reducing waste.

Waste Minimization Options

The assessment team for the organic salt process met in a brainstorming session and generated 19 possible options for reducing waste. They recorded their ideas by constructing a cause-and-effect "fishbone" chart, shown in Figure 3–4. In subsequent meetings, the

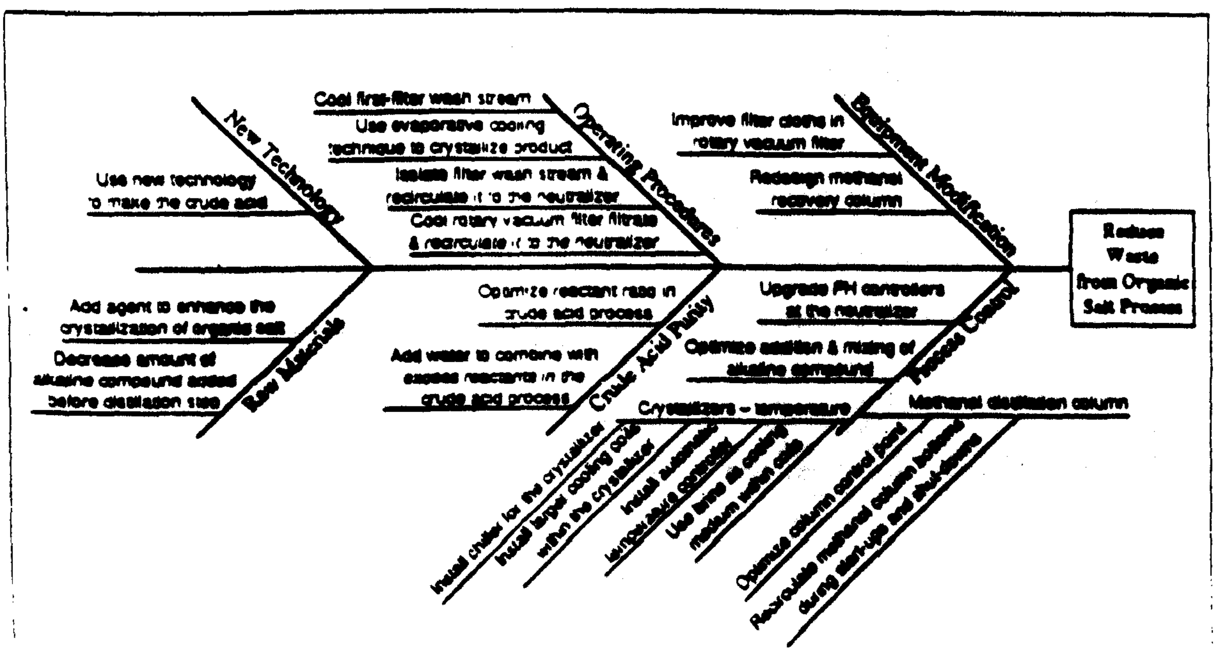


Figure 3–4. Organic Salt Waste Minimization Options

Table 3–3. Ranked Summary of Organic Salt Waste Minimization Options

Option	Pros	Cons	Comments	Score*
1. Optimize reactant ratio in crude acid process.	• Addresses a major cause of waste • Low capital and operating costs		This option would reduce the amount of byproducts which form in the crude acid process.	948
2. Use new technology to make the crude acid.	• Very high source reduction potential	• Very high capital cost	This option would ensure that virtually all of the reactants are consumed in the reaction that produces the crude acid.	822
3. Add water to combine with excess reactants in the crude acid process.	• High source reduction potential • Low operating cost	• Moderate capital cost • Safety concerns	This option would prevent excess reactants in the crude acid process from forming byproducts.	792
4. Recirculate methanol column bottoms during startups and shutdowns.	• Moderate recycling potential • Very good chance of success	• Moderate capital cost	This option requires the installation of piping and control equipment.	682
5. Install chiller for the crystallizer.	• Moderate source reduction potential • Very good chance of success	• Moderate capital cost	Lower temperatures would cause more organic salt to crystallize, improving the product yield and reducing waste.	636
6. Add agent to enhance the crystallization of organic salt.	• Low source reduction potential	• Unknown chance of success	A chemical agent that would enhance crystallization has not yet been identified.	521
7. Improve filter cloths in rotary vacuum filter.	• Low source reduction potential • Low capital and operating costs	• Low chance of success	At present, some organic salt is lost through the filter cloths. Previous attempts to identify better filter cloths have failed.	504
8. Optimize addition and mixing of alkaline compound.	• Presumptive source reduction	• Low chance of success	The prevailing view among assessment team members is that present method is already efficient.	487
9. Optimize column control point.	• Small recycling potential	• Low chance of success	This option involves finding a better location on the methanol recovery column for placing temperature and pressure controls.	465

*maximum score = 1,210

Table 3-3. Ranked Summary of Organic Salt Waste Minimization Options (cont'd)

Option	Pros	Cons	Comments	Score*
10. Install larger cooling coils within the crystallizer.	• Moderate source reduction potential • Moderate chance of success	• Very high capital cost	Larger cooling coils would cause more organic salt to crystallize, improving yield and reducing waste.	442
11. Install automatic temperature controller.	• Moderate source reduction potential • Moderate chance of success	• Moderate capital cost	This option would provide better control of the rate of cooling within the crystallizer.	436
12. Use brine as cooling medium within coils.	• Moderate source reduction potential • Moderate chance of success	• High capital cost • High operation and maintenance costs	Replacing water with brine would permit cooler temperatures within the crystallizer.	432
13. Decrease the amount of alkali added before distillation step.	• Low capital cost	• Low waste minimization potential • Low chance of success	The alkali protects process equipment from the acidic crude. This option would reduce waste by the amount of the alkali reduction, a very low amount.	402
14. Use evaporative cooling technique to crystallize product.	• Moderate source reduction potential • Moderate chance of success	• Very high capital cost • Very high operation and maintenance costs	This option would replace the present method of crystallizing the product.	396
15. Upgrade PH controllers at the neutralizer.	• Presumptive source reduction	• Low chance of success	Assessment team achieved consensus that present pH control is not a problem.	382
16. Isolate filter wash stream and recirculate it to the neutralizer.		• Low waste minimization potential • Low chance of success	This option seeks to recover the small amount of organic salt that is lost in the filter wash stream.	332
17. Cool filter wash stream.		• Low waste minimization potential • Low chance of success	Water in the rotary filter washes impurities out of the filter-cake. Inevitably, some crystals dissolve and wash away. This option would reduce this (small) yield loss by cooling the washwater.	296
18. Cool rotary vaccum filter filtrate and recirculate it to the neutralizer.		• Low waste minimization potential • Low chance of success	This would recover more product, but requires a method for separating the salt from the rest of the filtrate before it recirculates to the neutralizer.	286
19. Redesign methanol recovery column.		• Low recycling potential • Very high capital cost	This option hopes to achieve a more efficient distillation of the methanol from the waste stream.	252

*maximum score = 1,210

team discussed the options and ranked them using the weighted sum method described in Section 2 of this document.
Table 3–3 summarizes these discussions, and presents the options in rank order.

The 19 options generated during the brainstorming session fall into three categories:

- Source reduction of waste stream constituents (11 options)
- Recovery and recycling of methanol or organic salt (five options)
- Increased crude acid purity to reduce impurities which end up in the waste stream (three options)

Technical and Economic Feasibility

After considering the pros and cons of each option listed in Table 3–3, the assessment team chose five options for technical and economic feasibility analysis:

- Optimize reactant ratio in crude acid process
- Use new technology to make the crude acid
- Add water to combine with excess reactants in the crude acid process
- Recirculate methanol column contents during startups and shutdowns
- Install chiller for the crystallizer

Technical Analysis

The "optimize reactant ratio" and "add water...in crude acid process" options both involve changes to the present process for making crude acid. The former option requires no capital investment, while the latter requires a moderate investment. Both options have high source reduction potentials. Both are technically feasible, although only plant trials can confirm their effectiveness.

The new technology for making crude acid process has been successfully demonstrated in other applications. Although the waste minimization potential of this option is significant, the cost of implementing this option cannot be justified.

Recirculating the methanol column bottoms during startups and shutdowns is a recycling option that is easy to implement for a small capital investment. The installation of a chiller for the crystallizer is also easy to implement, although it does require a moderate capital investment. Neither option represents new technology, and both are technically feasible.

Economic Analysis

The economic analysis of these five options is presented in Table 3–4. Results are provided using both DuPont and EPA methodologies. The DuPont methodology uses the variable costs of wastewater treatment because the company uses its own wastewater facility. Thus, the DuPont methodology does not take into account the fixed costs of wastewater treatment, whereas the EPA methodology uses both the fixed and the variable costs in economic analyses.

The analysis reveals the most promising options to be:

- Optimize reactant ratio in crude acid process
- Recirculate the column contents during startup/shutdown
- Install chiller for the crystallizer

The three options have short implementation periods and high "internal rates of return" (IRR) with little capital investment. Implementation of the three options would yield a combined waste reduction of 25%.

Barriers to Implementation

There are no anticipated barriers to implementation of any of the three options. Projects for optimizing the reactant ratios and installing the chiller are well under way. A project for recirculating the contents of the methanol column is still in the planning stage, and completion is expected some time in 1993.

Opportunities for Others

The waste minimization options examined in this case study have general application for other processes. In most chemical processes, there is an inverse relationship between product yield and waste. If reactant ratios are not in balance, then an excess reactant is likely to become involved in a side reaction that produces byproducts. This lowers the product yield on raw materials and increases waste.

Equipment startups and shutdowns are frequent sources of waste. When process equipment is started up, there usually is a "line-out" period before the equipment achieves its standard operating conditions. Process streams that pass through the equipment during line-out usually emerge off spec and contain large amounts of waste. Methods for reintroducing these streams to the equipment after line-out can result in significant waste reductions:

Table 3–4. Economic Summary of Top Organic Salt Waste Minimization Options

Option	Waste Reduction	Capital Cost	EPA Method NPV (12%)	EPA Method IRR	DuPont Method NPV (12%)	DuPont Method IRR	Implementation Time
Optimize reactant ratio in crude acid process	5%	$0	$5,700,000	∞	$5,500,000	∞	6 months
Add water...in the crude acid process	19%	$206,000	$1,100,000	79%	$400,000	42%	1 year
Recirculate methanol column bottoms...	13%	$25,000	$700,000	211%	$200,000	103%	1 year
Install chiller...	7%	$190,000	$9,700,000	209%	$9,400,000	205%	6 months
Use new technology to make the crude acid	54%	$5,230,000	($600,000)	9%	($2,700,000)	< 0%	2 years

Comments: The economics for these options are given on a stand-alone basis, and do not consider possible synergies from implementing more than one option.

Parentheses denote negative numbers.

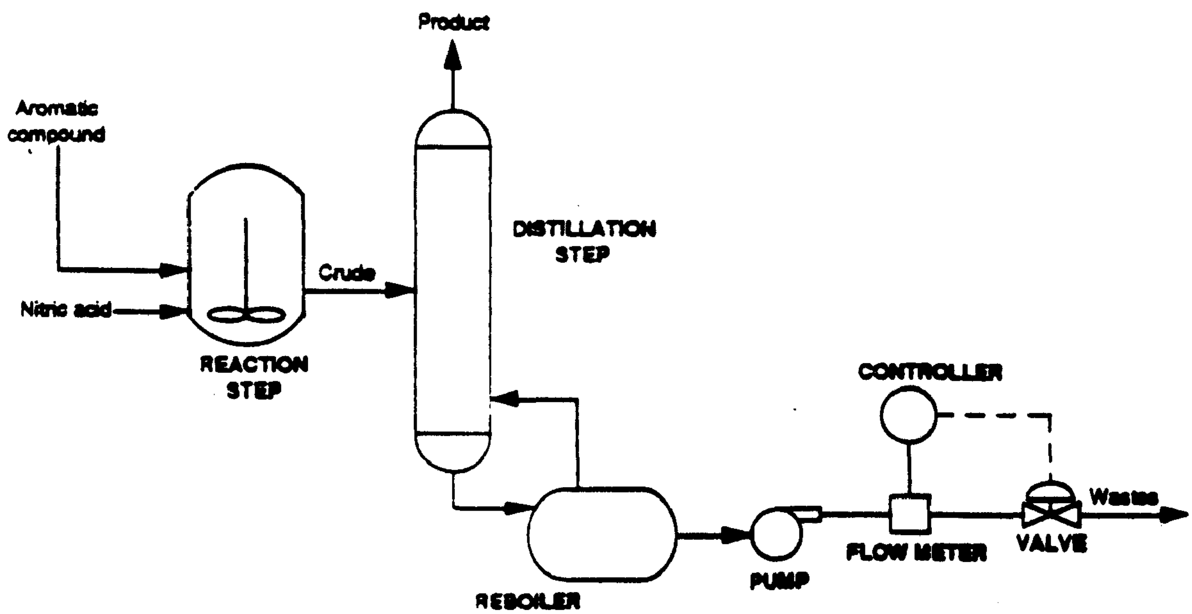
For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation" in Section 2: *Project Methodology*.

Case Study 3: Nitroaromatics

Improved flow control is the key to waste reduction in this distillation process

Abstract

A waste minimization assessment was performed for a process that produces nitroaromatic compounds. Continuous distillation separates the compounds into their constituent isomers and removes reaction byproducts. The chief impediment to reducing waste was found to be difficulties in controlling the rate of flow from the detarring column that discharges the wastes. The full benefit of a source reduction in reaction byproducts will not be realized unless the flow control problem is solved. Waste reduction for this process will consist of a series of small improvements rather than the implementation of a single solution.



Aromatic compounds and nitric acid enter the reactor where they are mixed to create nitroaromatic compounds and reaction byproducts. The crude leaving the reactor proceeds to the distillation step, where nitroaromatic compounds are removed from the crude and purified. Among the distillation equipment is a detarring column where nitroaromatic product boils off, leaving the reaction byproducts, unrecovered product, and distillation tars to accumulate within the reboiler. A pump removes these wastes continuously. The flow from the reboiler must be carefully measured and controlled to prevent a buildup of reaction byproducts to unsafe levels. This flow control is accomplished by means of a flow meter and valve. The flow rate is so low that a 1/8" flow-tube is used to obtain accurate measurements. At extremely low flows the valve and flow meter become plugged, forcing a process shutdown. To prevent this occurrence, the operation runs at a higher-than-optimal flow rate.

Figure 3-5. Nitroaromatics Process

Background

The Chambers Works site produces several nitroaromatic compounds which have a variety of commercial uses. The continuous process for producing these compounds, illustrated in Figure 3–5, consists of a reaction step and a distillation step.

In the reaction step, aromatic feedstock is combined with nitric acid within a reactor to produce a crude consisting of nitroaromatic compounds and some reaction byproducts. One of these byproducts, which has a higher boiling point than the others, has low thermal stability. This high-boiling byproduct could pose a safety hazard during distillation if allowed to concentrate above a certain threshold within the crude as product is removed. The formation of the high-boiling byproduct can be minimized through careful control of the ratio of feedstock to nitric acid within the reactor. Nevertheless, a certain amount of the high-boiling byproduct inevitably forms.

From the reactor, the crude undergoes a series of distillations to remove the byproducts and purify the nitroaromatic compounds to product specifications. Distillation exploits differences in the boiling points of each compound within the nitroaromatic crude, separating compounds with lower boiling points (low-boilers) from those with higher boiling points (high-boilers). The process stream enters a distillation column where it is subjected to heat. The low-boilers leave the top of the column as vapor, while the high-boilers leave the column reboiler as liquid. By controlling the temperature and pressure within the process equipment, one can control the chemical composition of the vapors and liquids leaving the column.

Included among the distillation equipment in the nitroaromatics process is a distillation column known as the "detarring column". It receives a continuous feed of crude, boiling off nitroaromatic products and discharging a viscous waste stream containing the reaction

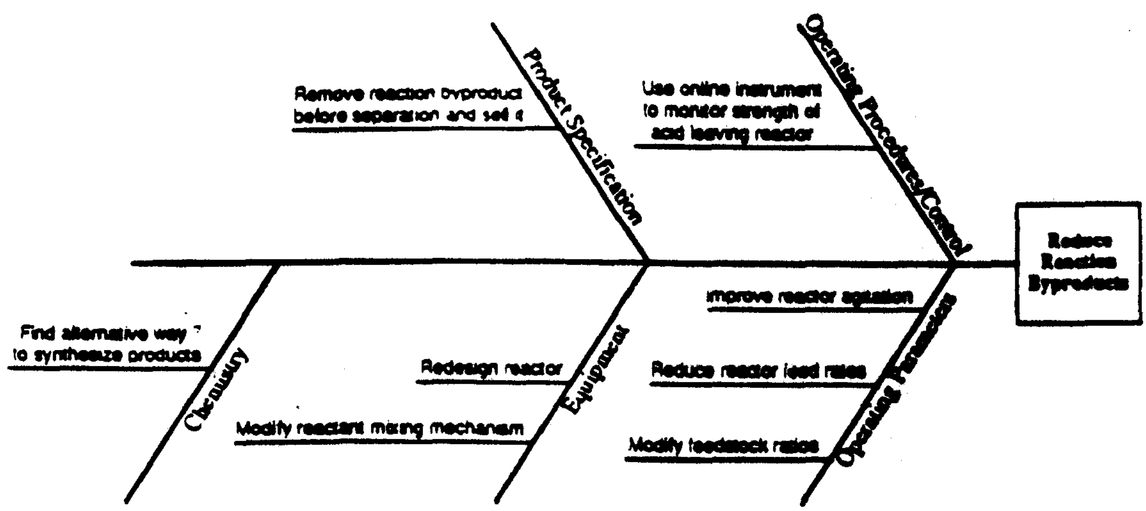


Figure 3–6. Nitroaromatics Waste Minimization Options (Reaction Step)

byproducts, unrecovered product, and a small amount of tars which form during distillation. The waste stream leaving the detarring column is incinerated.

The waste stream contains two major components and arises from two sources. The first component consists of the byproducts formed during the reaction step. These are chemically unstable and would pose a safety hazard if allowed to concentrate within the waste stream. The second component consists of nitroaromatic product purged as waste with the reaction byproducts from the detarring column reboiler. The source of this yield loss is an inability to adequately control the rate at which the wastes are purged. Waste leaves the reboiler through a flow meter that has a diameter of just 1/8". The flow meter controls a valve which opens to achieve the desired flow rate. When flow rates are extremely low, both flow meter and valve clog up, causing flow to stop completely and the process to shut down. To avoid this development, the process runs at higher flow rates. But at higher flows, larger amounts of otherwise recoverable product are removed with the waste.

The lower the purge rate, the more product is recovered in the detarring column. But at very low flows, reaction byproducts would accumulate to an unsafe level within the reboiler. Thus, process improvements aimed exclusively at reducing the purge rate can achieve only marginal waste reductions. Similarly, reducing the formation of reaction byproducts alone would not achieve much waste reduction because of the high purge rate at the detarring column. However, implementing both improvements together would greatly reduce the waste from the nitroaromatics process.

Description of Waste Stream

A typical analysis of the waste stream leaving the nitroaromatics column is provided below.

Unrecovered product	76%
Byproducts	20%
Distillation tars	4%

The amount of waste from this process has been constant for several years, and equals 0.014 lbs for every pound of nitroaromatic

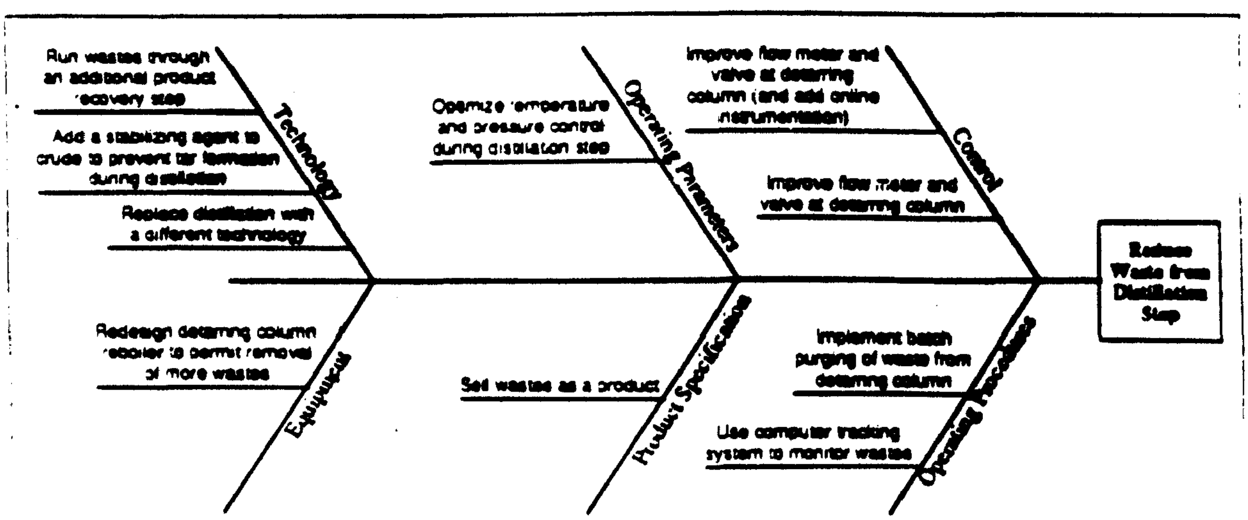


Figure 3–7. Nitroaromatics Waste Minimization Options (Distillation Step)

Table 3-5. Ranked Summary of Nitroaromatics Waste Minimization Options (Reaction Step)

Option	Pros	Cons	Comments	Score*
1. Use online instrument to monitor strength of acid leaving reactor.	• May achieve source reduction of reaction byproducts	• Could be difficult to implement	The strength of the spent acid leaving the reactor would control the rate of feed acid addition. Acid strength could be measured by a variety of instruments, including pH or density meters.	18
2. Improve reactor agitation.	• May achieve source reduction of reaction byproducts	• Uncertain chance of success	Improved agitation could reduce the formation of reaction byproducts.	14
3. Modify feed-stock ratios.	• Would achieve source reduction of reaction byproducts	• Reduced production capacity • Increased operating costs	Decreasing nitric acid would increase the amount of unreacted aromatic feed-stock to be removed during the distillation step.	12
4. Modify reactant mixing mechanism.	• Speculative source reduction of reaction byproducts	• Uncertain chance of success	Based on the assumption that improved mixing would reduce byproduct formation.	11
5. Reduce reactor feed rates.	• May achieve source reduction of reaction byproducts	• Reduced production capacity • May require redesign of reactor	Reduced reactor feed rates would result in longer residence times within the reactor. Some studies indicate that byproduct formation may decrease under these conditions.	9
6. Find alternative way to synthesize products.	• Has the potential for reducing reaction byproducts	• Uncertain chance of success because alternatives are not well understood • High development cost • High implementation cost	High costs make this option unattractive at this time.	7
7. Redesign reactor.	• Several possible designs offer promise for byproduct reduction	• High development cost • High implementation cost	High costs make this option unattractive at this time.	7
8. Remove reaction byproduct before separation and sell it.	• Virtually eliminates a significant component of waste • Reduces the major component of the waste by permitting greater product recovery	• Low concentrations of byproduct in crude before separation make chance of success unlikely • Large capital cost • Safety limitations	The low concentration of byproduct within the crude and high capital costs make this option unattractive.	6

*maximum score = 21

Table 3–4. Ranked Summary of Nitroaromatics Waste Minimization Options (Distillation Step)

Option	Pros	Cons	Comments	Score*
1. Use computer tracking system to monitor wastes.	• Permits optimization of waste purge control • Easy implementation	• Does not solve flow control problems and, therefore, doesn't reduce wastes	Capability of implementing this option exists in present process control equipment.	16
2. Improve flow meter and valve at detarring column and add online instrumentation.	• Reduction in major component of waste through better product recovery • Implementation required to realize benefits from source reduction of reaction byproduct	• Uncertain chance of success	On-line instrumentation may allow lower flow rates without compromising safety.	14
3. Implement batch purging of waste from detarring column.	• Reduction in major component of waste through better product recovery	• May present a more difficult control problem than continuous purging	This option would allow waste to accumulate in column reboiler to be purged periodically in batches. Batch purging would create additional safety concerns that would have to be addressed.	14
4. Improve flow meter and valve at detarring column.	• Reduction in major component of waste through better product recovery • Implementation required to realize benefits from source reduction of reaction byproduct	• Uncertain chance of success (may already be using the best available technology) • Safety concerns	Investigation required to determine if better equipment is available. It's possible that online instrumentation will also be required to enhance safety.	14

*maximum score = 21

crude produced. At present, wastes from the detarring column are incinerated.

Costs associated with this waste stream include the yield loss represented by unrecovered product and the cost of incinerating the waste stream.

Previous Waste Minimization Efforts

In recent years, several attempts have been made to reduce the waste stream from the nitroaromatics process:

- A study was performed on the effect of increasing the ratio of aromatic feedstock to nitric acid within the reactor. The study showed that changing the ratio could decrease byproducts. But these changes could not achieve its full measure of waste reduction unless the flow rate problem at the detarring column were solved.
- A process control software program was installed to track the amounts of waste discharged from the detarring column. The information provided by the program helped

Table 3–6. Ranked Summary of Nitroaromatics Waste Minimization Options (Distillation Step, cont'd)

Option	Pros	Cons	Comments	Score*
5. Add a stabilizing agent to crude to prevent tar formation during distillation.	• Would reduce the tars formed in isomer separation column	• Stabilizing agents in distillation columns greatly complicate waste management • Addresses a very small component of the waste stream	See "Case Study 5: CAP Purification" in this series for a description of the problems associated with using stabilizers in distillation columns.	12
6. Optimize temperature and pressure control during distillation step.	• Lower temperatures and pressures could reduce distillation tars	• Uncertain chance of success • Tars constitute only a small part of the waste stream	Although some tars do form during the distillation step, reaction byproducts are the major source of waste from this process.	11
7. Redesign detarring column reboiler to permit removal of more wastes.	• Would permit operation at greater flow rates	• High capital cost • Long development and implementation time	Source reductions in the reaction step would be more cost effective.	9
8. Replace distillation with a different technology.	• Reduces the major component of the waste by permitting greater product recovery	• High capital cost • Long development and implementation time	Source reductions in the reaction step would be more cost effective.	8
9. Sell wastes as a product.	• Would eliminate the waste stream	• May be difficult to find buyers		6
10. Run wastes through an additional product recovery step.	• Reduces the major component of the waste by permitting greater product recovery	• High capital cost • Long implementation time	Possible technologies include use of a wiped-film evaporator. Source reductions in the reaction step should be considered first.	3

*maximum score = 21

to decrease wastes somewhat. More importantly, it heightened awareness about the amount of waste produced and identified flow control as a major impediment to waste reduction.

Waste Minimization Options

The assessment team for the nitroaromatics process met in a brainstorming session and generated 18 options for reducing waste. They recorded their ideas by constructing the two cause-and-effect "fishbone" charts shown in Figures 3–6 and 3–7. One chart contains options which address reaction byproduct formation, and the other contains options for reducing wastes from the distillation step. In subsequent meetings, the assessment team discussed the options and ranked them using the weighted-sum method described in Section 2 of this document. Tables 3–5 and 3–6 summarize these discussions, and presents the options in rank order.

Determining how options generated for one process would affect conditions at the other process introduced a level of complexity not encountered in other case histories in this series. For this reason, the assessment team used the flexibility afforded by the DuPont and EPA methodologies to simplify the weighted-sum ranking method described in Section 2 of this document. The team assigned a weight of "1" to each criterion. They then assigned a score of "+1", "0", or "−1" to each option according to how well it satisfied the criterion.

Technical and Economic Feasibility

After considering the pros and cons of each option listed in Tables 3–5 and 3–6, the assessment team chose four options for technical and economic feasibility analysis:

- Improve flow meter and valve at detarring column
- Improve flow meter and valve at detarring column and add online instrumentation
- Use online instrument to monitor strength of acid leaving reactor
- Improve reactor agitation

Table 3–7. Economic Summary of Top Nitroaromatics Waste Minimization Options

Option	Waste Reduction	Capital Cost	EPA Method NPV (12%)	EPA Method IRR	DuPont Method NPV (12%)	DuPont Method IRR	Implementation Time
REACTION STEP:							
Use online instrument to measure strength of acid... & Improve reactor agitation	17%	$63,000	$398,000	87%	$291,000	72%	6 months
DISTILLATION STEP:							
Improve flow meter & valve	16%	$37,000	$396,000	75%	$243,000	57%	6 months
Improve flow meter & valve... online instrumentation	23%	$109,000	$484,000	54%	$287,000	39%	1 year

Comments: The economics for these options are given on a stand-alone basis, and do not consider possible synergies from implementing more than one option.

The waste reduction percentages for the distillation step options are not fully additive if both options are implemented.

Implementing the reaction step option and one of the distillation step options would give a combined waste reduction of about 37%.

For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation" in Section 2: *Project Methodology.*

The results of the analysis are presented in Table 3–7.

These four options were chosen because taken together, they seem to represent a coherent, stepwise plan for waste reduction, rather than a collection of disparate projects. The options "new flow meter and valve" and "new flow meter, valve, and online instrumentation" are designed to bring the detarring column flow rate under control, a necessary precondition for meaningful source reduction. The addition of online instrumentation will not improve waste reduction, but may be required to ensure that the present margin of safety is maintained.

The last two options (improve reactor agitation, continuous monitoring of acid strength) are designed to achieve source reductions in byproduct formation. These two options were combined for the economic evaluation because it may be necessary to implement both to achieve the desired source reduction. It's worth repeating that these source reductions will not reduce waste until the flow rate from the detarring column is brought under control.

Barriers to Implementation

It seems likely that the waste reduction from the detarring column purge stream can be achieved by improving the flow control, although there is some feeling among assessment team members that the present flow control mechanisms already represent the best available technology.

Methods for achieving source reductions in byproduct formation are more experimental. The waste reduction figures given in Table 3–7 are based on the assumption that these options will work. But in fact, the causes of byproduct formation require more study. Previous tests have yielded mixed results. It's possible that the options identified here will achieve less waste reduction than the figure given in Table 3–7.

In a best case scenario, implementing waste reduction options in both the reaction and purification steps will yield a 37% reduction. In the worst case, solving the flow rate problem should reduce waste by 16%. These steps would also provide a better understanding of the process, and prepare the nitroaromatics area for a future waste minimization effort.

Opportunities for Others

The nitroaromatics process demonstrates how waste minimization is sometimes an iterative process in which progress is made in small steps, and not in a single great leap.

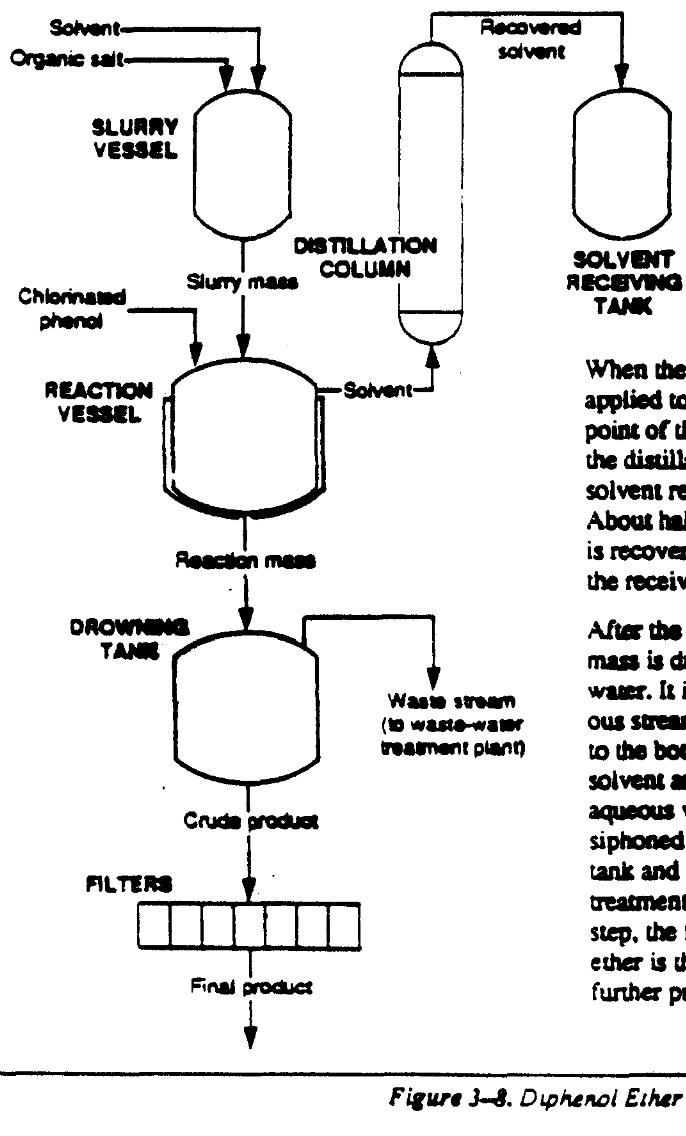
This case history, like others in this series, also demonstrates how a waste reduction effort must often expand beyond its original scope. The assessment team originally focused only on the reaction step. But it soon became apparent that significant reductions could be achieved only by expanding the scope of the assessment to include the distillation step as well.

Case Study 4: Diphenol Ether Process

Balancing the potential for waste reduction with operational safety

Abstract

This case study focuses on a waste stream from a batch process for making a substituted diphenol ether. The process uses a solvent as a reaction stabilizer. A recovery step recycles some of the solvent for future reuse, but safety concerns limit the amount of solvent recovered. Unrecovered solvent constitutes the greatest part of the waste. The chosen waste reduction option permits the recovery of more, but not all, of the added solvent. This report illustrates an increasingly frequent situation in which process engineers must balance safety considerations with the need to minimize waste.



A solid organic salt is slurried with solvent within the slurry tank and then introduced to the reaction vessel. There, the slurry is mixed with chlorinated phenol, and the mixture is heated. The resulting reaction produces diphenol ether and a small amount of byproducts. When the reaction is completed, a vacuum is applied to the equipment to lower the boiling point of the solvent. The solvent then boils up the distillation column and collects in the solvent receiving tank for eventual reuse. About half of the solvent in the reaction vessel is recovered in this way, enough to nearly fill the receiving tank.

After the solvent recovery step, the reaction mass is dumped into a drowning tank full of water. It is then washed with a large, continuous stream of water. The diphenol ether settles to the bottom of the tank, while the remaining solvent and reaction byproducts dissolve in the aqueous wash. The waste-bearing water is siphoned off continuously from the top of the tank and sent to the on-site wastewater treatment plant for disposal. After the wash step, the free liquid is filtered off. The diphenol ether is then sent to another facility on-site for further processing.

Figure 3–8. Diphenol Ether Process

Background

The DuPont Chambers Works facility produces a substituted diphenol ether which, after further processing at another facility on-site, becomes a raw material for the manufacture of various polymers. The process produces an aqueous waste stream containing a solvent and small amount of reaction byproducts.

The process for producing diphenol ether is illustrated in Figure 3–8. A solid organic salt is slurried with a solvent, introduced to a reaction vessel, and mixed with a chlorinated phenol. The subsequent reaction produces the diphenol ether and byproducts. When the reaction is complete, about half of the solvent is recovered for reuse by means of a distillation column connected to the reaction vessel. The reaction mass is then drowned and washed with copious amounts of water to remove the solvent and byproducts.

The solvent performs double duty in this process. It serves as a transport medium, carrying the organic salt to the reactor. Within the reactor, the solvent performs an important safety role. Both the raw material and reaction byproducts are extremely volatile and can explode when dry. The solvent prevents drying of the volatile compounds. Thus, there is a limit to how much solvent can be removed from the reaction vessel before process safety is compromised.

An additional recovery step for removing solvent from the drowning tank wash water cannot be seriously considered. The wash water is so dilute that no known recovery method can be made cost-effective. Reuse of the wash water is not an option because the byproduct it removes is at its solubility limit.

Description of Waste Stream

Water comprises almost 99% of the waste from the drowning tank. A typical analysis of the waste (excluding water) would reveal:

Inorganic salt	50%
Solvent	36%
Unreacted raw material	11%
Reaction byproducts	3%

The amount of waste from this process has been constant for several years and (excluding water) equals 0.24 lbs for every pound of

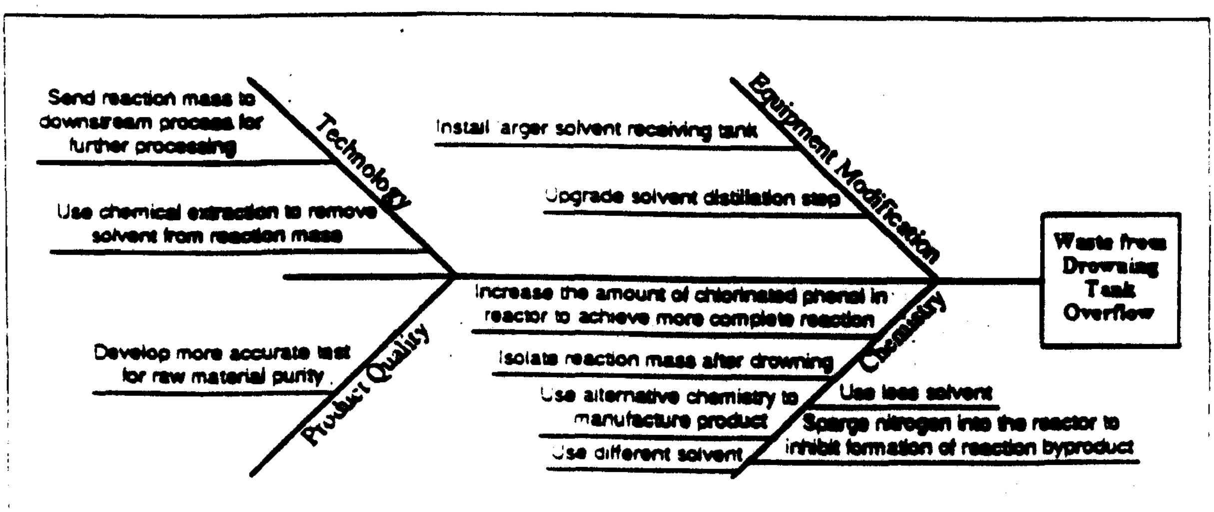


Figure 3–9. Diphenol Ether Waste Minimization Options

Table 3–8. Ranked Summary of Diphenol Ether Waste Minimization Options

Option	Pros	Cons	Comments	Score*
1. Use less solvent.	• Less solvent in waste • Lower raw material costs	• Safety concerns		900
2. Install larger solvent receiving tank.	• Less solvent in waste • Lower raw material costs	• Moderate capital investment • Safety concerns	Present tank size imposes a limit on how much solvent can be recovered.	875
3. Upgrade solvent distillation step.	• Less solvent in waste • Less reaction byproduct in waste • Lower raw material costs	• Prohibitive capital cost • Based in part on speculative hypothesis of how reaction byproduct forms • Safety concerns	This option proposes the installation of a new and larger distillation column as well as a larger solvent receiving tank.	800
4. Isolate reaction mass after drowning.	• Less solvent in waste • Lower raw material costs	• High capital cost • Poor chance of success because of safety concerns	Would require installation of a solvent purification system.	674
5. Develop more accurate test for raw material purity.	• Reduced reaction byproducts in waste • Low cost • High chance of success • Easy implementation	• Very low waste minimization potential	More precise knowledge of raw material purity would help reduce unreacted raw materials by permitting optimization of reactant ratios. But reaction byproducts are a very small part of the waste stream.	639
6. Use chemical extraction to remove solvent from reaction mass.	• Lower solvent costs • Less solvent in waste	• Increased raw material cost (for chemical extractor) • Produces a new waste stream • Moderate capital cost • Safety concerns		627

maximum score = 1,170

diphenol ether product produced. The waste stream is treated at the on-site wastewater treatment facility.

Major costs associated with this waste stream are the costs of wastewater treatment and the raw material costs represented by the unrecovered solvent. Yield losses from this process are extremely low.

Previous Waste Minimization Efforts

Past efforts to reduce solvent waste have consisted of incremental attempts to reduce the amount of solvent left unrecovered within the reactor. Each attempt is preceded by testing to ensure that the new target amount will still be sufficient to keep the reaction mass stable. As a result of these attempts, the

Table 3–8. Ranked Summary of Diphenol Ether Waste Minimization Options (cont'd)

Option	Pros	Cons	Comments	Score*
7. Increase the amount of chlorinated phenol in reactor to achieve more complete reaction.	• Product yield improvement • Lower raw material cost • Less unreacted raw material in waste	• More reaction byproduct in waste		598
8. Use different solvent.	• Speculative reduction in solvent waste	• Alternative solvent not specified (poor chance of success)		509
9. Use alternative chemistry to manufacture product.	• Speculative reduction in waste	• Alternative chemistry not specified (poor chance of success)	Previous attempts to use a different process to manufacture product have failed.	501
10. Send reaction mass to downstream process for further processing.	• Improved safety • Less solvent in waste • Lower raw material costs	• High capital cost • Introduces additional process steps to downstream process	The additional processing would stabilize the otherwise unstable compounds within the reaction mass.	432
11. Sparge nitrogen into reactor to inhibit formation of reaction byproduct.	• Less byproduct in waste	• High capital investment for emission abatement system • Could produce a waste stream of its own • Air permit modification needed	This high-cost option addresses a very small component of the waste stream.	417

*maximum score = 1,170

amount of unrecovered solvent has been reduced by about 40% over the past ten years.

Waste Minimization Options

The assessment team for the diphenol ether process met in a brainstorming session and generated 11 possible options for reducing waste. They recorded their ideas by constructing a cause-and-effect "fishbone" chart, shown in Figure 3–9. In subsequent meetings, the team discussed the options and ranked them using the weighted-sum method described in Section 2 of this document. Table 3–8 summarizes these discussions, and presents the options in rank order.

The options with the highest waste minimization potential are those which attempt to reduce the amount of solvent in the waste. Options which attempt to reduce the formation of byproducts or improve the purity of the raw materials have a very low potential for waste reduction because the reaction in this process is already very efficient, and the amount of byproducts in the waste is very small.

Table 3–9. Economic Summary of Top Diphenol Ether Waste Minimization Options

Option	Waste Reduction	Capital Cost	EPA Method NPV (12%)	EPA Method IRR	DuPont Method NPV (12%)	DuPont Method IRR	Implementation Time
Use less solvent	58%	$0	$3,070,000	∞	$1,290,000	∞	1 year
Install larger... receiving tank	47%	$128,000	$2,100,000	153%	$750,000	83%	1 year
Upgrade solvent distillation step	47%	$376,000	$2,100,000	78%	$550,000	38%	1.5 years

Comments: For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation" in Section 2: *Project Methodology.*

Technical and Economic Feasibility

Technical Evaluation

After considering the pros and cons of each option in Table 3–8, the assessment team chose three for technical and economic feasibility analysis:

- Use less solvent
- Install larger solvent receiving tank
- Upgrade solvent distillation step

Option 1 simply calls for using less solvent to slurry the organic salt. This option scores well in terms of ease of implementation and waste minimization potential. But any attempt to reduce solvent before the reaction step raises serious safety issues because of the volatility of the unreacted chlorinated phenol.

Option 2, "Install larger solvent receiving tank", is also relatively easy to implement. This option calls for distilling off more solvent after the reaction is complete and before the reaction mass is sent to the drowning tank. The extra distillation is not possible at this time because the solvent receiving tank is too small to accept additional solvent. Installing a larger tank would make implementation of this option possible.

Option 3, "Upgrade solvent distillation step", would require a significant capital investment in that it calls for the installation of both a larger distillation column and a new receiving tank. This option would reduce waste in two ways. First, an upgraded column would permit the removal of more solvent. (This is why the larger receiving tank is required.) Secondly, the new column would improve the purity of the solvent removed from the reactor. At present, some unreacted raw material boils up the column with the solvent, and this material ultimately becomes waste.

Economic Evaluation

Table 3–9 summarizes the results of the economic feasibility study for the three top-rated options. Option 1 is the most economically attractive since it requires no capital investment, and its Net Present Value (NPV) is higher than the other options. But safety concerns associated with this option offset its economic attractiveness, and move it to the bottom of the list of three as a candidate for implementation.

Option 2, "Install larger solvent receiving tank", was chosen as the best option. It has an acceptable NPV, and is far safer than

Option 1. The larger tanks enable additional solvent distillation after the volatile chlorinated phenol has been consumed in the reaction.

Option 3, "Upgrade distillation step", would require significant capital expenditure for a waste reduction that is approximately equal to that of the less costly Option 2. For this reason, it is not a candidate for implementation.

Barriers to Implementation
Safety concerns frustrate most attempts to reduce wastes from this process. Recently, the process chemist and representatives from the DuPont central research organization met to consider alternative chemistries for producing diphenol ether. The group concluded that none of the alternatives they identified resolved the safety issues or produced less waste.

A project for installing a larger receiving tank is currently in the planning stages. However, neither the capital nor the human resources to implement this option have yet been assigned.

Opportunities for Others

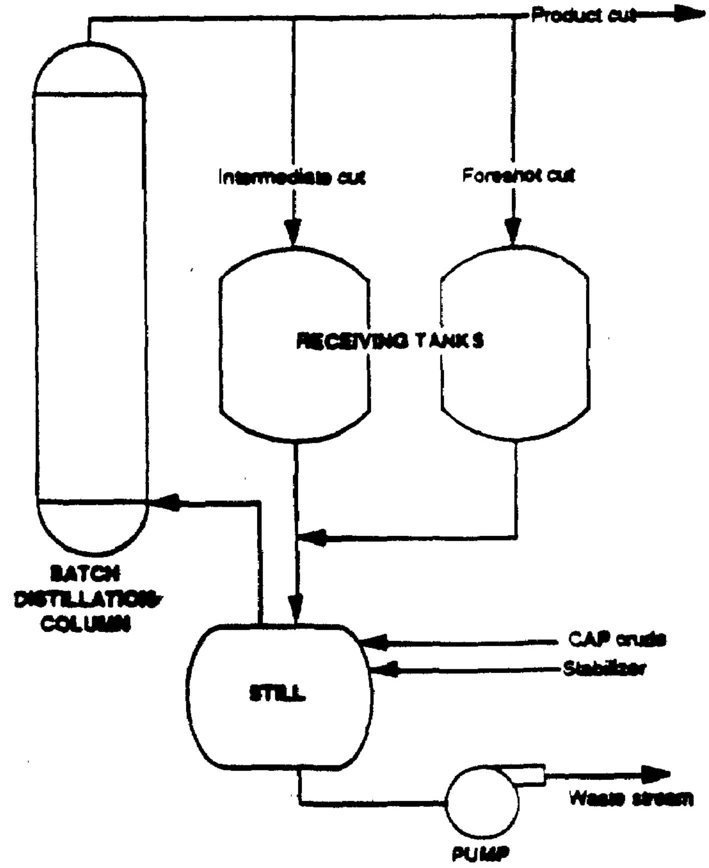
Several case studies in this series examine processes where a stabilizing agent is added for safety reasons. In all of those studies, the stabilizing agent either comprises the chief component of the waste stream, or otherwise frustrates attempts at waste reduction. All of these processes were designed long before waste reduction became a serious concern. As a rule, the original process designers allowed themselves large margins of safety by recommending the use of far more stabilizing agent than necessary. In these processes, waste reductions often can be achieved by simply reevaluating the amount of stabilizing agent required for safety so that the amount of stabilizer can be reduced.

Case Study 5: CAP Purification

Viable waste reductions are difficult to identify in old processes

Abstract

A waste minimization assessment was performed for a process which uses a distillation column to purify a chloroaromatic compound from a product crude. The addition of a solid stabilizing agent to minimize tar formation indirectly increases the process waste stream and frustrates attempts to reduce waste. Thus, the inauguration of a program to reduce the amount of stabilizer used was chosen as the best waste minimization option. This assessment exposes a possible flaw in the methodology for weighting and ranking waste reduction options. By not giving enough weight to an option's probability for success, several unworkable options placed near the top of the list.



The CAP crude and stabilizer enter the still and are heated while the column operates under normal atmospheric pressure. Water boils off, rises to the top of the column, and exits the process. The pressure within the column is then reduced.

During the transition from atmospheric to operating pressure, low-boilers continue to rise up the column. At first, the material consists largely of water, low-boiling impurities, and some CAP. This material, called the "foreshot cut", enters a receiving tank to be held until the end of the product campaign. At that time, it will be used to flush the process equipment in preparation for the next campaign.

As column pressure continues to drop, the amount of CAP boiling up the column with the low-boiling impurities increases. At some point, this "intermediate cut" is diverted to another receiving tank to be recycled back into the still with the next batch of the campaign. When the column has at last achieved its operating pressure, virtually pure CAP boils up in a final "product cut".

Figure 3–10. CAP Process

Background

The DuPont Chambers Works site produces a chlorinated aromatic product (CAP) in two separate processes at the site. One process makes CAP crude, and the other purifies the crude to product specifications.

The process which purifies CAP crude is among the oldest at the Chambers Works site. The process equipment is not dedicated to CAP purification, but is used to purify other products as well. Each CAP product "campaign" can purify a maximum of three batches of CAP crude before the amount of waste accumulating within the equipment precludes further processing.

The CAP is essentially boiled off from the crude by a heated still which is connected to a batch distillation column. This method exploits differences in the temperatures at which each constituent of the crude will boil. Lowering the pressure within the process equipment has the effect of lowering all boiling points. At the right temperature and pressure, compounds with lower boiling points (low-boilers) will vaporize and rise to the top of the column. There they condense, and either leave the process or pass to a receiving tank to be held for further processing. By controlling the temperature of the crude and the pressure within the process equipment, one can control the chemical content of the vapor taken off the top of the column.

Heating the CAP crude causes the formation of byproducts, some of which are heavy tars. To minimize byproduct formation, a stabilizing agent is added to the crude. If an insufficient amount of stabilizer is present, byproduct formation can be very rapid, causing damage to the process equipment. Although the stabilizer is a nonhazardous solid, its accumulation during a product campaign

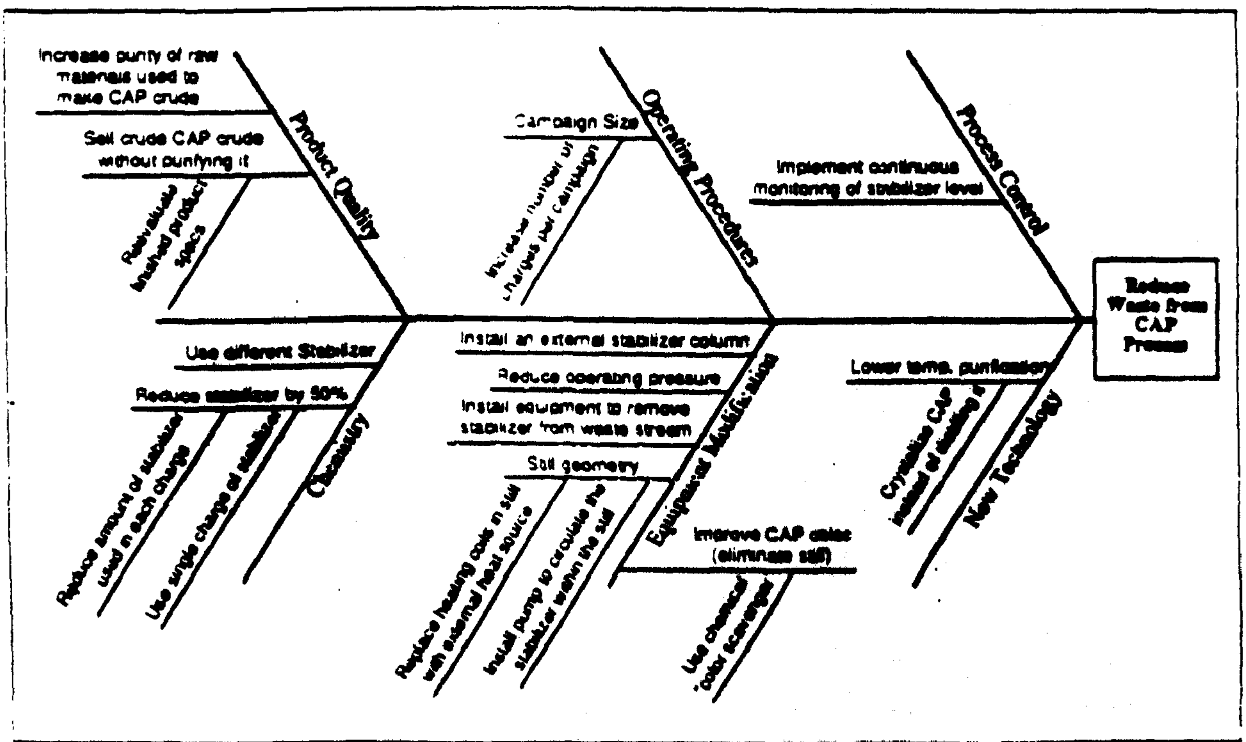


Figure 3-11. CAP Waste Minimization Options

Table 3-10. Ranked Summary of CAP Waste Minimization Options

Option	Pros	Cons	Comments	Score*
1. Reduce stabilizer by 50%.	• Addresses a major cause of waste • Low-to-moderate capital and operating costs	• Would require implementation of at least one and perhaps several other options to assure that the process remains stable	Ideas for reducing the amount of stabilizer include adding stabilizer only to the first batch of a campaign, or adding progressively smaller amounts to each batch.	1,060
2. Use chemical "color scavenger".	• Would eliminate the need for distillation process	• Virtually no chance of success	The chief reason for purifying CAP crude is to eliminate color and produce a water-white liquid. But a search of the chemical literature failed to identify a scavenger that would eliminate color.	1,010
3. Install equipment to remove stabilizer from the waste stream.	• Would reduce waste • Would permit recycling of stabilizer	• High capital cost • Long implementation time		950
4. Sell CAP crude without purifying it.	• Would eliminate the need for distillation process	• Virtually no chance of customer acceptance		910
5. Implement continuous monitoring of stabilizer level.	• Would reduce the amount of stabilizer used	• Developing a suitable measuring device could be difficult	Assumes that more precise control would reduce stabilizer while maintaining an acceptable margin of safety.	890
6. Install pump to circulate the stabilizer within the still.	• Would reduce the amount of stabilizer used • Low-to-moderate capital cost		A pump would circulate CAP within the still to keep the stabilizer in suspension. (Mechanical agitation is not an option because of still geometry.)	870
7. Reduce operating pressure.	• Would permit distillation at lower temperatures, which would in turn reduce tars formed during distillation and allow a reduction of stabilizer used	• May be difficult to implement		840
8. Install an external stabilizer column.	• Would greatly increase CAP recovery by keeping stabilizer out of the still	• Very high capital costs • May be difficult to implement technically		830

*maximum score = 1,450

Table 3–10. Ranked Summary of CAP Waste Minimization Options (cont'd)

Option	Pros	Cons	Comments	Score*
9. Increase number of charges per campaign.		• Accumulating stabilizer buildup probably renders this option undoable in present process		820
10. Crystallize CAP instead of distilling it.	• Would eliminate the need for stabilizer • May improve CAP recovery	• Prohibitive capital cost		780
11. Replace heating coils in still with external heat source.	• Would reduce amount of stabilizer by improving circulation within still	• High capital cost		780
12. Use different stabilizer.	• Presumed increase in CAP recovery	• Very low probability of success • High research cost	Previous attempts to find alternative stabilizers have failed.	780
13. Increase purity of raw materials used to make CAP crude.		• Would merely shift some of the waste disposal problem to another process		480

maximum score = 1,460

indirectly contributes to waste by preventing complete recovery of CAP product. Moreover, the stabilizer is chiefly responsible for the gritty, extremely viscous consistency of the waste stream.

Figure 3–10 illustrates the CAP purification process. The distillation process consists of three phases:

- *the "foreshot cut"*. Water and low-boiling impurities boil off first. This material is stored in a holding tank to eventually flush the still after the final batch of the campaign.
- *the "intermediate cut"*. A transition period during which increasing amounts of CAP boil up with the last of the low-boilers. This material is stored for recycling into the still during the next batch.
- *the "product cut"*. With the low-boilers gone, virtually pure CAP boils up the column.

After the third and final batch of the campaign, a viscous "heel" of tar and stabilizer remains at the bottom of the still. The still is heated to maximum temperature and pressure to recover as much residual product from the heel as possible. Then the tank that holds the foreshot cut empties into the still to flush the heel. The flush is dewatered and incinerated.

Description of Waste Stream

A typical analysis of the waste stream leaving the CAP still is provided below.

CAP (unrecovered product)	60%
Stabilizer	34%
Impurities	3%
High-boiling tars	3%

The consistency of the organic portion of the waste stream is much like that of heavy motor oil. However, the stabilizer thickens the waste considerably, and limits the amount of CAP that can be recovered from the crude.

The amount of waste from this process has been constant for several years, and equals 0.12 lbs for every pound of CAP product recovered. At present, wastes from CAP purification are incinerated.

Costs associated with this waste stream include the yield loss represented by the unrecovered CAP, replacement cost of the stabilizer, and the costs of incinerating the waste stream.

Previous Waste Minimization Efforts

Over the years, several efforts were made to reduce wastes from the CAP purification process:

- The practice of recycling the intermediate cut was designed into the process to increase the amount of CAP recovered. This yield improvement reduced the CAP component of the waste.
- Successful introduction of the stabilizer to the process minimized the formation of tars during distillation. These tars would otherwise contribute to the organic component of the waste.
- An effort to eliminate the stabilizer failed. Had it succeeded, it would have removed a major cause of waste generation.

Waste Minimization Options

The assessment team for CAP purification met in a brainstorming session and generated 13 possible options for reducing waste. They recorded their ideas by constructing a cause-and-effect "fishbone" chart, shown in Figure 3–11. In subsequent meetings, the team discussed the options and ranked them using the weighted-sum method described in Section 2 of this document. Table 3–10 summarizes these discussions, and presents the options in rank order.

Most of the options focus on the solid stabilizer. One option that was not suggested during brainstorming is changing the method of stabilizer addition from batch to continuous. This was among the most promising options in Case Study 9: "CAP Isomers Process". But that case study examined a continuous distillation process. The CAP purification process is a batch distillation; adding stabilizer in continuous mode would result in no waste reductions at all.

Technical and Economic Feasibility

After considering the pros and cons of each option listed in Table 3–10, the assessment team chose six options for technical and economic feasibility analysis:

- Option 1: Reduce stabilizer by 50%
- Option 3: Install equipment to remove stabilizer from the waste stream
- Option 5: Implement continuous monitoring of stabilizer level
- Option 6: Install pump to circulate the stabilizer within the still
- Option 7: Reduce operating pressure
- Option 8: Install an external stabilizer column

Table 3–11. Economic Summary of Top CAP Waste Minimization Options

Option	Waste Reduction	Capital Cost	EPA Method NPV (12%)	IRR	DuPont Method NPV (12%)	IRR	Implementation Time
Reduce stabilizer by 50%	34%	$20,000	$66,000	59%	$66,000	59%	6 months
Install equipment to remove stabilizer...	59%	$331,000	($156,000)	< 0%	($156,000)	< 0%	1 year
Implement continuous monitoring of stabilizer level	34%	$57,000	$32,000	24%	$32,000	24%	6 months
Install pump to circulate stabilizer...	34%	$48,000	$41,000	29%	$41,000	29%	6 months
Reduce operating pressure	34%	$104,000	($9,000)	10%	($9,000)	10%	1 year
Install an external stabilizer column	59%	$237,000	($73,000)	3%	($73,000)	3%	1 year

Comments: The economics for these options are given on a stand-alone basis, and do not consider possible synergies from implementing more than one option.

Waste reduction percentages for these options are not fully additive if more than one option is implemented.

Parentheses denote negative numbers.

For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation" in Section 2: *Project Methodology*.

The results of the economic analysis are presented in Table 3–11. Option 1 is easy to implement, has a good chance of reducing waste, and has a good economic return. However, safety concerns will probably prevent it from being implemented. Options 5, 6, and 7 achieve the same waste reduction as Option 1, but provide additional process controls that would maintain the present level of safety.

Option 3 offers greater waste reductions and would be fairly easy to implement, but the capital cost is prohibitive. Similarly, Option 8 would reduce wastes substantially but at a high cost.

Of the options considered, Option 6, "Install pump to circulate the stabilizer within the still", offers the best chance of success.

Barriers to Implementation

The addition of stabilizer is a safety practice that prevents rapid byproduct and tar formation and consequent equipment damage. It will be difficult to arouse interest in reducing the amount of stabilizer unless other changes are made that will maintain the margin of safety at current levels. Moreover, CAP purification is a batch process which shares equipment with several other products. Economics would make changes that benefit just one product difficult to justify.

Opportunities for Others

This series of assessments examines six processes in which the waste streams exit from distillation columns. The CAP process features a unique combination of process-specific considerations, i.e., the age of the process, the particular stabilizer it requires, and its sharing of equipment with other processes. Thus the ideas generated for reducing the waste stream seem specifically relevant to the CAP process. However, many of the options generated for the other distillation waste streams will surely be relevant for other processes throughout industry.

Several case studies in this series examine processes where a stabilizing agent is added for safety reasons. In all of those studies, the stabilizing agent either comprises the chief component of the waste stream, or otherwise frustrates attempts at waste reduction. As a rule, the designers of such processes allowed large margins of safety by recommending the use of more stabilizing agent than necessary. Thus, waste reductions often can be achieved by simply reevaluating the amount of stabilizing agent required for safety so that the amount of stabilizer can be reduced. However, it is likely that such reductions will have to be accompanied by such additional changes as better process controls, different operating conditions, or equipment changes in order to maintain the present margin of safety.

Case Study 6: Polymer Vessel Washout

High-pressure water cleaning eliminates the use of a hazardous solvent

Abstract

This report describes a successful effort to achieve a 98% source reduction in a waste stream generated by the washing of a process vessel with a flammable solvent. The solvent wash has been replaced by a high-pressure stream of water. The method used to identify and evaluate alternatives to the solvent wash contained some essential features of the EPA waste minimization methodology. However, this effort began not as a waste minimization project, but as part of an overall process improvement program. The new washout system was implemented because it attained most of the goals of the program, of which waste minimization was but one. This assessment highlights the importance of considering all business objectives when trying to minimize waste; waste reduction is often interrelated with such other business objectives as quality improvement, increased capacity, and reduced cycle times.

Background

The DuPont Chambers Works site produces several grades of polymer. The process uses an agitated vessel which must be cleaned periodically to maintain product quality. During processing, polymer accumulates on the vessel walls, agitator blades, and baffles. Cleanup is complicated by the vessel's construction, which renders opening the vessel to facilitate cleaning difficult and time-consuming.

Until recently, the vessel was cleaned by washing with a flammable solvent. The solvent was pumped into the vessel, agitated, and drained through a bottom flange. This process was typically repeated six times per cleaning. The solvent and dissolved polymer were drummed for eventual incineration on site.

In December of 1991, the polymers process area implemented a waste minimization option that has completely eliminated the solvent component of the waste stream. Moreover, the potential exists for eliminating the small amount of polymer waste as well. Solvent washing of the vessel has been replaced by cleaning with a high-pressure water jet.

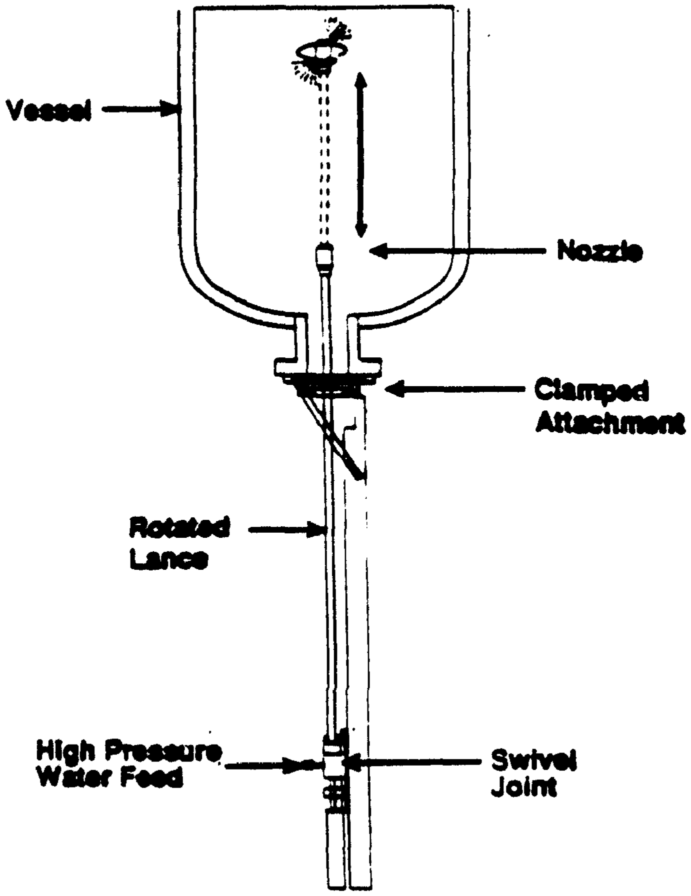
The alternative cleaning method originated not from a dedicated waste minimization effort, but from a process improvement program that had waste minimization as just one of its goals. The other goals were improved quality, shorter cycle times, reduction of inventories, etc. This waste minimization effort did not conform to the EPA methodology in that responsibility for its implementation fell to a single person in consultation with other area personnel. But the process contained some basic features of the EPA methodology, i.e., option generation and economic/technical feasibility analysis.

The process improvement program focused on vessel washout for several reasons:

- *The solvent waste*. The copious amounts of solvent required for washout produced a large waste stream that had to be incinerated.
- *Safety concerns during washout*. Solvent fumes constitute an explosion hazard, and special safety precautions had to be observed in the vicinity of the vessel during washout.

- *Safety concerns associated with handling and storing solvent-filled drums.* Solvent fumes released during loading and unloading posed a safety hazard, as did the ergonomics of drum handling.
- *Product quality considerations.* The solvent wash never really did a thorough job of cleaning the vessel.
- *The need to improve uptime.* The amount of time required for vessel washout frustrated attempts to increase production.

Figure 3–12 illustrates the new cleaning system. A special nozzle and lance assembly is connected to a high-pressure water source and inserted through the flange at the vessel bottom. The flange itself has been enlarged to accommodate the equipment and to enhance draining of the wash water. A stream of water at a pressure of 10,000 psi with a flow rate of 16 gpm blasts the residual polymer from the interior surfaces. For safety reasons, the entire system is operated remotely, and no high-



The high-pressure water lance is attached to a carriage, which is in turn affixed to the bottom of the vessel. A chain-drive moves the lance up and down the carriage as needed. A swivel joint at the base of the lance permits free rotation. The nozzle at the tip of the spinning lance has two aperatures, which emit cone-shaped sprays of water at 10,000 psi with a combined flow rate of 16 gpm.

Operation of the lance is controlled from a panel well removed from the vessel. The process is designed such that no high-pressure spray leaves the interior of the vessel. These precautions assure operator safety during vessel washout.

Figure 3–12. High-Pressure Water System pressure spray escapes the vessel. The system was designed with the help of an external vendor. With the exception of the nozzle and lance assembly, the system is operated using leased equipment.

Description of Waste Stream

A typical analysis of the waste stream resulting from the solvent washout of the polymer vessel would reveal:

Solvent	98%
Residual polymer	2%

Costs associated with this waste stream included the replacement cost of the solvent, the yield loss represented by the accumulation of residual polymer, and the costs of incinerating the waste stream.

Before the waste minimization effort, the solvent washout produced 0.013 lbs of hazardous waste to be incinerated for every pound of polymer product made. After implementation of the high-pressure water system, waste generation fell to 0.0001 lbs of nonhazardous waste for evey pound of polymer produced.

Table 3–12. Ranked Summary of Polymer Vessel Waste Minimization Options

Option	Pros	Cons	Comments
1. Replace solvent washout with cleaning by high-pressure water jet.	• Complete source elimination of solvent wash • Potential for applying residual polymer to as yet unexplored uses • Attainment of other process improvement goals	• Safety concerns • Equipment modification (i.e., enlargement of flange at vessel bottom) required	To prevent injuries to employees, spray equipment must be operated remotely, and spray must be completely enclosed within the vessel. The polymer is insoluble in water and can easily be separated from the wash. It will be landfilled until uses for it are found.
2. Use a still to recover and recycle solvent.	• Would achieve 90% reuse of solvent	• Would not achieve other process improvement goals • Requires significant capital cost and increased operation and maintenance costs	
3. Use an antistatic coating (such as glass) on vessel walls.	• Would reduce the number of solvent washes required • Would attain other process improvement goals	• Would not eliminate solvent washes because some polymer would still stick to coated vessel walls • Requires equipment modification • Would significantly increase maintenance costs	
4. Open process vessel and clean it manually.	• Complete source elimination of solvent wash • Potential for applying residual polymer to as yet unexplored uses	• Poor attainment of other process improvement goals • Would not enhance employee relations	A dirty and tedious job for whomever must perform it.

This represents a source reduction of 98% in the amount of waste generated.

The new cleaning system does produce a small wastewater stream, which is sent to the on-site wastewater treatment plant. Because the residual polymer is virtually insoluble in water, the wastewater contains no TOC or other contaminants and adds only a small hydraulic load on the wastewater treatment plant.

Previous Waste Minimization Efforts

In 1989, a project was started for which waste minimization was the chief goal. The project would have used a still to separate the solvent from the dissolved polymer and recycle it for future washes. Some of the process equipment required for this project was actually procured, but never installed. Work on the project stopped once the high-pressure washout process was demonstrated.

The solvent recycling project would have eliminated about 90% of the waste sent to the incinerator. However, this option was judged to be less satisfactory than the water-jet option because:

- it represented a recycling of waste rather than a source reduction, and
- it did not meet the other goals established for the process improvement program.

Waste Minimization Options

In 1990, four options were considered for achieving waste minimization, and these are summarized in Table 3–12. Option 1, "Replace solvent washout with cleaning by high-pressure water jet", emerged as the clear best choice. It satisfied all of the process improvement goals, including complete source reduction of solvent waste.

Technical and Economic Feasibility

Technical Evaluation

By April of 1991, a prototype nozzle had been designed with the help of the vendor and was ready for testing. The system operated at a pressure of 10,000 psi and a flow rate of 16 gpm. The test was not a complete success in that the nozzle failed to reach all of the required interior surfaces. Nevertheless, results were judged good enough to warrant further development.

Table 3–13. Economic Summary of Top Polymer Vessel Waste Minimization Options

Option	Waste Reduction	Capital Cost	EPA Method NPV (12%)	EPA Method IRR	DuPont Method NPV (12%)	DuPont Method IRR	Implementation Time
Replace solvent... with...high-pressure water jet	98%	$125,000	$2,720,000	181%	$2,690,000	180%	1 year
...recover and recycle solvent	90%	$500,000	($358,000)	< 0%	($393,000)	< 0%	2 years

Comments: Parentheses denote negative numbers.

For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation" in Section 2: *Project Methodology*.

Economic Evaluation

Only two options were subjected to an economic analysis: Option 1 "Replace solvent washout with cleaning by high-pressure water jet", and Option 2 "Use distillation column to recover and recycle solvent". Results are summarized in Table 3–13 using both DuPont and EPA methodologies.

When evaluating waste minimization projects, it's important to consider all factors that can contribute to their cost effectiveness. Focusing narrowly on waste minimization objectives could cause a business to overlook cost-saving options that have a better chance of implementation. The high-pressure water jet option had a very attractive internal rate of return (IRR) when considered for its attainment of both waste minimization and process improvement goals. Had it been evaluated on the basis of waste minimization alone, the IRR would have been marginal, and its chances for implementation would have been diminished.

The recovery of solvent option (Option 2) began as a low capital project with a limited scope. It had assumed the use of drums to handle and store the recovered solvent, and this helped keep the capital cost down. However, the handling of drums was later deemed to be inconsistent with other process improvement goals, and the scope of the project was changed to eliminate the use of drums. This required the use of holding tanks and associated equipment, which increased capital costs prohibitively.

Barriers to Implementation

Barriers to implementing the high-pressure water option included concerns over safety. The same technology is employed in some industries to cut rock! A wayward jet stream could easily disable a person. A way had to be found to operate the system remotely, and to completely enclose the water jet within the polymer vessel. Moreover, a specialized nozzle which could reach all interior surfaces of this particular vessel had to be designed.

Evaluation of Performance

The experimental lance/nozzle assembly was modified to achieve complete washing of the vessel interior. The flange at the bottom of the vessel was enlarged to accommodate the lance and to improve drainage. The new system was tested in December of 1991 and resulted in flawless cleaning of the vessel. Since then, the system has met all of its process improvement program goals. The solvent waste has been completely eliminated. The remainder of the waste stream, i.e., a small amount of non-hazardous polymer, is now being landfilled. But process area management is already considering ways in which this waste can be sold for various applications.

This waste minimization success story is being communicated throughout the DuPont community in a number of ways, including a description of the technology in an internal technical bulletin distributed to engineers. This waste minimization effort has won an "Environmental Excellence Award", a DuPont award which recognizes people or teams that have made significant contributions toward the company's goal of global environmental leadership.

Opportunities for Others

Many industrial processes depend upon solvent washes for cleaning equipment. High-pressure water cleaning now presents an environmentally sound alternative. Nozzle designs and ancillary equipment have advanced sufficiently to permit automated and safe high-pressure water cleaning systems. Even in those processes where water cannot be introduced into the equipment, an alternative exists. Vessels can be cleaned with solid carbon dioxide (dry ice) particles suspended in a nitrogen gas carrier. The solid CO_2 cleans in a manner similar to that of sandblasting, but evaporates, leaving only the material removed from the equipment.

This assessment highlights the importance of considering all business objectives when trying to minimize waste. Waste reduction is often interrelated with such goals as quality improvement, cycle time reduction, and lower materials cost. Solutions which satisfy all of these goals are those which are most likely to be implemented. The lesson for option generation is to look at the big picture, and not to focus narrowly on a waste stream.

Case Study 7: Reusable Tote Bins

Returnable product containers eliminate 55-gallon drums

Abstract

This report describes the successful implementation of an environmentally friendly product packaging system to reduce the use of single-use 55-gallon drums. This effort both conserves landfill space and reduces a waste stream consisting of the chemical residue remaining within thousands of empty drums. The new packaging system uses returnable metal tote bins which drain much more completely than drums, and provide better ergonomics for users and handlers. Customers view the new packaging as a value-adding part of the product offering because it relieves them of the burden of drum disposal. The combination of product improvement with waste minimization helped to ensure the success of this effort.

Background

The Chambers Works site produces a line of more than 500 specialty chemicals which are sold in small-volume orders to customers in a variety of industries. These chemicals, some of which are custom-made for specific customer applications, are collectively known as "small-lot" chemicals. Until recently, all customers of small-lot chemicals received their products in single-use containers such as 55-gallon drums. When emptied, the drums could contain about a pound of product residue. Customers had to wash out the drums and properly dispose of the wash and residue, and then dispose of the empty drum, usually within a landfill. Given the rising costs of waste disposal, customers clearly had great value for an alternative packaging method that would relieve them of this waste disposal burden.

Recently, a DuPont assessment team of business leaders and plant personnel completed an effort to identify and implement alternative packaging for several customers of small-lot chemicals. The team had established several goals that the chosen alternative would have to meet:

- relieve customers of the waste disposal burden
- provide better ergonomics and ease of use than that afforded by drums
- have no adverse affect on product quality or shelf life

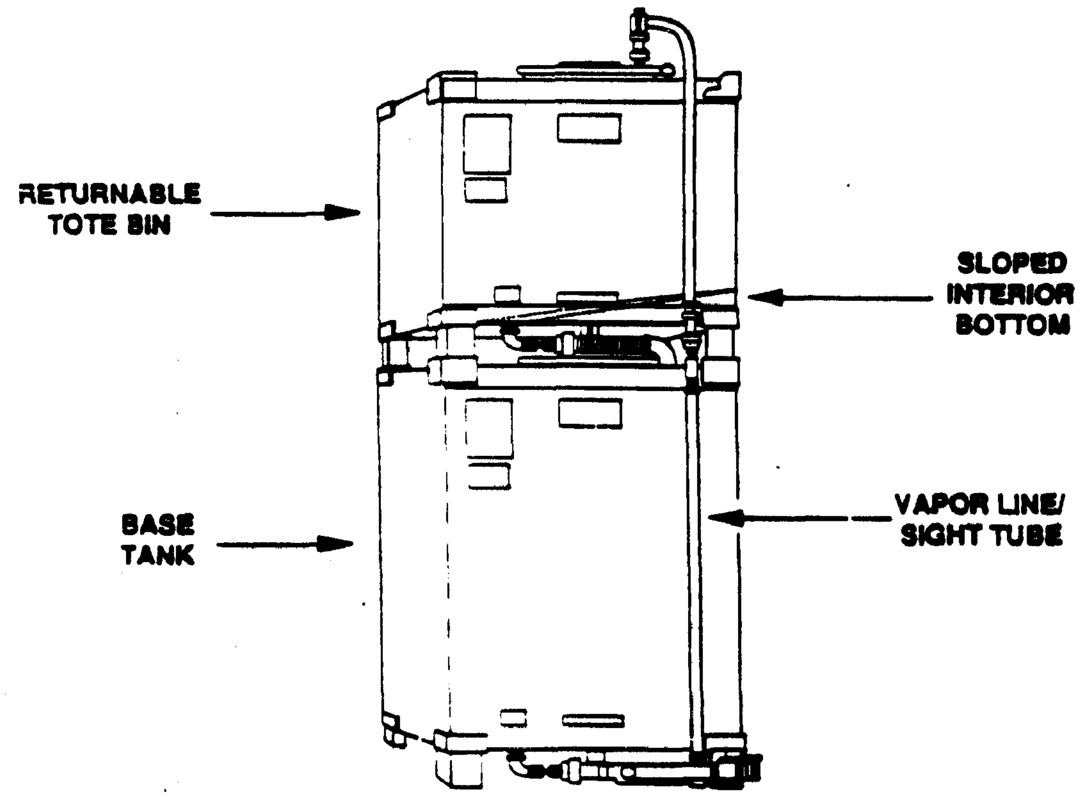
The chosen alternative, illustrated in Figure 3–13, is a returnable metal tote bin with an optional base tank. Customers receive a full tote bin and mount it atop the base tank which dispenses the product. When the tote bin is empty, the customer ships it to a third-party cleaning vendor located near the Chambers Works site. The cleaning vendor uses a high-pressure water system to clean the tote bins, and then sends the clean bins and the washwater to Chambers Works. There, the empty tote bins are refilled with whatever small-lot chemical is ready for shipment. The washwater goes to the on-site wastewater treatment plant for disposal.

The returnable tote bins are purchased by DuPont, which retains ownership of them throughout their service life. The base tanks are the property of the customer. DuPont bears the costs for the return shipment of the tote bins and for their cleaning.

The totes bins are specially designed for complete drainage. Any residue left behind in an empty tote bin is an extremely small fraction of that left behind in the equivalent number of empty drums. Moreover, the elimination of the drums themselves is a waste reduction which conserves landfill space. And because the tote bins meet the goals established for this effort, they have won acceptance by those customers who receive them.

Description of the Waste Stream

The waste stream from drum packaging originates not from the Chambers Works plant, but from the customer's site. After the product is consumed, about one pound of waste remains within each drum. Disposal of this waste is the responsibility of the customer. Costs to the customer include labor cost for washing the drum, disposal cost for the residue, disposal cost for the empty drum,



The returnable tote bin is a 345-gal. stainless steel container. It meets all DOT specifications for shipping the chemicals it contains. The tote bin has a stacking pad and leg positioners to permit stacking. The container is designed to be assessible to a fork lift from three sides. The inner bottom of the container is sloped to allow material to drain quickly and completely.

The base tank holds about 500 gallons. The returnable tote bin is placed on top of the base tank and feeds its contents to the tank. A vapor line attached between the tote bin and base tank prevents vapor from escaping to the atmosphere. The base tank contains an instrument or site tube to indicate fluid level. The tote bin/base tank assembly provides a steady supply of product, even during tote bin changeovers.

Figure 3–13. Reusable Tote Bin and Base Tank Assembly and yield loss represented by the residue. These costs can easily total more than $25 per drum.

The use of returnable containers virtually eliminates this cost for the customer. It also greatly reduces the total wastes represented by product residue in empty drums. But a more dramatic waste reduction is the number of drums that will not occupy space in landfills. One returnable tote bin holds as much product as six drums. Over its expected service life, the tote bin will package as much product as 360 drums.

Shifting the waste disposal burden from many customers to DuPont helps to ensure that wastes will be disposed of properly. It also protects DuPont from liabilities resulting from improper disposal of drums by customers.

Previous Waste Minimization Efforts

The small-lot chemicals business had previously studied the use of 275-gallon polyethylene totes. However, permeation of the polyethylene by the solvent was observed, and it was judged an unsuitable material of construction for this end use. Implementation of this option would have required either costly modification to the polyethylene or the adoption of an alternative polymer with specific resistance to the solvent. No such polymer is known to be commercially available.

Waste Minimization Options

The assessment team examined four waste minimization options, and these are summarized in Table 3–14. Option 1, "Stainless steel, returnable container", emerged as the best choice because it satisfies to some degree all of the goals established for this waste minimization effort.

Technical and Economic Feasibility

Only two options would result in waste elimination: Options 1 and 2, both of which use the same container. Option 1 requires a cleanout of the tote bins between uses, whereas Option 2 eliminates cleaning by dedicating tote bins to single products.

Option 1 simplifies the packaging process. Cleaning a tote makes it suitable for packaging any product for shipment to any customer. Given the great number and low volume of

Table 3–14. Ranked Summary of Tote Bin Waste Minimization Options

Option	Pros	Cons
1. Stainless steel, returnable container.	• Eliminates disposal at customer sites • Reduces total waste by 50%	• Does not completely eliminate waste • High capital cost
2. Dedicated returnable containers.	• Complete elimination of waste stream	• Too many containers required • Quality concerns from potential contamination or decomposition of product remaining in tote
3. Make on-demand deliveries ("milk run" option) using multi-compartment tankers.	• Eliminates drum disposal	• Impractical and costly because of number of products and customers • Would not eliminate waste because tanker trucks would have to be cleaned between runs
4. Use plastic totes with vapor barrier.	• Much lower cost than stainless steel tote bins	• Can be used only once, and would not ameliorate disposal problems

Table 3–15. Economic Summary of Top Tote Bin Waste Minimization Options

Option	Waste Reduction	Capital Cost per Container	NPV (12%)	IRR	Change in Product Cost for Acceptable IRR
Returnable containers, six trips per year with washout	50%	$1,500	($1,997)	< 0%	$0.07/lb increase
Returnable containers, six trips per year with no washout	100%	$1,500	$360	17%	None required

Comments: Parentheses denote negative numbers.

For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation:" in Section 2: *Project Methodology*.

small-lot chemicals sold to individual customers, dedicating totes to single products would lengthen their turnaround time and require a greater number of tote bins. Cleaning the totes for reuse with any product available for shipment shortens their turnaround time, and helps to offset the cost of the bins.

Because Option 2 eliminates washout, the tote bins would have to be modified with seals and check valves to prevent contamination from the surrounding environment in which the totes are used. But dedicating tote bins to customers who buy a product in high volume could make economic sense.

The economic feasibility of reusable tote bins depends on such customer-specific factors as distance from Chambers Works and tote bin turnaround frequency. The evaluation presented in Table 3–15 assumes a shipping distance of about 1000 miles, six round trips per-tote per-year, and a tote bin service life of 10 years. It factors in cost savings to DuPont from the elimination of drums, pallets, and stretch wrapping. No customer cost savings were assumed.

Offsetting these savings are costs associated with washing the tote bins, shipping them back to Chambers Works, and tracking them throughout the product cycle. The greatest of these costs is the washing, accounting for about 60% of the total.

Table 3–15 presents evaluations for two cases:

- *Case 1: Six turnovers per year with washout between uses*. An acceptable internal rate of return (IRR) for purchasing the totes would require additional revenue equal to about $0.07 per pound of product shipped.
- *Case 2: Six turnovers per year using product-dedicated totes and no washout*. Not only does this option provide a 100% reduction in waste, but it also provides sufficient IRR to support purchase of the returnable totes without any additional revenue.

The products within the small-lot chemicals line generally are sold in such low volume that dedicated tote bins are not likely to have six turnovers per-tote per-year as Case 2 assumes. But other product lines now packaged in drums are sold in sufficient volume to benefit from a switch to dedicated, returnable totes. Each product and customer has to be evaluated on a case-by-case basis.

Such "soft" benefits as increased customer satisfaction and maintenance of market position will undoubtedly influence the decision of whether to use drums or totes.

Evaluation of Performance

In the spring of 1991, 50 tote bins were ordered to demonstrate the validity of the returnable container concept. There were some initial problems with the materials used for sight glass tubes and gaskets, but these were solved by fall 1991. The small-lot chemicals business now uses the tote bins for many products and expects to extend their use to more products in the future.

Opportunities for Others

This assessment demonstrates that good waste reductions don't always originate in the process area. The replacement of drum packing with reusable bins was suggested by the sales force and driven by the business organization.

There are probably many products for which switching from drum packing to returnable containers would benefit both supplier and customer. For the supplier, the cost of a returnable tote over its service life could be less than the cost of the nonreturnable drums that would otherwise be used. But the real beneficiaries of returnable containers are customers, happy at last to be rid of a disposal headache. Switching to reusable containers in businesses still dominated by drums can confer upon a supplier a competitive advantage.

The Chemical Manufacturer's Association (CMA) promulgates Product Stewardship guidelines as part of its Responsible Care® program. These guidelines are intended to promote the safe handling of chemicals, from initial manufacture to ultimate disposal, by member organizations, their distributors, and customers. In many cases, returnable containers are a good way to advance the objectives of the Product Stewardship guidelines.

Case Study 8: Monomer Production

A reaction/distillation process achieves waste reduction through better process control

Abstract

A process for making monomers uses a reactor to create the product, and a distillation column to separate the product from the reaction mass. Some of the reaction mass polymerizes within the reaction vessel, forming waste and entrapping a large quantity of otherwise good product. To increase product yield and reduce waste, the monomers process will replace its outmoded process control system with a modern distributed control system (DCS). This assessment demonstrates the importance of process control to waste reduction. It also demonstrates the interrelationship between waste reduction and other business objectives such as reduced cycle time, higher product yield, and greater process productivity.

Background

A batch process at the DuPont Chambers Works site produces several monomers used to manufacture various polymers. One of the raw materials used in the process, methyl methacrylate (MMA), is itself a monomer. During processing, MMA tends to polymerize within the process equipment, forming a very viscous tar and entrapping a large quantity of otherwise recoverable product. These wastes are currently drummed and landfilled on site.

Figure 3–14 illustrates the process for producing monomers. MMA and long-chain alcohol are reacted in the presence of a catalyst to form the product monomer. Despite the addition of a polymerization inhibitor, some MMA polymerizes when heated to process temperatures. When processing of a product batch is complete, the polymer tar is drained from the bottom of the reactor into 55-gal drums, mixed with wax to enhance solidification, and landfilled.

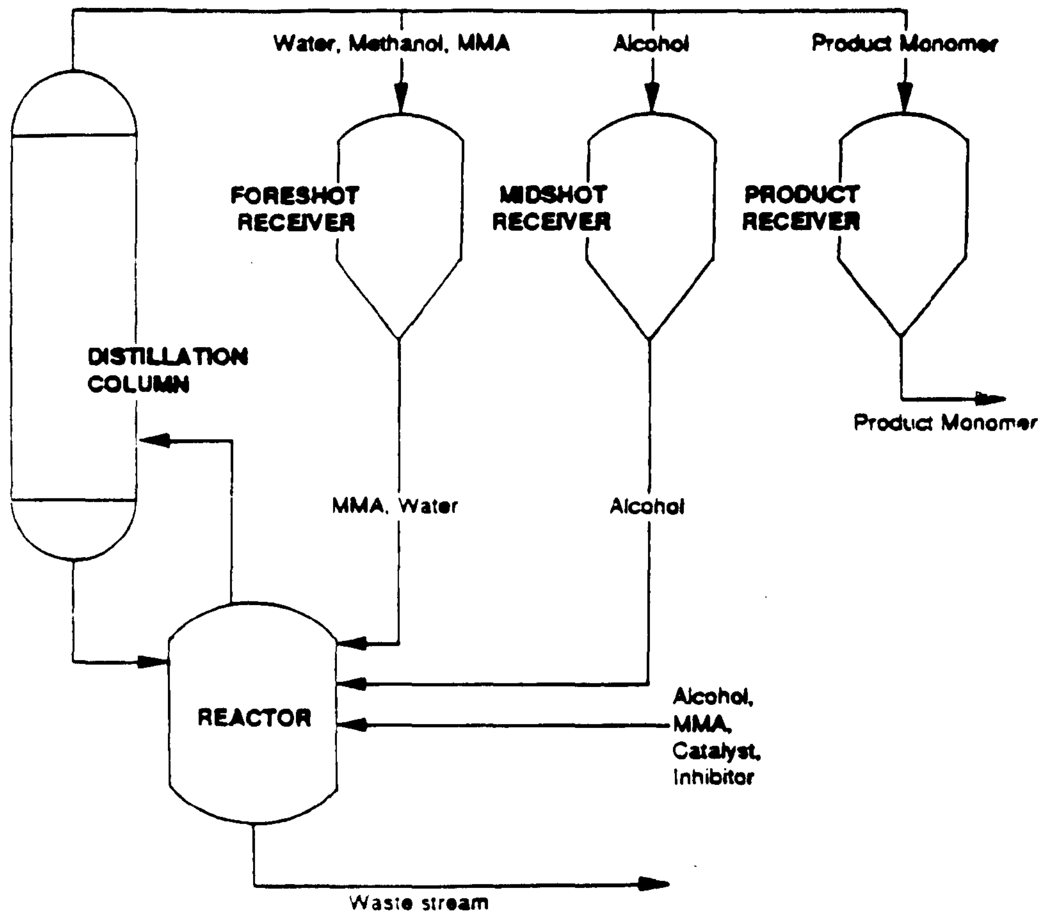
A waste minimization assessment was performed to generate options for reducing the tar stream from the monomers process. The assessment team determined that the best option for implementation would be the complete replacement of the present pneumatic control system with an electronic distributed control system (DCS). This project will require considerable capital investment, but is expected to cut the tar stream in half. In addition to reducing waste, the DCS will also improve product yield, shorten cycle time, and improve quality. Indeed, it is for all of these reasons that the DCS option was selected. It's questionable whether such a high-capital project could have been justified based on reducing the waste stream alone.

Description of the Waste Stream

A typical analysis of the tars leaving the monomers reactor would reveal:

Unrecovered product monomer	50%
Polymer tars	45%
Decomposition products	5%

The tars leave the hot reactor as a viscous liquid, but form a solid mass upon cooling. Some wax is added to help solidify the tars. Decomposition products include inhibitors and catalyst left over from the reaction.



Virgin MMA and alcohol, a recycle stream of MMA and water, a recycle stream of alcohol, and a polymerization inhibitor are placed in a heated reactor. Water boils off, rises as vapor to the top of the column, and exits the process. Then a catalyst is introduced to the reactor. The resulting reaction produces the product monomer and methanol byproduct. As the methanol forms, it boils up the column and passes to the foreshot receiver, taking some MMA with it. The reaction continues until methanol ceases to form. Then the pressure within the reactor and column is reduced. This causes unreacted alcohol to boil up the column and pass on to the midshot receiver. The pressure within the process equipment is reduced again, and the product monomer boils up the distillation column to the product receiver.

Despite the addition of the inhibitor, some MMA and product monomer polymerizes upon exposure to heat and forms a viscous tar. At the end of each product batch, the tar is drained from the bottom of the reactor into drums and then landfilled.

Methanol is washed out of the foreshot receiver with water. Some residual water remains behind with the MMA. At the start of the next product batch, the contents of the foreshot and midshot receivers are reintroduced to the reactor.

Figure 3-14. Monomers Process

The amount of waste currently generated by this process is 0.12 lbs of waste for every pound of monomer produced. The wastes are currently landfilled on site.

The major costs associated with this waste stream are the costs of landfilling and the yield loss represented by the unrecovered product. Included in the landfilling costs are the costs of purchasing and handling drums, and the cost of the wax which is used to solidify the tars.

Previous Waste Minimization Efforts

Over the years, several efforts have been made to reduce wastes from the monomers process.

In 1970, the process began operating at lower reactor and column pressure. This allowed the reaction and distillation steps to run at lower temperatures. Lower temperature retarded polymerization of the reaction mass, resulting in a waste reduction of about 25%. Unfortunately, the lower temperature increased both the reaction time and distillation time, resulting in reduced production. So in 1975, the pressure and temperature were raised back to their previous levels.

In 1975, the amount of inhibitor added to the reactor was doubled, which improved product yield and reduced wastes by about 14%. This measure is still in effect in the current process.

In 1990, the monomers process tested an alternative method for disposing of tars: mixing the tars with solvent and then incinerating the mixture. This option was tested because of concern about off-site landfill costs in the event that the Chambers Works landfill became full. Also, adding solvent would make the tars pumpable, eliminating the ergonomic safety concerns associated with drum handling. However, test results showed that the cost of incineration and solvent were greater than the cost of off-site landfilling.

In 1992, an alternative inhibitor was tested for its possible waste minimization value. Labo-

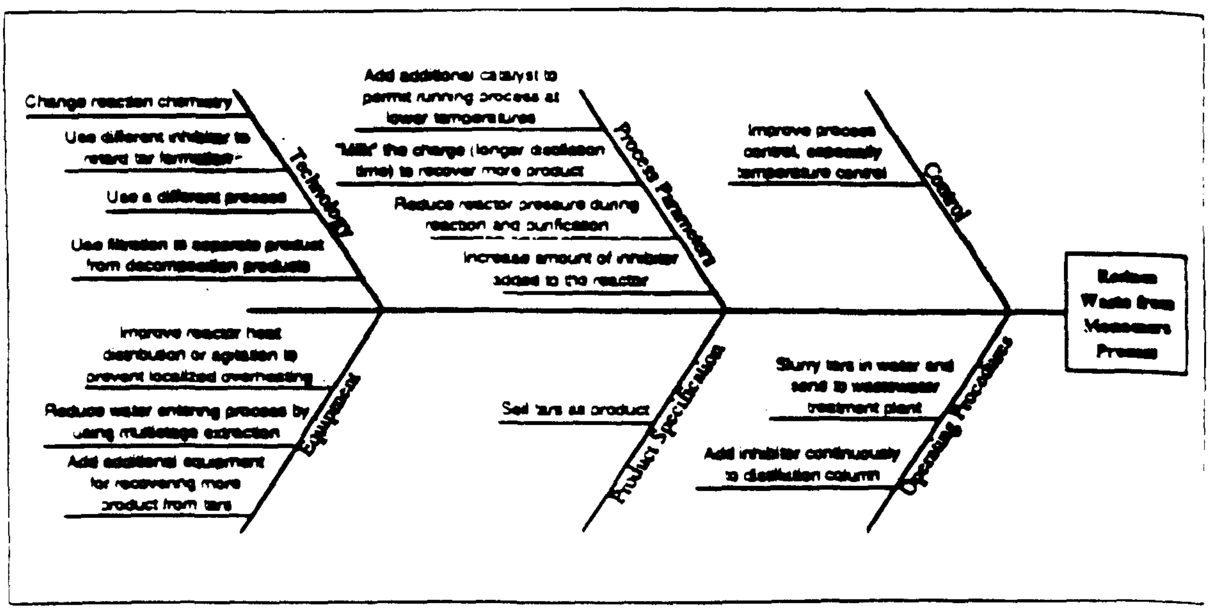


Figure 3-15. Monomers Process Waste Minimization Options

ratory tests indicated that the new inhibitor might decrease tar formation. However, a plant trial revealed no decrease in tars. It is often difficult to reproduce laboratory results in an actual process because the control of a large scale process usually lacks the precision of control in the laboratory. However, this option may be reconsidered after the DCS is installed.

Waste Minimization Options

An assessment team consisting of the area chemist, area engineer, two operators, and three people from outside of the process area generated 15 waste minimization options. They recorded their ideas by constructing a cause-and-effect "fishbone" chart, shown in Figure 3–15. In subsequent meetings, the team discussed the options and ranked them using the weighted-sum method described in Section 2 of this document. Table 3–16 summarizes these discussions, and presents the options in rank order.

Both the MMA raw material and the product monomer tend to polymerize when heated to process temperatures, and this produces the tar stream. For this reason, source reduction options tended to address reactor temperature, the polymerization inhibitor, or residence time of the reactants within the reactor. Because the tar stream contains a large percentage of unrecovered product monomer, several recyling options looked at ways to recover additional product from the waste stream.

Technical and Economic Feasibility

After considering the pros and cons of each option listed in Table 3–16, the assessment team chose five options for technical and economic feasibility analysis:

- Option 1: Reduce reactor pressure during reaction and purification
- Option 2: Add additional catalyst to permit running process at lower temperatures
- Option 4: Increase amount of inhibitor added to the reactor
- Option 5: Improve process control, especially temperature control
- Option 11: "Milk" the charge (longer distillation time) to recover more product

The results of the economic analysis are presented in Table 3–17.

Option 5, "Improve process control...", is currently being implemented. The process area is replacing their outmoded pneumatic controls with a DCS. The more precise control afforded by the DCS will permit shorter residence times within the reactor. This in turn will reduce waste by perhaps 50%.

The DCS project did not rank at the top of the option list, and might not have been selected for waste reduction alone. But other benefits from the DCS, such as increased production, higher product yield, shorter cycle time, and higher product quality, all contributed the additional cost savings required to justify this project.

After the DCS has been installed, several other options might be considered to achieve further reductions. The economic analysis for these options as well as for the DCS are presented in Table 3–17.

Option 4, "Increase amount of inhibitor added to the reactor", could be implemented quickly and with no capital cost. In the past, doubling the amount of inhibitor reduced tar formation. It's possible that doubling it again, or changing the method or location of inhibitor addition, could achieve further reductions. The analysis in Table 3–17 assumes several person-months of a chemist's time to evaluate

Table 3–16. Ranked Summary of Top Monomers Process Waste Minimization Options

Option	Pros	Cons	Comments	Score*
1. Reduce reactor pressure during reaction and purification.	• May reduce amount of tars which form in reactor • Little or no capital cost	• May require plant to run at lower production rates • Longer residence time in reactor could actually increase tar formation	Modifications to the distillation column packing may permit operation at lower pressures without reducing production rates.	811
2. Add additional catalyst to permit running process at lower temperatures.	• Lower temperatures would reduce tar formation • Little or no capital cost	• Increased raw material cost (cost of additional catalyst) • May require plant to run at lower production rates	May require laboratory trials to determine optimum amount of catalyst.	787
3. Slurry tars in water and send to wastewater treatment plant.	• Would eliminate waste stream from landfill	• Much more expensive than landfilling • No waste reduction	This option would not reduce waste, but it would conserve landfill space.	773
4. Increase amount of inhibitor added to the reactor.	• Would reduce amount of tars which form in reactor • Little or no capital cost	• Increased raw material cost (cost of additional inhibitor)	Experience has shown that increasing inhibitor does reduce tar formation. This option may require laboratory trials to determine optimum amount of inhibitor.	713
5. Improve process control, especially temperature control.	• Better process control could reduce residence time in reactor, thus reducing tar formation	• High capital cost	Cost savings in areas other than waste minimization would be needed to help justify this option.	711
6. Improve reactor heat distribution or agitation to prevent localized overheating.	• May reduce amount of tars that form in reactor	• High capital cost • Underlying assumption (that localized high temperatures cause tar formation) is uncertain	The project team speculated that reactor agitation may splash the reaction mass onto exposed heating coils. Exposed coils are considerably hotter than coils that are continually covered with reaction mass.	677
7. Sell tars as product.	• The tars could be formed into shapes and sold	• Low molecular weight of the tars makes it unlikely to have many uses	It may be possible to add a catalyst to increase the molecular weight of the tars.	659
8. Change reaction chemistry.	• Totally new chemistry could reduce tar formation	• Alternative chemistry could compromise process safety • High capital cost • Long development time • Uncertain chance of success	Cost savings from other areas would be required to make this option economically feasible.	653

*maximum score = 1,170

Table 3–16. Ranked Summary of Top Monomers Process Waste Minimization Options (cont'd)

Option	Pros	Cons	Comments	Score*
9. Use different inhibitor to retard tar formation.	• Tests show that other inhibitors can be used	• Plant trials with alternative inhibitors showed no reduction in tar formation	This option could be reconsidered after installation of the new DCS.	649
10. Use a different process.	• Fair chance of success	• Alternative process produces a large wastewater stream	An alternative process for producing a similar product does exist on site.	619
11. "Milk" the charge (longer distillation time) to recover more product.	• The yield increase can reduce waste by about 50% • Good chance of success (option has been demonstrated)	• Concentrated tars are difficult to remove from the reactor • Option tends to force tars up the column with product, thus affecting quality • Option could cause tar formation in the column	Past experience shows that concentrated tars are extremely difficult to remove from reactor. Perhaps high-pressure water cleaning with subsequent filtration of tars could be used.	612
12. Reduce water entering process by using multi-stage extraction.	• Reduced raw materials loss (cost savings) • Shorter batch cycle time • Increased production • Reduced tar formation through shorter residence time in reactor	• High capital cost • Requires installation of a multi-stage extractor	The process currently uses a single-stage extraction to recover excess raw materials. This extraction uses water, which must be removed from the process. Using additional extraction stages reduces both the amount of water in the process and the time that the reactor is held at elevated temperatures.	577
13. Add inhibitor continuously to distillation column.	• Could reduce tar formation in column	• Tar reduction is likely to be small if tars are formed primarily in the reactor	It remains to be determined whether tars are formed primarily in the reactor or the distillation column.	575
14. Add additional equipment for recovering more product from tars.	• Possible waste reduction of 50%	• High capital cost • Long implementation time	One possible method is the use of a wiped-film evaporator.	464
15. Use filtration to separate product from decomposition products.	• Eliminates distillation • Increased yield • Reduces waste by 50% • Shorter cycle time • Increase production • Low capital cost	• Unacceptable quality deterioration (some tars would remain in product)	Implementation of this option would require customers to agree to lower product quality specifications.	463

*maximum score = 1,170

in a laboratory the optimum amount of inhibitor and to conduct a trial on the actual process equipment. The analysis also assumes an additional 50% reduction in waste. Combined with the waste reduction achieved by the DCS, total waste reduction would be about 75%.

Option 2, "Add additional catalyst...", could also reduce tars if the catalyst caused a faster reaction and at lower temperatures. Again, this option would require no capital costs, but would require several man-months of lab evaluation and trials.

Option 11, "Milk the charge...", i.e., prolong the distillation step to recover more product) has been shown to reduce waste by about 50%. However, the concentrated tars at the bottom of the reactor become too thick to remove easily. (These tars are actually molten polymer.) This option could be implemented if a way were found for easily removing the waste from the reactor. A high-pressure water system has been successfully adopted for cleaning a process vessel at another process area on site. (See Case Study 6: "Polymer Vessel Washout".) If this option were imple-

Table 3–17. Economic Summary of Top Monomers Process Waste Minimization Options

Option	Waste Reduction	Capital Cost	EPA Method NPV (12%)	EPA Method IRR	DuPont Method NPV (12%)	DuPont Method IRR	Implementation Time
Improve process control...	50%	$1,200,000	$2,600,000	51%	$2,600,000	51%	1.5 years
The evaluation of the following options assumes successful implementation of "Improve process control..."							
Increase amount of inhibitor...	75%*	$0	$205,000	51%	$165,000	45%	6 months
Add additional catalyst...	75%*	$0	$166,000	45%	$126,000	39%	6 months
"Milk" the charge...	75%*	$150,000	$120,000	28%	$81,000	23%	1 year
Reduce reactor pressure	75%*	$100,000	$109,000	25%	$69,000	20%	1 year

Comments: Waste reductions given for options with an asterisk (*) assume an additional 50% waste reduction after implementation of "Improve process control..." This results in a total reduction of 75%. The economics for asterisked options include cost savings resulting only from the reduction of waste from 50% to 75%.

The economics for these options are given on a stand-alone basis, and do not consider possible synergies from implementing more than one option.

For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation" in Section 2: *Project Methodology*.

mented for the monomers process, it would combine with the new DCS to achieve a waste reduction of about 75%.

Option 1, "Reduce and column pressure..." has been tried before, and is known to reduce tar formation. But it also reduces production by requiring longer reaction and distillation times. However, it may be possible to redesign the distillation column to speed up the distillation step. The column contains "packing", specially shaped material that increases the interior surface area of the column thereby enhancing the distillation. A different kind of packing called "structured" packing might permit lower column pressures without decreasing the production rate.

It's probably a good idea to defer implementation of any additional waste minimization options until after the DCS startup. Past experience with DCS conversions shows that the wealth of data that a DCS can provide leads to better understanding of the causes of byproduct formation. It is possible that new options for reducing waste will become apparent after the process has begun operating under DCS control.

Barriers to Implementation
The high capital cost of a DCS conversion is an impediment to implementation, but people at the monomers process are confident that they will secure the funding. Most of the planning, installation, and system configuration will be done by process area personnel, with the full participation of operators and mechanics. They expect to have the DCS installed and running by the end of 1993.

Opportunities for Others

This case study, like others in this series, demonstrates the interrelationship between process improvement goals and waste minimization. Control system improvements can reduce waste in many processes. But these improvements are often expensive, and can be justified economically only after considering the returns expected from improved quality, increased productivity, better product yields, etc.

This assessment also demonstrates how important the assessment team composition is to the success of a waste minimization effort. The monomers assessment team included representatives from among those who actually run the process: operators and mechanics. One of the most promising waste minimization options, that of increasing distillation time to recover more product, was suggested by an operator. The hands-on experience that such people have is an important complement to the theoretical understanding possessed by process engineers and chemists.

Case Study 9: CAP Isomers Process

Switching from batch to continuous feeding of a chemical stabilizer reduces waste in a distillation process

Abstract

This case study examines a waste reduction project for a distillation process that purifies chloroaromatic isomers from a product crude. The project will reduce the amount of a chemical stabilizer that is used to prevent dechlorination of the crude. This stabilizer ultimately forms a substantial part of the process waste stream. The project will replace the current method of batch feeding the stabilizer with continuous feeding. Although this change will significantly reduce wastes, a waste assessment was nevertheless performed to identify additional waste reduction options. These options could have general application to other distillation processes.

The CAP crude is fed continuously to the isomer distillation column where it is subjected to heat at reduced pressure. The low-boiling isomer vaporizes, exits the top of the column, and collects as a liquid in a product catch tank.

To limit dechlorination of the crude, a 50/50 mixture of solid stabilizer and carrier solvent is added to the isomer column in batches through the isomer column pump. The pump impellers ensure good mixing of stabilizer and CAP crude. At present, the stabilizer level in the isomer column is monitored by drawing samples from the column and sending them to a lab for analysis. The turnaround time from the drawing of samples and the communication of the lab results is several hours.

The crude passes from the isomer column reboiler to the detarring column, where it is again subjected to heat at reduced pressure. The high-boiling isomer vaporizes and exits the process through the top of the column. The heavier material remaining at the column bottom then passes on to a vacuum still-pot. This material is again heated, and much of the remaining isomers boil off to be recycled back to the start of the process. The material which remains at the bottom of the still-pot consists of tars, stabilizer, and unrecovered isomers. This tar stream is pumped to a waste collection tank where it is thinned with a stream of the low-boiling isomer. The thinned tar stream is then sent to the on-site incineration plant for disposal.

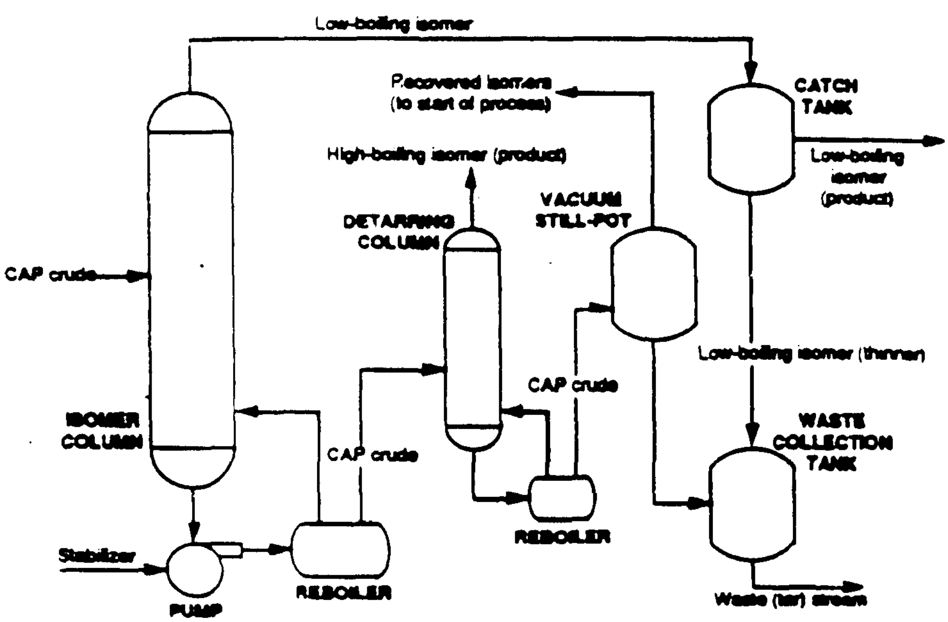


Figure 3-16. CAP Isomers Process

Background

A process area at the DuPont Chambers Works site purifies chlorinated aromatic products (CAP) from a feedstream of crude produced elsewhere on site. The crude contains two CAP isomers, both of which have commercial value when separated. Isomers are structural variations of the same chemical formula. The molecules of a compound's isomers contain the same atoms, but differences in the way these atoms are arranged impart different chemical properties to each isomer. The two CAP isomers have different boiling points, and therefore are known as the "low-boiling isomer" and the "high-boiling isomer".

Figure 3–16 illustrates the CAP isomer purification process. A series of distillations removes first the low-boiling isomer, then the high-boiling isomer. A final distillation recovers isomers trapped within the spent crude and recycles it back to the start of the process. The remaining tar stream is routed to a waste collection tank, where it is mixed with some of the low-boiling isomer to thin it in preparation for incineration on-site.

Exposing CAP to the high temperatures of distillation can cause a dechlorination reaction. This reaction is exothermic (i.e., it generates its own heat), and could become a safety hazard if it proceeds undetected and uncontrolled. Moreover, dechlorination reaction byproducts are corrosive and can cause equipment damage. To prevent dechlorination, a solid stabilizing agent is slurried with an organic solvent and added to the crude in batches. Stabilizer levels are monitored by drawing samples of the in-process crude and analyzing them in a laboratory. The turnaround time between the drawing of samples and the receipt of results is several hours. This lag time forces process operators to increase their margin of safety by adding large amounts of stabilizer.

The CAP isomers process has undertaken a waste reduction project that will reduce waste by 25%. The project will replace the present method of batch feeding the stabilizer with continuous feeding. This will reduce waste in two ways. First, it will permit a reduction in the amount of stabilizer used. Second, it will

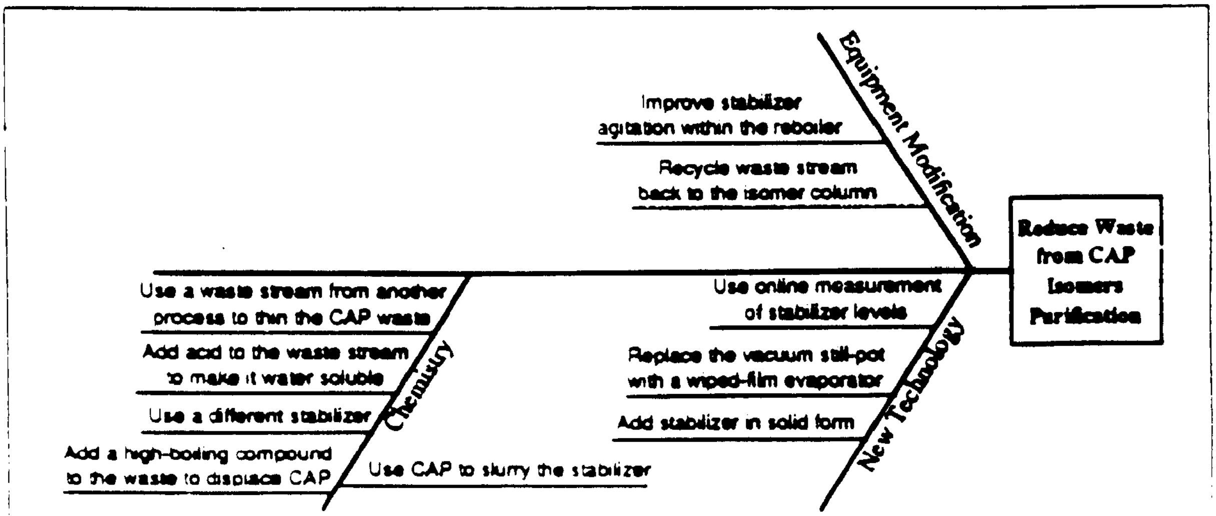


Figure 3–17. CAP Isomers Process Options

Table 3–18. Ranked Summary of CAP Isomers Process Waste Minimization Options

Option	Pros	Cons	Comments
1. Use CAP to slurry the stabilizer.	• Source reduction through elimination of the organic carrier used to slurry the stabilizer • Low-to-moderate capital cost		This option would eliminate the organic solvent that is now used to slurry the stabilizer.
2. Use online measurement of stabilizer levels.	• Good source reduction potential through reduction in the amount of stabilizer required for safe column operation	• Moderate capital cost	This option would replace manual sampling and lab analysis with real-time measurement of stabilizer levels.
3. Add acid to the waste stream to make it water soluble.	• Elimination of the incinerated waste stream • Source reduction by withholding the low-boiling isomer from the waste stream • Low capital cost	• Uncertain chance of success • Creation of a wastewater stream • Moderate capital cost	This option would change the waste disposal medium from incineration to wastewater treatment.
4. Recycle waste stream back to the isomer column.	• Reduction in the amount of stabilizer required for safe column operation	• Moderate capital cost	This option would reuse the stabilizer that remains in the waste stream. It would have to be implemented in conjunction with Option 2 ("Use online measurement of stabilizer levels") to ensure that safe levels of stabilizer were being maintained.
5. Add a high-boiling compound to the waste to displace CAP.	• Yield improvement through increased product recovery • Low capital cost	• Small overall waste reduction • Increased operating cost	This option would use waste from another Chambers Works process to displace CAP from the waste in the detarring column. The difficulty lies in finding a process that emits a suitable waste stream.

Table 3-18. Ranked Summary of CAP Isomers Process Waste Minimization Options (cont'd)

Option	Pros	Cons	Comments
6. Use a different stabilizer.	• Presumptive source reduction through a reduction in the amount of stabilizer required for safe column operation • Low capital cost	• Poor chance of success	Previous informal efforts to identify an alternative stabilizer have yielded nothing.
7. Use a waste stream from another process to thin the CAP waste.	• Increased product yield of the low-boiling CAP isomer • Waste reduction by withholding the low-boiling isomer from the waste stream • Low capital cost	• Low chance of success	This option would use liquid waste from another Chambers Works process to thin the CAP waste in the waste tank, replacing the present method of using the low-boiling isomer as the thinner. The difficulty lies in finding a process that emits a suitable waste stream.
8. Add stabilizer in solid form.	• Source reduction through elimination of the organic carrier used to slurry the stabilizer	• High capital cost • Ergonomic safety concerns associated with handling the solid stabilizer • Low chance of success	No technique for adding a solid to equipment under vacuum has been identified.
9. Replace the vacuum still-pot with a wiped-film evaporator.	• Source reduction through increased product recovery	• Very high capital cost	The wiped-film evaporator would probably recover more product than the present still-pot. For information about the operation of a wiped-film evaporator, see Case Study 10, "Wiped-Film Evaporator".
10. Improve stabilizer agitation within the reboiler.	• Good source reduction potential through reduction in the amount of stabilizer required	• Moderate capital cost • Low chance of success	Good mixing of stabilizer means that more of it reacts with the process stream. But the present method of adding the stabilizer to the reboiler pump already provides good mixing.

permit a reduction in the amount of the low-boiling isomer required to thin the waste at the end of the process.

A waste assessment team was recently formed to identify other possible waste reduction options. Their efforts are motivated by a desire to both cut cost and reduce waste. At present, the CAP isomer process produces the largest stream of incinerated waste on the Chambers Works site.

Description of the Waste Stream

A typical analysis of the waste stream leaving the CAP isomer process is provided below.

Tars	33%
Low-boiling isomer	33%
Stabilizer and solvent	24%
High-boiling isomer	10%

The amount of waste from this process has been constant for several years, and equals 0.12 pounds for every pound of CAP product recovered. Wastes from CAP isomers purification are incinerated.

Costs associated with this waste stream include the yield loss represented by the unrecovered CAP (including the low-boiling isomer used to thin the waste), replacement cost of the stabilizer, waste handling and storage costs, and the costs of incinerating the waste stream.

Previous Waste Minimization Efforts

Over the past decade, several options for reducing waste have been considered. These include:

- *Use a different stabilizer*. It was hoped that a different stabilizer, used in smaller amounts, would maintain the current level of process safety. But this idea was rejected after preliminary studies failed to identify such a stabilizer.
- *Use less of the present stabilizer while continuing to add it to the process in batches*. This idea too was rejected after a preliminary study concluded that reductions in the amount of stabilizer would correspondingly reduce the margin of process safety.
- *Use less stabilizer by replacing batch feeding with continuous feeding*. Studies showed this idea to be workable and effective, and it is currently being implemented.

Waste Minimization Options

The CAP isomers assessment team met in a brainstorming session and generated 10 options for achieving additional waste reductions. They recorded their ideas by constructing a cause-and-effect "fishbone" chart, shown in Figure 3–17. In subsequent meetings, the team discussed the options and subjectively

Table 3–19. Economic Summary of Top CAP Isomers Process Waste Minimization Options

Option	Waste Reduction	Capital Cost	EPA Method NPV (12%)	EPA Method IRR	DuPont Method NPV (12%)	DuPont Method IRR	Implementation Time
Use CAP to slurry the stabilizer	10%	$100,000	$1,640,000	151%	$1,300,000	133%	6 months
Use online measurement..	15%	$40,000	$1,640,000	257%	$1,160,000	209%	1 year

Comments: For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation" in Section 2: *Project Methodology*.

ranked them according to their practicality and waste minimization potential. Table 3–18 summarizes these discussions, and presents the options in approximate rank order.

Technical and Economic Feasibility

After considering the pros and cons of each option listed in Table 3–18, the assessment team chose two options for technical and economic feasibility analysis:

- Option 1: Use CAP to slurry the stabilizer
- Option 2: Use online measurement of stabilizer levels

Option 1 would eliminate the solvent component of the waste stream. Option 2 would reduce waste by permitting more precise control of stabilizer levels, thus eliminating the tendency to use excess stabilizer to ensure a good margin of safety.

The results of the economic analysis are presented in Table 3–19. Both options have very high internal rates of return (IRR).

Barriers to Implementation

The addition of stabilizer is a safety practice that prevents an exothermic dechlorination with its attendent risks to people and equipment. Any attempt to alter the amount of stabilizer or the manner in which it is introduced to the process must take safety into account.

Opportunities for Others

This series of assessments examines six processes in which the waste streams exit from distillation columns. The CAP isomers process is typical of many distillation processes in use today throughout industry. Therefore, many of the options generated for the CAP isomers process may be more generally applicable.

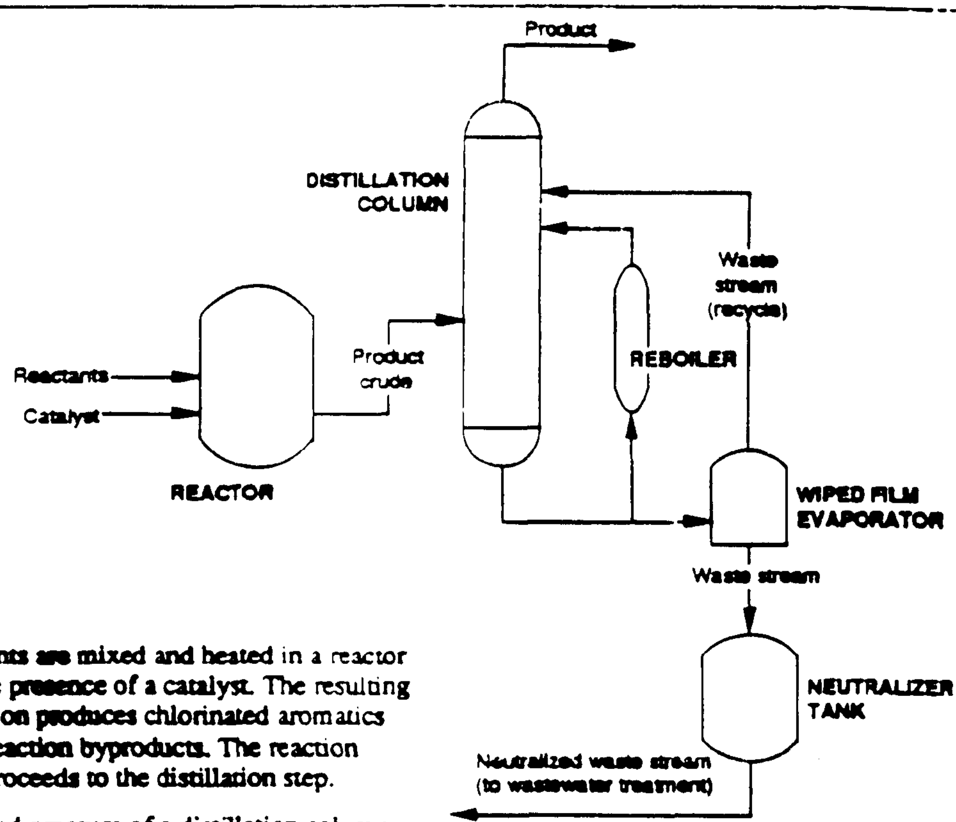
Several case studies in this series examine processes where a stabilizing agent is added for safety reasons. In all of those studies, the stabilizing agent either comprises the chief component of the waste stream, or otherwise frustrates attempts at waste reduction. The amount of stabilizer added to such processes is dictated by worst-case scenarios and the need for comfortable margins of safety. Therefore, waste reductions must usually be accompanied by such additional changes as better process controls, different operating conditions, or equipment changes.

Case Study 10: Wiped-Film Evaporator

Existing technology for reducing waste through increased product recovery

Abstract

This case study examines an attempt to reduce waste through enhanced product recovery in a process which produces chlorinated aromatics. The process area will install a wiped-film evaporator to recover residual product from a distillation tar stream. This effort is part of an ongoing waste reduction program which has also achieved source reductions in the process byproducts that create the tar stream. This case study demonstrates that improved product recovery is a way to continue reducing waste even after all practical source reductions have been made.



Reactants are mixed and heated in a reactor in the presence of a catalyst. The resulting reaction produces chlorinated aromatics and heavy reaction byproducts. The reaction mass then proceeds to the distillation step.

In the reduced pressure of a distillation column, the lighter chlorinated aromatics begin to boil off as the remainder of the hot reaction mass falls to the bottom of the column. The reaction mass is then recycled through a reboiler back into the column. Part of this recycle stream will pass through the wiped-film evaporator. The evaporator will boil off most of the unrecovered product and reintroduce it back into the column. As is the current practice, the remaining waste will pass to a neutralization tank to be mixed with caustic and water before passing on to the wastewater treatment plant.

Figure 3-18. Chlorinated Aromatics Process with Wiped-Film Evaporator

Background

The DuPont Chambers Works site includes a process, illustrated in Figure 3–18, that manufactures chlorinated aromatics. The continuous process consists of a reaction step which produces a product-crude, followed by a distillation step which purifies the product. The reaction step produces heavy tar as a byproduct. The tar entraps significant amounts of otherwise saleable product, and carries it away from the distillation step as waste.

The chlorinated aromatics process has long pursued waste minimization as a key strategy for increasing production. Over the years, the process area reduced reaction byproducts to a point where each additional pound of reduction has become very costly. So the process area is now implementing a product recovery project that will further reduce waste.

The project involves the design, testing, and installation of a wiped-film evaporator. The evaporator will receive the tar stream that emerges from the distillation step and recover some of the chlorinated aromatics that are trapped within the tar. The process area first considered this project in the mid-1970s, and rejected it as being too costly. But rising waste disposal costs and the need for production increases forced a subsequent reconsideration. To date, the wiped-film evaporator project has completed its design and testing phases. Installation is expected in 1994.

Figure 3–19 illustrates the principles of operation of a wiped-film evaporator. In general terms, a wiped-film evaporator exposes a tar stream to a heated surface upon which the lighter compounds are boiled off and recovered. In the chlorinated aromatics process, the material recovered by the evaporator will be recycled back to the distillation step for further purification.

Description of the Waste Stream

A typical analysis of the present waste stream from the chlorinated aromatics process would reveal:

Chlorinated aromatics	60%
Heavy byproduct	40%

These acidic wastes are neutralized with an alkaline compound, dissolved in water, and sent to the on-site wastewater treatment plant for disposal.

Costs associated with this waste stream include the yield loss represented by the unrecovered product, preparation costs associated with wastewater treatment, and the wastewater treatment itself.

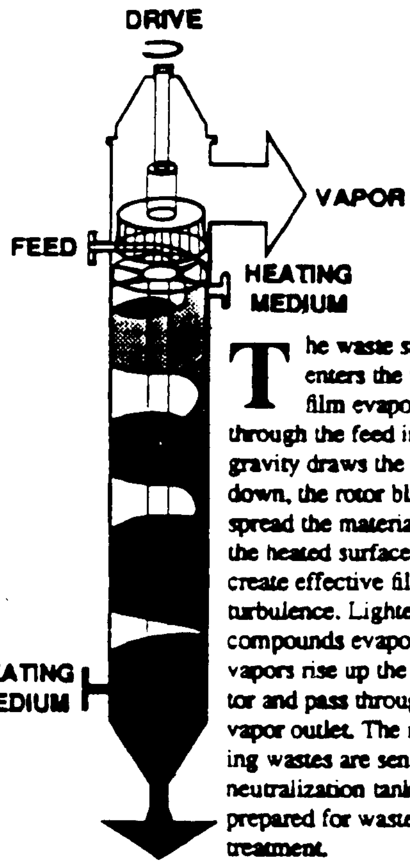
At present, the chlorinated aromatics process produces 0.015 lbs of waste for every pound of product. When operation of the wiped-film evaporator begins, this total will fall to 0.007 lbs of waste.

Previous Waste Minimization Efforts

The need to continuously increase production has ingrained waste minimization into the working culture at the chlorinated aromatics process. Over the years, byproduct formation in the reaction step has been substantially reduced. The marginal cost of reducing byproducts even more is now high. Therefore, the process area has focused on recovering more product per pound of crude. The wiped-film evaporator will help to accomplish this.

Waste Minimization Options

Few records exist of past option generation activity. Suggestions for waste minimization projects were made informally, and little effort has been made to maintain recorded proceedings. The area is continuously evaluating its performance in decreasing wastes.



The waste stream enters the wiped-film evaporator through the feed inlet. As gravity draws the material down, the rotor blades spread the material over the heated surface and create effective film turbulence. Lighter compounds evaporate. The vapors rise up the evaporator and pass through the vapor outlet. The remaining wastes are sent to a neutralization tank to be prepared for wastewater treatment.

Figure 3–19. Wiped-Film Evaporator

Technical and Economic Feasibility

Not all waste streams are suitable for wiped-film evaporation. By removing the recoverable product, the evaporator effectively concentrates the wastes. Several streams in this series of reports consist of thermally unstable components which cannot safely be concentrated above a certain threshold.

Although the waste produced by the chlorinated aromatics process is thermally stable, it is highly corrosive. Off-the-shelf wiped-film evaporators are generally constructed of stainless steel, which will corrode if exposed to the chlorinated aromatics waste. Therefore, a specially designed evaporator constructed of a corrosion-resistant alloy is required.

Initial testing of the wiped-film evaporator at a DuPont laboratory yielded mixed results, probably because of problems with material flows and operating parameters. But a subsequent test at the vendor's site in 1991 proved successful. The test demonstrated a 50% reduction in the waste stream, concentrating it from 40% to 77% byproducts.

Table 3–20 summarizes the economic analysis of the wiped-film evaporator.

Table 3–20. Economic Summary of Wiped-Film Evaporator Option

Option	Waste Reduction	Capital Cost	EPA Method NPV (12%)	EPA Method IRR	DuPont Method NPV (12%)	DuPont Method IRR	Implementation Time
Wiped-film evaporator	52%	$1,450,000	$2,869,000	45%	$135,500	14%	1 year
Comments: For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation" in Section 2: *Project Methodology*.							

Barriers to Implementation

Over the years, the chief barrier to the implementation of the wiped-film evaporator option has been its large capital cost. Three factors offset this barrier:

- the rising cost of waste disposal
- the need for production increases
- the cost of unrecovered product in the waste

Another barrier to implementation has been the corrosive nature of the waste, which has important implications for the evaporator's materials of construction. This barrier was overcome by working closely with the vendor to develop the evaporator, and by extensive testing.

Opportunities for Others

The chlorinated aromatics process delayed implementation of the wiped-film evaporator option until after substantial source reductions in generated waste were made. The process area found that the source reductions were for a time less costly than recycling or product-recovery schemes. By waiting to install the evaporator until after the source reductions, the process area realized the maximum benefit from both options. This case study demonstrates that improved product recovery is a way to continue reducing waste even after all practical source reductions have been made.

Case Study 11: Specialty Surfactant

A partnership between customer and manufacturer leads to the elimination of CFC from a surfactant product

Abstract

This case study describes a successful effort to eliminate the chlorofluorocarbon (CFC) content of a specialty surfactant product. The CFC, which served as a solvent for dissolving the surfactant, has been replaced by water. This effort was undertaken in response to customer demand for a non-CFC product. Customers played a crucial role in the success of this effort by providing input in the development of the new product formulation. This study illustrates the increasing value customers place on environmental friendliness. Many future waste reduction efforts are likely to involve collaborations between producers and customers.

Background

The DuPont Chambers Works site produces a surfactant which is sold to manufacturers of cleaning products. In its pure state, the surfactant is a waxy solid with the consistency of bar soap. But customers require a liquid for their manufacturing processes. Liquification is achieved by dissolving the surfactant in a mixture of solvents. This enables the surfactant to be sold as a nearly transparent liquid with the viscosity of a light oil.

An important quality consideration is that the surfactant be well-dissolved within the solvent. The appearance of sediment in the product is evidence of undissolved surfactant. Quality improvement efforts over time have been directed at reducing the amount of high-molecular weight compounds within the surfactant, as these compounds are largely responsible for sediment formation.

Before waste minimization, a combination of three solvents had been used: water, isopropyl alcohol (IPA), and Freon® 113. The Freon 113 had been particularly effective in dissolving high-molecular weight compounds, and was thus considered crucial to maintaining product quality and customer acceptance. Unfortunately, Freon 113 is a CFC, and its use is believed to contribute to the depletion of ozone in the upper atmosphere.

In 1989, the Chambers Works site began a program to eliminate Freon 113 from the surfactant product. The impetus for this program was a growing desire among DuPont and its customers to eliminate CFCs from their processes. Eliminating Freon 113 required a reformulation of the product. Customers cooperated in the effort by agreeing to evaluate the product reformulation.

In 1991, a plant trial successfully produced a surfactant in which the CFC had been replaced with water. The new product has since replaced the old formulation, thus achieving a 100% source reduction in CFC released to the environment.

Description of the Waste Stream

Wastes from production of the old surfactant product consisted of airborne emissions of CFC and IPA, both volatile organic compounds (VOCs). These emissions occurred primarily at the sites where the surfactant product was consumed, with a very small amount occurring as fugitive emissions from the Chambers Works site.

Table 3–21. Ranked Summary of Specialty Surfactant Waste Minimization Options

Option	Pros	Cons
1. Replace CFC with water.	• Elimination of CFC from product • Reduction of VOCs from product	• Risk of customer resistance to slightly increased sediment in product
2. Replace CFC with a non-ozone depleting alternative.	• Elimination of CFC from product	• Little or no reduction in VOCs from product • Non-ozone depleting alternative is more costly than CFC
3. Eliminate both CFC and IPA.	• Elimination of CFC from product • Elimination of VOCs from product	• High development cost (new manufacturing and handling processes required) • Very poor chance of success
4. Manufacture and sell material as a solid.	• Elimination of CFC from product • Elimination of VOCs from product	• High development cost (new manufacturing and handling processes required) • Very poor chance of success • Merely shifts the burden of waste disposal to customers (customers will have to add solvents to the product)
5. Use basic or acidic water to dissolve product.	• Elimination of CFC from product • Elimination of VOCs from product	• Poor chance of success • Customer resistance
6. Use other solvents.	• Elimination of CFC from product	• Poor chance of finding combination of solvents having less VOC emissions, flammability, or toxicity than IPA and water
7. Reduce IPA and replace with water.	• Reduction of VOCs from product • Small materials cost savings	• Customer resistance to increased sediment in product
8. Replace CFC with IPA.	• Elimination of CFC from product	• No reduction of VOCs from product

A typical analysis of the product leaving the Chambers Works process before the reformulation would have revealed:

Water/surfactant	67%
IPA	22%
CFC	11%

Virtually all of the organic solvents added to the surfactant were inevitably released into the atmosphere.

Costs associated with this waste stream include the cost of the solvents added to the product, and the small amount of solvent lost as fugitive emissions at Chambers Works.

More importantly, failure to remove CFC from the product would have eventually forced it off of the market.

Previous Waste Minimization Efforts

No previous attempts to eliminate CFC from the surfactant products had been made. In 1986, a new product development effort successfully reduced the amount of high-molecular weight compounds in this surfactant, and this in turn reduced the amount of sediment in the product. Given that the purpose of adding CFC was to dissolve such compounds, this product development effort set the stage for CFC elimination. In 1989, the business organization learned that a product with a small amount of sediment could gain customer acceptance if it were CFC-free. This customer acceptance made the CFC elimination possible.

Waste Minimization Options

In 1989, a team was formed to consider ways in which CFC might be removed from the surfactant product. They generated eight possible options, and these are summarized in Table 3–21. With the exception of Option 7, "Manufacture and sell surfactant as a solid", the options involve reformulations of the solvent system used in the product. Responsibility for evaluating these options and implementing the elimination of CFC fell to the process chemist, who performed these tasks in consultation with surfactant customers.

Technical and Economic Feasibility

Technical Evaluation

A series of laboratory experiments were performed to evaluate alternative solvent systems. Replacing CFC with water was determined to be the best option. It was the only option which eliminated CFC and reduced VOC emissions without forcing major changes to the process or to product quality. Removing CFC did slightly increase the amount of sediment in the product, but the amount was still low enough to gain customer acceptance. The new solvent system contains 33% less VOCs than the old one, and eliminates all CFC.

Economic Evaluation

Table 3–22 summarizes the economic evaluation of the chosen option. Although CFC elimination required modifications to the procedures used to manufacture the surfactant, equipment modifications or other capital expenditures were not required. Cost savings resulted from replacing CFC with water. The evaluation did not assume an increase in sales resulting from CFC elimination, nor did it assume loss of sales resulting from the failure to eliminate CFC.

Barriers to Implementation

The chief impediment to this waste minimization effort was a possible lack of customer acceptance for the new product formulation. In the absence of CFC, a small amount of sediment forms within the surfactant product. Keeping the amount of this sediment low was the key to achieving customer acceptance.

Evaluation of Performance

The chosen waste reduction option eliminated 100% of the CFC emissions and 33% of VOC emissions. This was accomplished without

Table 3–22. Economic Summary of Top Specialty Surfactant Waste Minimization Option

Option	Waste Reduction	Capital Cost	EPA Method NPV (12%)	IRR	DuPont Method NPV (12%)	IRR	Implementation Time
Replace CFC with water	100% CFC 33% VOCs	$0	$2,000	13%	$2,000	13%	1 year

Comments: For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation" in Section 2: *Project Methodology*.

affecting the quality of the finished product. The new product has met with good customer acceptance.

Opportunities for Others

This case study demonstrates the opportunity that exists to eliminate CFCs from those products that use them as solvents. More importantly, this case study shows that a great potential for waste minimization exists in partnerships between producers and customers. Customers have traditionally represented a major impediment to waste reduction. Failure to place value on environmentally friendly products provided producers with little incentive to reduce wastes. But this situation is likely to change as the growing public demand for waste reductions affects customers and producers alike. In the new business climate, the development of environmentally friendly products will increasingly become a collaborative effort between producers and customers.

Case Study 12: CAC Process

Involving people from all disciplines in waste reduction effort is a key factor in eliminating a waste stream

Abstract

This study describes a successful effort to eliminate a waste stream of solvent from a multiproduct chemical processing area. The solvent had been used to flush the process equipment at the conclusion of each product campaign. Elimination of the solvent wash was accomplished by installing drainage valves at low elevations on the process equipment, and building a wheeled collection vessel to collect the drainage at the conclusion of a product campaign. In addition to eliminating a large waste stream, the new drainage system has shortened product changeover time and increased product yield through recovery of the product residue. This waste elimination solution was conceived and implemented by line workers, highlighting the importance of including representatives from all disciplines on waste assessment teams.

Background

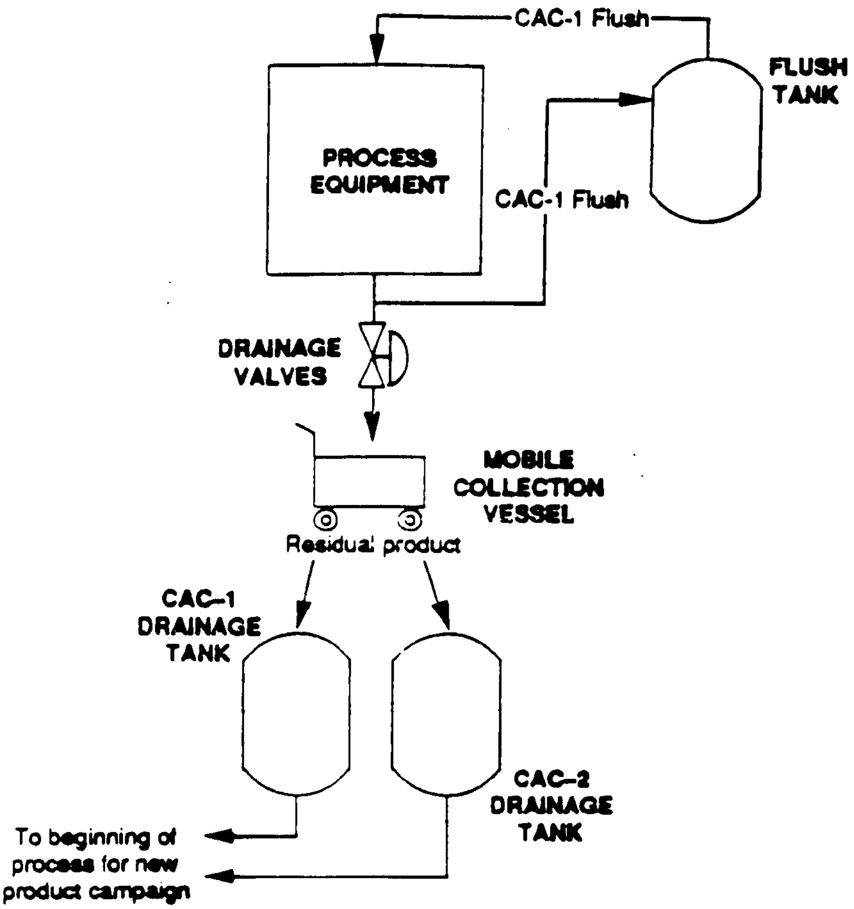
One process area at the DuPont Chambers Works site makes two types of chlorinated aromatic compounds (CAC), and from them produces three products. The pure forms of both compounds, known as CAC-1 and CAC-2, account for two of the products; the third is a mixture of the two compounds. The process area uses many pieces of equipment to produce these products, including reactors, distillation columns, heat exchangers, and storage tanks. The two compounds cycle through the equipment in separate product "campaigns".

At the conclusion of each campaign, a large amount of residual product remains within the process equipment. This residue must be removed before the start of the next campaign to prevent it from contaminating the new product. In the past, this was done by flushing the process equipment with solvent. The solvent wash has long been the focus of remediation efforts for a variety of reasons.

- It created a large waste stream for incineration.
- It was a major contributor to long equipment setup times between product campaigns.
- It made reprocessing large amounts of product necessary because the solvent contaminated the initial product made in a new campaign.
- The residual product washed away by the solvent represented a significant yield loss.

In 1990, a waste minimization team at the CAC process area conceived and subsequently implemented an equipment drainage system to completely eliminate the solvent wash. Drainage valves were installed at strategic locations of low elevation on the process equipment. A movable, insulated collection vessel was designed and built by area personnel. At the conclusion of a product campaign, workers drain the residue from each valve in turn. The collected product residue is held in a storage tank for reintroduction to the process during that product's next campaign. Figure 3–20 illustrates the operation of the new drainage system.

In deciding whether or not to implement the system, the assessment team had to consider its effect upon product quality. After the process equipment is drained, only a fraction of the original residue remains. The team was



At the end of a product campaign, residual product is drained from the process equipment into a specially built "mobile collection vessel". This vessel is emptied into the product drainage tanks, where product residues accumulate until they are eventually recycled back to the process at the start of a future campaign.

During changeovers from CAC-2 to CAC-1 production, the drainage procedure is supplemented with a washout of the process equipment. A reserve of CAC-1 is held in a flush tank until it is released to flush away any remaining CAC-2. The amount of CAC-2 within the flush tank is held constant by periodically drawing down small quantities of the flush to either recycle back to the process or to make the mixed CAC product. This drawdown amount is replaced with virgin CAC-1.

The mobile collection vessel was designed and built by CAC process operators and mechanics. It consists essentially of a 55-gallon tank securely fastened to a wheeled carriage. The tank has been insulated to prevent solidification of the product residue upon exposure to ambient temperatures. A flexible hose is used to connect the mobile vessel to the drainage valves to permit drainage from the most hard-to-reach drain points. The mobile vessel is designed to be operated by a single person.

The mobile collection vessel offers several advantages over the use of drums for collecting the drainings. It's built low to the ground, allowing collection from low spots that drums could not service. The mobile vessel provides better ergonomics than drums, and avoids the disposal problems that occur with drum use.

Figure 3–20. CAC Process

uncertain if even this small amount would have to be flushed to avoid unacceptable contamination of the next product to be made.

In the case of CAC-2, the team found that flushing was not required. However, the purity specifications for CAC-1 are much stricter and require flushing. But instead of using solvent for this flush, the new system uses an amount of CAC-1 product held in reserve for this purpose. The CAC-1 flush is recovered and stored for repeated reuse in future campaigns. Over time, residual CAC-2 builds up within the CAC-1 flush. When it exceeds an acceptable level, the flush is reworked back into the process or is used to make the mixed CAC products.

Figure 3-21 depicts the CAC campaign strategy and product purity requirements.

Description of the Waste Stream

A typical analysis of the waste stream resulting from the solvent wash would reveal:

- Unrecovered product residue 20%
- Solvent 80%

The costs associated with this waste stream included the replacement cost of the solvent, costs associated with the disposal of the solvent wash, the yield loss represented by the unrecovered product residue, lost productivity and capacity due to lengthy setup time between campaigns, and the cost of reprocessing solvent-contaminated product.

Before the waste elimination effort, the CAC process generated 0.015 lbs of waste for every pound of product produced. This waste was once treated at the on-site wastewater treatment plant. In later years, the waste was incinerated after a pretreatment that reduced its chlorine content.

Implementation of the new drainage system has eliminated this waste stream completely.

Previous Waste Minimization Efforts

Over the years, the CAC process area has devoted considerable effort to address the problems posed by the solvent wash. At first these efforts focused on end-of-pipe waste treatment. Later, a recycling scheme was implemented to reduce the amount of waste. Finally, the area began looking at source reductions to reduce and then eliminate the waste entirely.

In the original process, the solvent flush and its load of residual product simply passed through the process equipment and on to the on-site wastewater treatment plant. In 1987, the CAC area began incinerating the solvent

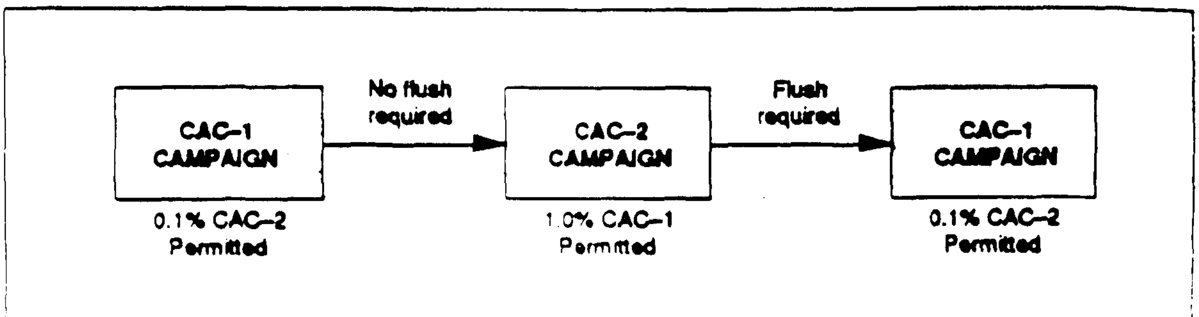


Figure 3-21. CAC Product Campaigns

Table 3-23. Ranked Summary of CAC Process Waste Minimization Options

Option	Pros	Cons	Comments
1. Drain the process equipment and eliminate the solvent wash.	• Eliminates use and disposal of solvent • Recovers saleable product • Low capital cost • Shortens product changeover time • Eliminates solvent storage and associated working capital charges	• Product purity concerns	This option requires the installation of drainage valves on the process equipment and a means of collecting the product residue. The assessment team judged the risk to product purity to be a prudent one in view of the potential benefits of this option.
2. Drain the process equipment and flush with CAC product.	• Eliminates use and disposal of solvent • Recovers saleable product • Low capital cost • Shortens product changeover time • Eliminates solvent storage and associated working capital charges • No risk to product purity	• Costs associated with recovering and repro-cessing the flush streams	This option requires the installation of drainage valves on the process equipment and a means of collecting the product residue. The potential benefits are less than those of Option 1, but so are the risks to product quality.
3. Loosen product specifications to eliminate the need for cleaning equip-ment.	• Eliminates use and disposal of solvent • Recovers saleable product • Low capital cost • Shortens product changeover time • Eliminates solvent storage and associated working capital charges	• Low chance for success (customer resistance)	Discussions with customer reinforced the need to maintain the present product specifications.
4. Substitute solvent flush with water.	• Eliminates use and disposal of solvent • Low capital cost • Eliminates solvent storage and associated working capital charges	• No reduction in product changeover time • Creation of an aqueous waste stream • No product yield increase • Risk to product quality by contamination with water	Although this option is known to be suitable for at least some of the process equipment, it clearly is less desirable than Options 1 and 2.
5. Use waste solvent from another process to flush equipment.	• A reduction in total solvents used on site	• Not a source reduction • No reduction in product changeover time • No product yield increase	Clearly the least desirable option.

Table 3–24. Economic Summary of Top CAC Process Waste Minimization Options

Option	Waste Reduction	Capital Cost	EPA Method NPV (12%)	IRR	DuPont Method NPV (12%)	IRR	Implementation Time
Eliminate the solvent wash by implementing Options 1 & 2	100%	$10,000	$2,212,000	671%	$2,212,000	671%	6 months
Comments: For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation" in Section 2: *Project Methodology*.							

wash on-site. The waste first had to be pretreated with a nitroaromatic compound to reduce its chlorine content. Later, the area arranged to have the waste incinerated at another DuPont site where pretreatment was not required.

The first waste reduction was achieved when the CAC area developed a method for recovering and recycling much of the solvent from the spent wash. However, this still left a considerable amount of residual product and unrecovered solvent to be incinerated. In 1990, the area reduced the number of flushes between campaigns. This measure alone reduced waste by 33%, and represented the area's first successful source reduction.

Waste Minimization Options

In 1990, an interdisciplinary CAC assessment team met in a brainstorming session and generated five options for eliminating or improving the solvent washout. These options are summarized in Table 3–23. Option 1, "Drain the process equipment and eliminate the solvent wash", and Option 2 "Drain the process equipment and flush with CAC product", were the only options seriously considered.

Technical and Economic Feasibility

Technical Evaluation

Both Options 1 and 2 required the installation of drainage valves on the process equipment, and a way to collect and accumulate the product residue. An insulated 55-gal tank was mounted securely onto a specially built handcart. This mobile collection vessel would be wheeled to each drainage point to collect product residue. The contents of the mobile vessel would then be emptied into a storage tank for eventual recycling to a future campaign. Because the CAC residual has a very low volatility, air emissions were not a consideration in the design of the cart.

Option 1 was implemented and tested in 1991. The new drainage system removed about 75% of the residual product from the process equipment. This was good enough for starting a CAC–2 campaign. Although some initial product left the process contaminated with residue, the amount was small enough to permit easy reprocessing.

Unfortunately, the new system was not adequate for starting a campaign of CAC–1, which has much more demanding purity specifications than CAC–2. Contamination of the CAC-1 continued well into the campaign, producing a volume of off-spec material that was simply too great to reprocess.

Option 2 was then tested for a CAC-1 campaign, using a small reserve of CAC-1 to flush the process equipment. This test proved successful. When the campaign began, operators were able to bring the product within specifications quickly. The amount of contaminated material was small enough to permit reprocessing.

Economic Evaluation

Implementation of Options 1 and 2 was completed by plant personnel with only minimal cost. The low capital cost coupled with the benefits realized by the waste reduction made these waste minimization options very attractive. The economics of implementing both options are summarized together in Table 3-24.

Barriers to Implementation

Concern about product quality was the only barrier to the implementation of these options. Flushing the equipment with CAC-1 solved this problem. Once it was demonstrated that product quality could be maintained without generating an additional waste stream, it was possible to implement these options.

Evaluation of Performance

The CAC area has successfully demonstrated the complete elimination of washwaste between product campaigns, and has achieved the cost savings identified in Table 3-24. The people involved with this waste elimination effort have been recognized with a site achievement award.

Opportunities for Others

This study illustrates the importance of including representatives from all process disciplines on the assessment team. The new drainage system was conceived and implemented by a process operator with help from two mechanics. The mobile collection vessel they designed avoided the ergonomic and disposal problems associated with drums, and can reach lower spots on the process equipment. Their solution for eliminating the waste stream was achieved with low capital cost and short implementation time, and demonstrates that waste reduction need not require technical solutions and elaborate equipment.

This study also shows that waste reduction is often an iterative process. The CAC team implemented a number of options over time that gradually reduced the waste. Had they stopped after a few initial successes, the waste stream would not have been eliminated. In hindsight, their solution for eliminating the waste stream seems simple and obvious. In reality, the team gained the confidence to implement a somewhat risky solution through their experience with incremental waste reductions.

Finally, this assessment shows that taking prudent risks can yield big waste reductions. Conventional wisdom held that quality would suffer unless the process equipment received an overkill of solvent washing. But the assessment team made the imaginative leap to a breakthrough solution that eliminated the waste and greatly reduced costs. And they did it without compromising the quality of their products.

Case Study 13: Solvent Emissions

Upgrading the filtration system for recovering a metal catalyst has eliminated solvent emissions to the atmosphere

Abstract

This case study describes a successful effort to reduce air emissions of a volatile solvent by 99%. The emissions originate from an in-process filtration system that recovers a precious metal catalyst for shipment to a reclamation facility. The emissions were reduced by replacing a plate-and-frame filter press with an alternative filtration system. The waste reduction effort was undertaken to comply with stricter state regulation of air emissions. Cost savings generated by the new filtration system were not great enough to offset capital investment. This study discusses some aspects of waste reduction efforts that are regulatory driven.

Background

A batch process at the DuPont Chambers Works site produces a specialty aromatic product. The process includes a reaction step that produces a product crude, and a purification step that separates the product from the impurities in the crude. The reaction step uses a precious metal catalyst. A volatile solvent is used to slurry the catalyst and one of the reactants before the reaction step.

Before arriving at the purification step, the product crude passes through a filtration system to remove the metal catalyst. The filtered catalyst, which is wet with solvent and aromatic product, is drummed and shipped to an off-site reclamation facility. There the catalyst is recovered through an incineration process that burns off the combustible impurities.

In the past, the filtration was performed by a plate-and-frame filter press. This type of filter consists of a series of perforated plates that are covered with filter cloths and sandwiched between two metal frames. As the crude passed through the filter press, the catalyst collected on the filter cloths, forming a wet cake. After each filtration, the press had to be opened manually to remove the cake.

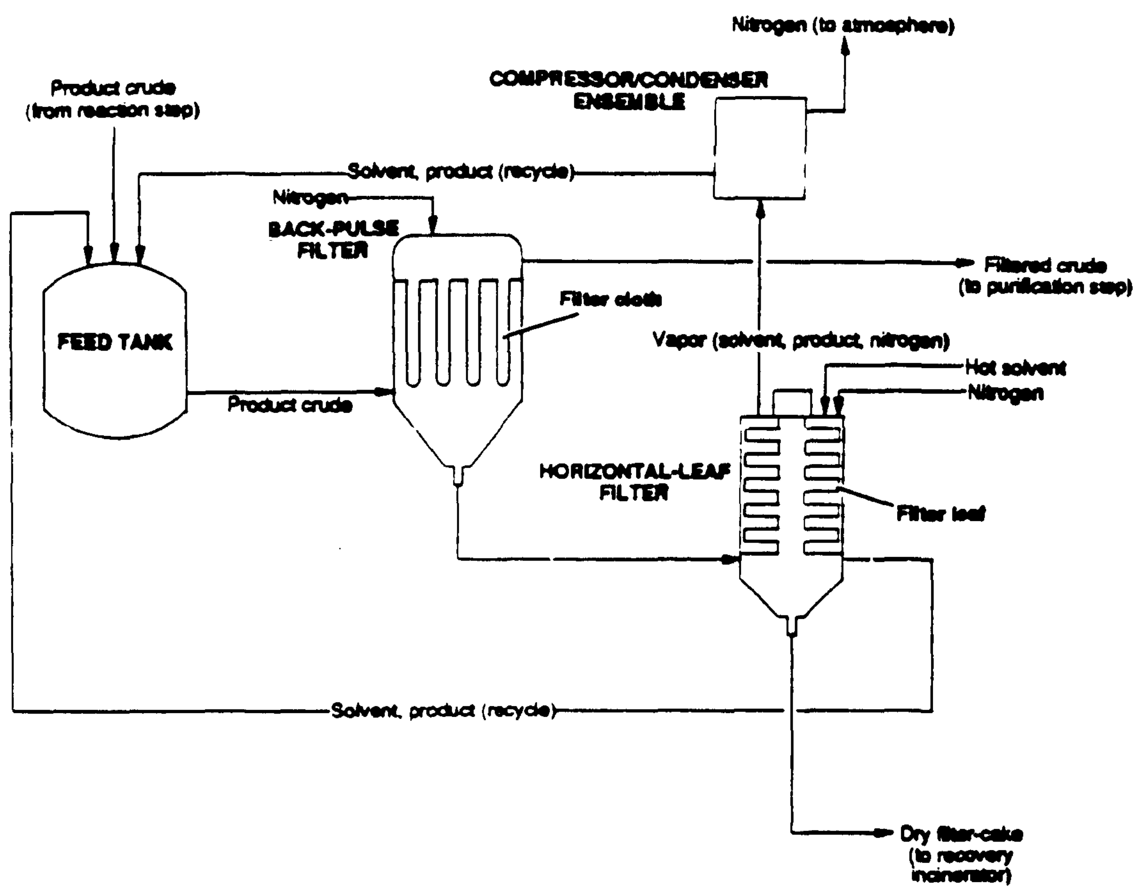
The old filtration system released solvent vapors to the atmosphere in two ways:

- Opening the filter press caused some of the solvent in the cake to evaporate.
- When reassembling the press, it was impossible to create a perfect seal due to wicking of the filter cloths. The filter leaked during operation, and this leakage was the source of fugitive solvent emissions.

Reducing solvent emissions became a priority because of stricter air emissions standards imposed by the New Jersey Department of Environmental Protection (NJDEP). In 1989, the specialty aromatics process area began looking for an alternative filtration system.

In 1991, the process area replaced the filter press with the modern dual-filtration system illustrated in Figure 3–22. The system uses a "back-pulse" type primary filter and a "horizontal-leaf" secondary filter. This design offers several advantages over the old press:

- The new filters do not have to be opened to remove the filter cake. This virtually eliminates leakages and fugitive emissions. Only trace amounts of solvent are released to the



In the new filtration system, a batch of product crude passes from a feed tank through a back-pulse filter. The filter concentrates the catalyst, which collects in the filter bottom along with some solvent and product. This slurry is then sent to a horizontal-leaf filter to remove additional solvent and product. The liquid from the horizontal-leaf filter is recycled back to the feed tank for reprocessing with the next batch of crude. The catalyst-bearing filter cake is sent to an off-site reclamation facility.

The back-pulse filter contains tubes covered with filter cloths. The liquid portion of the crude passes through these tubes, while the filter cake collects on the outside of the filter cloths. The back-pulse filter is so named because periodic back-pulses of nitrogen gas dislodge the wet cake from the filter cloths, causing it to collect on the filter bottom along with a "heel" of product and solvent.

The horizontal-leaf filter contains an assembly of filter leaves connected to a central shaft. The catalyst-bearing slurry cascades over the leaves from the top to the bottom of the filter. The liquid portion is recycled to the feed tank, while the filter cake collects on the leaves. Hot solvent is then introduced to the filter to wash recoverable product out of the cake. The solvent wash is pumped to the feed tank. Then hot nitrogen is blown into the secondary filter to dry the cake. The nitrogen is vented to the atmosphere after first being stripped of solvent and product vapors by a cooler/condenser ensemble. At the end of the drying step, the central shaft rotates. The filter cake is spun off of the leaves and falls by gravity to the bottom of the filter. The cake is then drummed and sent to the reclamation facility.

Figure 3–22. New Catalyst Filtration System atmosphere from solvent/product recovery equipment. Solvent emissions have been reduced by 99%.

- Most of the saleable product that was previously lost in the filter cake is now recovered.

Description of the Waste Stream

The air emissions from this process consist of 100% volatile solvent. Costs associated with these emissions consist of the replacement cost of the solvent. Had the alternative filtration system not been implemented, regulatory noncompliance would have forced a shutdown of the process.

Before the emissions reduction, the catalyst filtration produced 0.09 lbs of solvent emissions for every pound of product produced. After the reductions, this figure fell to 0.001 lbs of waste.

Previous Waste Minimization Efforts

Although the specialty aromatics process area has reduced waste streams in other parts of the process over the years, no known attempts have previously been made to reduce solvent emissions to the atmosphere from the filter-press operation.

Waste Minimization Options

The dual-filtration system described in this report was the only option seriously considered for reducing the solvent emissions. It would have been possible to comply with the NJDEP regulations by installing the back-pulse filter alone. The reduction in air emissions would have been as great with one filter as with two. But the single-filter "option" would have actually increased net waste. The filter cake from the back-pulse filter contains more solvent than was previously lost to air emissions. This solvent would have added to the incinerable waste that is sent to the reclamation facility. Dual-filtration provides a net waste reduction by producing a dryer filter cake and recycling most of the liquid filtrate.

An upgrade to the new filtration system currently under investigation would reduce the solvent in the filter cake even more. The hot nitrogen that is used to dry the filter cake

Table 3–25. Economic Summary of Air Emissions Minimization Options

Option	Waste Reduction	Capital Cost	EPA Method NPV (12%)	EPA Method IRR	DuPont Method NPV (12%)	DuPont Method IRR	Implementation Time
Install dual filtration system	99% air emissions	$2,200,000	($1,880,000)	< 0%	($1,880,000)	< 0%	6 months
Install dual filtration system & steam drying	99% air emissions 62% reclamation	$2,200,000	($1,390,000)	< 0%	($1,390,000)	< 0%	6 months

Comments: Parentheses denote negative numbers.

For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation" in Section 2: *Project Methodology*.

would be replaced with steam. The steam would promote better drying by displacing the solvent in the cake. Most of the displaced solvent would then be recycled back into the process.

Although not seriously considered, another option for reducing the solvent emissions would have been to shut the process down. As the economic analysis reveals, replacing the filtration system required a large capital investment with little offsetting return. If the product were one that was considered marginal, shutting the process down would have received more serious consideration as a waste reduction option.

Technical and Economic Evaluation

Technical Analysis
In designing the new filtration system, the specialty aromatics project team first considered a primary filter that used sintered (permeable) metal elements as the filter medium. Although this type of filter works well in other applications, lab testing proved it to be unsuitable for the specialty aromatics process. The catalyst tended to clog the element pores, forcing frequent replacement of the filter elements.

After further investigation and testing, the project team selected a primary filter that uses disposable filtercloths. The new filtration system was installed in 1991, and has met its waste reduction goals.

Economic Analysis
Table 3–25 summarizes the economic analysis of the dual-filtration system, both with and without the steam-drying upgrade. Although the filtration system resulted in an economic loss, a substantial part of the operating cost can be reduced by using steam instead of hot nitrogen to dry the filter cake. Neither option yields an internal rate of return (IRR), and both have a negative net present value (NPV). Implementation of the new filtration system has resulted in a financial loss to DuPont, which often happens in cases of regulatory driven waste reductions.

Barriers to Implementation
The chief barrier to implementation of the new filtration system was the identification of an appropriate filtration technology. Precious metal recovery requires very efficient filtration, and the choice of a filter medium must be made carefully. The specialty aromatics process considered and tested a filtration technology (sintered metal) that proved unsuitable before adopting the chosen design.

Opportunities for Others

If a process area is going to make a substantial capital investment for new equipment, it's better to install equipment that will actually reduce waste rather than merely shift the waste to another medium. It would have been easy for the specialty aromatics process to comply with tougher emissions regulations while creating a new waste stream. Installing the primary filter alone would have brought the process into compliance for air emissions, but would also have generated additional liquid waste.

In an existing process, the additional amounts of solvent and product recovered by a new filtration system may not be enough to offset the capital costs of the implementation. Had this waste assessment not been regulatory driven, it is unlikely that the new system would have been installed.

Regulatory driven waste reductions have the potential of killing off existing processes. The specialty aromatics business described here was judged by the corporation to be strong enough to absorb the cost of the capital investment in the new filtration system. This is not true of all businesses. There are always two other options that don't appear on option generation tables. One is to do nothing, a credible option if all others have negative NPVs with no "soft" benefits, and if the waste is handled in an environmentally sound manner. But if regulatory waste reduction is imposed upon a business, then doing nothing is not an option. Under these circumstances, if the value of a business does not justify the cost of regulatory compliance, then shutting down could well become the chosen "waste reduction" option.

Case Study 14: SAC Process

Improvements in raw material quality open the door to substantial waste reductions

Abstract

This case study examines ongoing waste reduction efforts for a process that manufactures aromatic compounds. The process produces a waste stream of heavy tars which are incinerated. Extreme variability in the quality of one of the incoming raw materials had previously frustrated waste reduction efforts by creating uncertainty about the causes of waste generation. But recent improvements in the quality of the raw materials have made waste reduction possible. The waste reductions described in this study result from improvements in process control, changes in reaction conditions, and improved waste handling.

Background

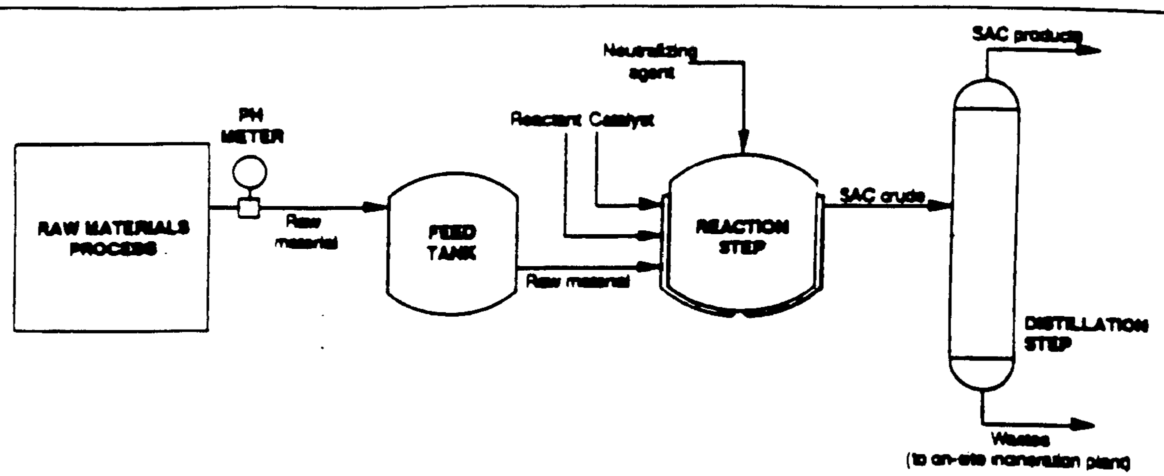
A continuous process at the DuPont Chambers Works site uses reaction and distillation to produce specialty aromatic compounds (SAC). The process, illustrated in Figure 3–23, produces a waste stream containing heavy tars which form during the reaction step and exit the process from the distillation step. These viscous tars entrap significant amounts of SAC product and carry it away from the process as waste. In fact, saleable SAC product constitutes the greatest proportion of the waste stream. The yield loss represented by the entrapped SAC provided a strong incentive for tar reduction from the SAC process.

The SAC reaction step produces two types of tar. So-called "thermal" tars are an inevitable consequence of the high-temperature reaction. "Acid" tars, on the other hand, form when one of the raw materials enters the process with excessively low pH, i.e., it is acidic. The presence of acids during the reaction step triggers a side reaction which produces the tar.

The ratio of thermal tar to acid tar in the SAC waste is unknown because there is no practical way to distinguish between them in waste stream samples. This fact used to discourage waste reduction efforts at the SAC process. Poor pH control at the on-site process that makes the raw material caused substantial and unpredictable fluctuations in acidic content. This in turn caused the level of tar formation to fluctuate, and made it impossible to measure the impact of a waste reduction effort.

Not only did acidic raw material directly produce tar, it increased waste in an indirect way as well. In time, uncertainty over the acid content of the raw material prompted the SAC process area to add a neutralizing agent to the reaction step. This neutralizing agent itself became part of the waste stream.

In 1990, the raw materials process installed online instrumentation to provide rapid and continuous readouts of pH levels. Operators could now control their process more effectively and keep acidity low. This resulted in an immediate tar reduction at the SAC process area. Moreover, reliable knowledge of raw material pH enabled the SAC area to implement successful waste reduction options of their own. These include running the SAC reaction at lower temperatures, and reducing the amount of a neutralizing agent added to the reaction.



The process for making SAC raw material includes a neutralization step in which an alkaline compound is added to reduce acidity. The amount of alkali is controlled by operators according to pH-level readouts from a recently installed online pH meter.

The raw material enters the SAC process through a feed tank, from which it is fed continuously into the reaction step. There it is mixed with another reactant and a catalyst. Historically, a neutralizing agent has been added to the reaction step to ensure against excess acidity in the raw material. The neutralizing agent is still added, but in much reduced amounts since the improvement in pH control back at the raw materials process.

The SAC crude which leaves the reaction step contains several saleable compounds, each of which must be separated out from the crude. This is accomplished through a complex series of distillations. The resulting waste stream is sent to the on-site incineration facility for disposal.

Figure 3–23. SAC Process

A waste minimization team was formed to find ways of improving product yield and reducing wastes from the SAC process. Their efforts to date, together with the control improvement in the raw materials process, have reduced waste by almost 60%.

Description of Waste Stream

Before the waste reductions, a typical analysis of the SAC process waste stream would have revealed:

SAC product	93.5%
Tars	5.8%
Neutralizing agent	0.7%

Costs associated with this waste stream included the yield loss represented by the unrecovered product, the cost of incineration, waste handling and storage costs, and the replacement cost of the neutralizing agent.

Before the waste reductions, the SAC process produced 0.07 lbs of incinerated waste for every pound of product recovered. After implementation of the waste reductions, this figure fell to 0.03 lbs. This represents a source reduction of 58.5%.

Previous Waste Minimization Efforts

Uncertainty over the pH of the incoming raw material had long discouraged the SAC process area from investigating tar reductions. Instead, attention was directed at ways to upgrade the distillation step to recover more product from the SAC crude. Changes in such distillation variables as temperature, pressure, and flow rate were considered but never implemented. Such measures would certainly not have matched the waste reductions achieved by the tar reductions described in this case study.

Waste Minimization Options

The implementation of four waste reduction options accounts for the waste reductions so far at the SAC process:

- *Install online pH meter at the raw materials process*. The raw materials process controls pH by adding an alkaline compound to the raw material. In the past, pH had been measured by sampling and laboratory analysis, with a turnaround time of several hours between sample collection and the receipt of lab results. This made it difficult to know how much alkali to add. Undetected changes in acidity occurred, and this caused concurrent fluctuations in tar formation at the downstream SAC process.

  The new instrumentation now provides operators with rapid and continuous feedback of process conditions. This enables them to more effectively control the acidity of the outgoing material.

  Improving the pH consistency of the raw material made subsequent waste reductions possible by permitting the accurate evaluation of proposed options.

  Improved pH control has resulted in a direct waste reduction of 7.1%.

- *Run SAC reaction step at lower temperature*. This option targets the formation of thermal tars. Lower temperature reduces tar formation, but it also slows the reaction. The resulting productivity decrease would have prevented the implementation of this option. But people at the SAC process area were able to adjust other process parameters to permit operation at lower temperature with no reduction in productivity.

  Reducing reaction temperature has resulted in a waste reduction of 42.9%.

- *Reduce the amount of neutralizing agent in the reaction step*. The use of this agent was made necessary by uncertainty about the pH of the incoming raw material. But now that better pH control in the raw materials process has eliminated the uncertainty and has reduced acidity, the amount of neutralizing agent added to the reaction step has been reduced. Further reductions are now under consideration.

  Implementation of this option has reduced waste from the SAC process by 1.4%.

- *Improve waste handling*. Tars are pumped from the process equipment into a tank truck for transportation to the on-site incinerator. In the past, trucks were dispatched to the incinerator only when full. But it takes several days to fill a truck. During that time, the SAC waste can solidify into an unflowable sludge and become difficult to handle at the incinerator. So hot SAC product was routinely added to the waste to thin it and make it flowable.

  Today, the trucks are dispatched from the SAC process to the incinerator daily while the waste is still partially fluid. This minimizes the need for the SAC-product thinner.

  This waste handling improvement has contributed 7.1% to the overall waste reduction effort with no capital costs or reductions in productivity.

The impetus for these waste reduction efforts has been the need to improve yield by reducing tars, and the need to reduce the cost of waste disposal.

Table 3–26. Economic Summary of Top SAC Waste Minimization Options

Option	Waste Reduction	Capital Cost	EPA Method NPV (12%)	EPA Method IRR	DuPont Method NPV (12%)	DuPont Method IRR	Implementation Time
Install online pH meter	7.1%	$50,000	$990,000	195%	$920,000	189%	6 months
Lower reaction temperature	42.9%	$0	$6,180,000	∞	$5,810,000	∞	3 months
Reduce neutralizing agent	1.4%	$0	$30,000	∞	$10,000	∞	1 month
Improve waste handling	7.1%	$0	$1,030,000	∞	$970,000	∞	1 month

Comments: For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation" in Section 2: *Project Methodology*.

With the exception of the improved pH control, the waste minimization team generated these options at informal, undocumented brainstorming sessions. The idea for reducing reaction temperature emerged after extensive research into reaction kinetics by the engineer who led the team. Sources for the research included site records and technical literature in the public domain.

The SAC area continues to pursue additional waste reductions. Changes in distillation strategies to recover more product from the waste are now under consideration. In 1992, people from the SAC area and experts from other DuPont organizations convened a technical symposium to examine ways to achieve greater process improvement and waste reduction. The symposium produced two long-term options that are worthy of investigation: develop entirely new reaction chemistry, or keep the current reaction but install state-of-the art reaction equipment. Either of these long range solutions could virtually eliminate tar formation from the reaction step.

Technical and Economic Feasibility

Studies conducted before implementation of the four waste reduction options had shown them all to be technically feasible and effective. Economic evaluation of the options, summarized in Table 3–26, had shown them all to be cost effective.

Barriers to Implementation

For years, the variable pH of the incoming raw material discouraged tar reductions at the SAC process. Uncertainty of the amount of acid tars forming in the reaction step made it impossible to measure the success of any tar reduction efforts. This barrier was removed when the raw materials process area improved its pH control.

Improved pH control removed the only barrier to reducing the amount of neutralizing agent in the reaction step.

The proposal to lower reaction temperature met with some organizational resistance because of its possible effect upon process productivity. This resistance was overcome by demonstrating that productivity could be maintained by adjusting other process conditions.

There were no barriers to the waste handling improvement described in this report.

Opportunities for Others

This case study demonstrates how problems in one manufacturing process can exacerbate waste generation at subsequent "downstream" processes. The failure to control pH at the raw materials process was a direct cause of waste generation at the SAC process, and made it extremely difficult to pursue any significant waste reductions. Variability in acid tar formation would have hidden any waste reduction successes in the SAC process. But once raw material pH was brought under control, it became possible for the SAC process area to test improvements for their effectiveness in reducing tars.

Like other studies in this series, this study demonstrates the importance of good process control to any waste reduction effort. There is usually hesitancy about upgrading the control systems of older processes because of the capital investment that's usually required. But several processes at the Chambers Works site have been able to reduce the cost of upgrades by relying heavily upon site personnel, instead of outside resources, to implement the control upgrades. These processes typically realize greater than anticipated process improvements from upgraded control, and find the capital investment well justified.

Case Study 15: Distillation Train

Relaxing cross-contamination limits in a multiproduct process helps reduce waste

Abstract

This case study describes an effort to reduce incinerated wastes from the washing of distillation equipment during product changeovers. A waste reduction of nearly 80% was achieved through several steps requiring little capital investment. The effort was prompted by rising incineration costs and the need to increase product yields. A key to the reduction was the finding that product cross-contamination limits could be relaxed with no negative impact upon final product quality. This finding could be of general interest to the chemical processing industry.

Background

The Chambers Works "distillation train" is a collection of separation equipment that operates continuously to purify products from two crude streams produced at another process onsite. The product crudes cycle through the equipment in separate "campaigns". At the conclusion of each campaign, a portion of the product crude from the next campaign is used to wash out the equipment to prevent contamination of the new product with residue from the old. This washout crude becomes too contaminated with residue to recycle back into the process. It therefore leaves the distillation train as waste for incineration.

Three types of equipment in the distillation train are relevant to this study:

- *Distillation columns*. The distillation train includes a series of distillation columns, the largest of which contains packing to enhance separation. The amount of residue left on the packing is sufficient to cause unacceptable cross-contamination. Cleaning the packing actually begins after the new campaign has started. The initial material distilled by the column carries away the old product residue and becomes part of the washout waste.
- *Piping and storage tanks*. Pipe interiors and tank bottoms are flushed between campaigns to remove residue.
- *Decant tank*. The distillation train includes a decant tank that separates liquids of different densities. Historically, large amounts of new product crude have been used to flush the decant tank between campaigns.

In 1990, a project team was formed to identify ways to reduce waste from equipment washout. Their goals included a reduction in incineration costs and improvement in product yields. As a result of the team's activities, four options for reducing waste have been implemented. These have reduced the washout waste by about 78%. The four options are:

- *Reduction in the amount of material used to flush the decant tank*. The waste reduction team performed an evaluation of how much material is actually required to do an adequate cleaning job. They found that just one-tenth the amount that had been used was sufficient. Reducing the material used for cleaning the decant tank contributed 27.4% to the overall waste reduction effort.
- *Installation of a dedicated pipeline*. Previously, a single pipeline had been used to transport both of the product crudes from the process that made them to the distillation train. In 1990, another pipeline was installed to provide dedicated pipelines for both crudes. This eliminated the need for flushing between campaigns and contributed 20.6% to the overall reduction effort.

- *Implementation of a column drain and pump-out procedure*. In the new procedure, the large distillation column is placed under slight positive pressure for a period of 24 to 48 hours. During this time, operators periodically pump out the column as residue blows off of the packing. The pumped residue is sent to a storage tank to be recycled back to the process during a future campaign. The new procedure permits a reduction in the amount of contaminated product taken as waste from the column at the start of a campaign, and accounts for 17.1% of the overall waste reduction.
- *Relaxation of cross-contamination limits*. The waste reduction team found that a greater amount of old product residue could be tolerated without compromising the purity specifications for the new product. This finding enabled waste reduction in two ways. First, the amount of material used to clean the piping and tanks was simply reduced. Secondly, the amount of material taken as waste from the large column at the start of a new campaign was further reduced. Some cross-contaminated product from the column is allowed to enter the product collection tank where it mixes with the purer product that arrives later. The overall amount of product contamination is kept within product purity specifications. Relaxation of cross-contamination limits has contributed 13.1% to the overall waste reduction.

Description of the Waste Stream

The waste stream from this process consists entirely of product crude. Thus the cost of this waste stream, in addition to the costs of incineration, includes the yield loss represented by unrecovered product.

Before implementation of the four options described above, the distillation train washout produced 0.032 lbs of waste per pound of product produced. After implementation, this figure dropped to 0.007 lbs.

At present, the replacement of product crude with waste material for flushing the decant tank is under consideration. If implemented, this option would reduce the washout waste to 0.006 pounds per pound of product.

Previous Waste Minimization Efforts

Over the years, reductions in other waste streams from the distillation train have been achieved. However, no known attempts to reduce washout waste were made before formation of the waste reduction team in 1990.

Waste Minimization Options

The waste reduction team generated a number of washout waste reduction options in addition to the four that were implemented. These include:

- *Use waste material to flush the decant tank*. The option would use the high-boiler waste from one of the distillation columns to clean the decant tank instead of good product crude. Implementation of this option is seriously being considered.
- *Flush the column packing with water*. This option involves pouring water over the large-column packing to wash out the residue. This option is not being seriously considered because of concerns about equipment corrosion.
- *Simply reduce further the amount of material used for equipment washout*. The waste reduction team determined that no such reduction can now be made without compromising product quality.

Table 3–27. Economic Summary of Top Distillation Train Waste Minimization Options

Option	Waste Reduction	Capital Cost	EPA Method NPV (12%)	IRR	DuPont Method NPV (12%)	IRR	Implementation Time
Install dedicated pipeline	20.6%	$700,000	$3,280,000	79%	$3,080,000	76%	6 months
Relax cross-contamination limits	13.1%	$0	$400,000	∞	$270,000	∞	6 months
Reduce flush in decant tank	27.4%	$0	$840,000	∞	$570,000	∞	3 months
Column drain & pump-out procedure	17.1%	$0	$530,000	∞	$360,000	∞	3 months
Use waste material as flush	3.4%	$0	$110,000	∞	$70,000	∞	1 month

Comments: For an explanation of terms used in this analysis, see the discussion under "Feasibility Evaluation" in Section 2: *Project Methodology.*

Technical and Economic Evaluation

No technical problems were encountered in implementing the waste reduction options. Table 3–27 summarizes the economic evaluation of the four implemented options, as well as the option, "Use waste material to flush the equipment set", which is now under consideration. The option, "Install dedicated pipeline", is the only one that required capital investment. This option nevertheless had a favorable internal rate of return (IRR) and net present value (NPV).

Barriers to Implementation

Concern about product quality was the only barrier to relaxing the cross-contamination limits. Once it was demonstrated that product quality could be maintained, it was possible to implement that option.

Capital investment was a barrier to implementation of the dedicated pipeline option. This barrier was removed when the option was shown to have favorable IRR and NPV.

There were no barriers to implementing the reduction in decant tank washout material and the new procedure for cleaning the packing inside the large distillation column.

Opportunities for Others

This case study, like others in this series, demonstrates that equipment washouts provide a good opportunity for significant waste reductions with little capital cost. The experience of the distillation train team shows that waste reductions can be achieved through a series of small, inexpensive steps rather than by a great leap of investment in new equipment.

Reevaluation of product specifications and cross-contamination limits presents more waste reduction opportunities. There are probably many older processes that have overly strict purity standards that were established at a time when waste generation was less of an issue. Today, these "purity cushions" seem unnecessary in view of the increasing importance of waste reduction.

SECTION 4

Methodology Critique

In recent years, a number of waste reduction methodologies have been developed in government, industry, and academe. Their purpose is to provide manufacturers with a systematic approach to identifying and reducing waste from their processes. Cataloging these methodologies is beyond the scope of this report, but extensive literature exists about programs promulgated by various levels of government, industry organizations, and individual companies.[1–6]

This section examines the EPA and DuPont methodologies in light of the experience of the Chambers Works Waste Minimization Project. As a participating member of the Chemical Manufacturers Association (CMA), DuPont has committed to implementing CMA's Responsible Care® Codes. Any discussion of the DuPont methodology must also include a description of the codes.

In applying the EPA methodology, the Chambers Works project team performed those tasks defined in this critique as "waste stream selection" and "assessment". In general, the team did not perform tasks defined herein as "chartering", "implementation", or "auditing", and the discussions of those tasks in this critique are based on the experience that DuPont and the Chambers Works site have accumulated in the course of their own waste reduction efforts.

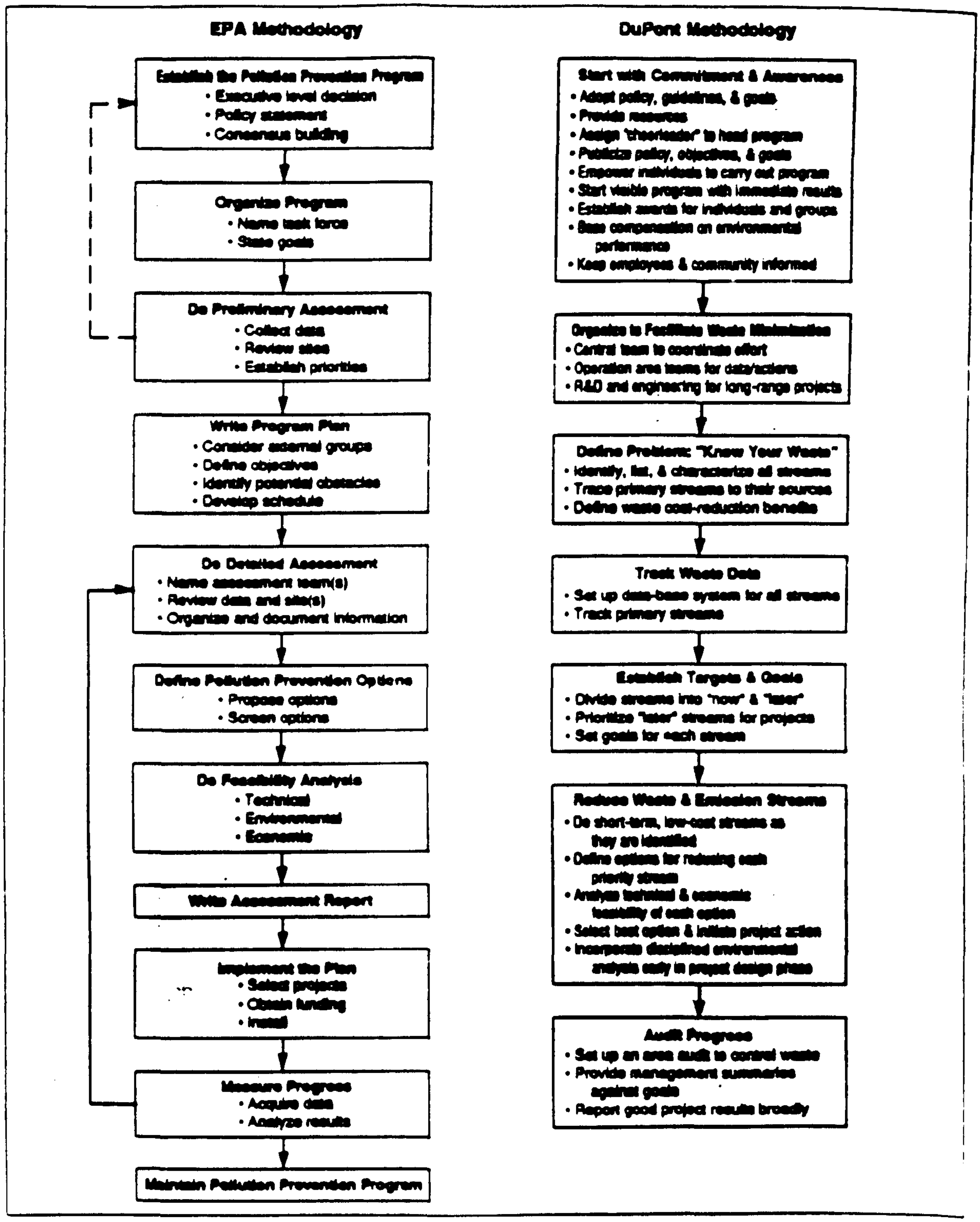


Figure 4-1. Comparison of EPA and DuPont Methodologies

Methodology Overview

Figure 4–1 provides a side-by-side comparison of the basic steps prescribed by the EPA and DuPont methodologies. The EPA methodology shown is taken from the newly published *Facility Pollution Prevention Guide*[7]. Both methods can be said to contain the following elements:

- *Chartering*–in which the highest organizational levels commit to a waste reduction program, policies are articulated and communicated, goals are set, and participants are identified.
- *Waste stream selection*–in which information about wastes are collected and waste streams are prioritized for reduction.
- *Assessment phase*–in which options for reducing the target waste stream are generated, prioritized, evaluated, and selected for implementation.
- *Implementation*–in which action is taken to reduce the target waste stream.
- *Auditing*–an ongoing process in which wastes are monitored and reductions are measured.

One difference between the two methodologies is that "waste stream selection" is actually a part of the EPA method's chartering activities. It constitutes a separate process in the DuPont methodology.

Responsible Care

The CMA has recently published its *Responsible Care Codes*[8], to which all member organizations, including DuPont, have committed. The codes aim to improve the chemical industry's management of chemicals, safety, health, and environmental performance. They prescribe specific management practices in six areas: community relations, pollution prevention, chemicals distribution, process safety, employee health and safety, and product stewardship.

Figure 4–2 presents the Responsible Care Codes for pollution prevention. The codes do not constitute a methodology in that they do not prescribe how an organization implements them. Rather, they describe hallmarks that successful pollution programs share. The codes also provide a series of checkpoints for an organization to incorporate into its own methodology.

The EPA Methodology

At the start of the Chambers Works project, the EPA's methodology was embodied in its *Waste Minimization Opportunity Assessment Manual*[9]. As its name implies, it placed great emphasis on the assessment phase of a waste reduction program, and offered tools for conducting a waste assessment. The Manual placed less emphasis on the establishment and management of an ongoing waste reduction program.

The recent publication of the EPA *Facility Pollution Prevention Guide*[7] represents a major upgrade to the methodology. It places additional emphasis on the management of a continuous waste reduction program. For example, the single chartering step prescribed in the old manual has expanded to four iterative steps in the new guide. And whereas auditing had been a constituent task of implementation in the manual, the guide presents it as a discrete, ongoing step. The guide's inclusion of "maintain pollution prevention program" as part of the methodology is also new.

Code 1
A clear commitment by senior management through policy, communications, and resources to ongoing reductions at each of the company's facilities in releases to air, water, and land.

Code 2
A quantitative inventory at each facility of wastes generated and released to the air, water, and land measured or estimated at the point of generation or release.

Code 3
Evaluation, sufficient to assist in establishing reduction priorities, of the potential impact of releases on the environment, and the health and safety of employees and the public.

Code 4
Education of, and dialog with, employees and members of the public about the inventory, impact evaluation, and risks to the community.

Code 5
Establishment of priorities, goals, and plans for waste and release reduction, taking into account both community concerns, and the potential safety, health, and environmental impacts as determined under Codes 3 and 4.

Code 6
Ongoing reduction of wastes and releases, giving preference first to source reduction, second to recycle/reuse, and third to treatment.

Code 7
Measure progress at each facility in reducing the generation of wastes and in reducing releases to the air, water, and land, by updating the quantitative inventory at least annually.

Code 8
Ongoing dialog with employees and members of the public regarding waste and release information, progress in achieving reductions, and future plans. This dialog should be at a personal, face-to-face level, where possible, and should emphasize listening to others and discussing their concerns and ideas.

Figure 4-2. Responsible Care Codes for Pollution Prevention

The methodology described in the guide is a major step forward. The old manual correctly assumed that assessments are at the heart of a waste reduction program. But the new methodology increases the likelihood that assessments will actually be performed because it prescribes waste reduction roles for people at all levels of the organization.

The DuPont Methodology

The DuPont methodology, like that of the EPA, has also evolved over the years. It began in 1988 as a set of tools for tracking waste. In fact, "waste stream selection" is still the methodology's most explicitly articulated step. The DuPont methodology provides more detailed prescriptions for chartering and waste

Code 9
Inclusion of waste and release prevention objectives in research and in the design of new or modified facilities, processes, or products.

Code 10
An ongoing program for promotion and support of waste and release reduction by others.

Code 11
Periodic evaluation of waste management practices associated with operations and equipment at each member company facility, taking into account community concerns and health, safety, and environmental impacts, and implement ongoing improvements.

Code 12
Implementation of a process for selecting, retaining, and reviewing contractors and toll manufacturers, that takes into account sound waste management practices that protect the environment, and the health and safety of employees and the public.

Code 13
Implementation of engineering and operating controls at each member company facility to improve prevention of and early detection of releases that may contaminate groundwater.

Code 14
Implementation of an ongoing program for addressing past operating and waste management practices, and for working with others to resolve identified problems at each active or inactive facility owned by a member company taking into account community concerns, and health, safety, and environmental impacts.

Figure 4-2. Responsible Care Codes for Pollution Prevention (cont'd)

stream selection than for the assessment phase. The company views the commitment of all organizational levels as crucial to the success of the program. Given the number and diversity of the DuPont manufacturing facilities, it is felt that how-to prescriptions for conducting assessments are best left to the site.

The development of the present methodology has been greatly influenced by the CMA's Responsible Care Codes. Many of the activities prescribed for each step came directly from the codes. Today, the DuPont methodology can best be viewed as a plan for implementing the Responsible Care Codes.

Application to the Chambers Works Project

At the start of the Chambers Works project, the old EPA methodology was current. An original goal of the project was to apply the Chambers Works experience to a critique of the EPA's assessment methodology. Because the assessments were of primary interest, the project's chartering and waste stream selection activities were governed less by adherence to a methodology, and more by project-specific requirements. (See Section 2: *Project Methodology*.) However, the project team did apply tools provided by the EPA methodology in a preliminary selection of waste streams.

The assessment phase of the project included seven assessments involving waste streams that had not yet been eliminated or greatly reduced. These applied the EPA's tools for conducting assessments. The remaining eight assessments featured waste streams that had already been eliminated or reduced. The purpose of including them was to share successful experiences with others in the processing industries. They applied the EPA's assessment tools retrospectively. (The full assessment reports are contained in Section 3: *Case Studies*.)

Methodology Comparison

Most methodologies consist of the same basic steps of chartering, waste stream selection, assessment, implementation, and auditing. What distinguishes them in terms of success or failure is the tools they provide for assessment teams at the process level. Tools are methods for accomplishing the tasks prescribed by a methodology. Ideally, publications which support methodologies contain descriptions of these tools, describe how they are applied, provide clear examples, and perhaps include helpful forms or checksheets.

The EPA *Pollution Prevention Guide* provides a variety of tools for performing waste minimization assessments. The 15 assessment teams that participated in the Chambers Works project used many of these tools. The discussions which follow, particularly those concerning the assessment phase, focuses on the assessment teams' experiences with the tools they chose.

Chartering Activities

The five tasks that the EPA prescribes under "Establish the pollution prevention program" and "Organize program" are essentially the same as the tasks included in the DuPont steps called "Start with commitment and awareness" and "Organize to facilitate waste minimization".

In the DuPont methodology, chartering occurs not just at the executive level, but is repeated at each organizational level. The replication of commitment from the highest levels down to the line organizations is intended to integrate waste minimization into the way that people work everyday. It's the key to the success of the waste minimization program.

At the executive level, the commitment to a waste reduction program began with DuPont CEO Edgar Woolard, who has declared, "I want to create a corporate culture in which there is no such thing as industrial waste". A policy statement has been written and communicated throughout the corporation which states: "It is DuPont policy to minimize the generation of waste to the extent that it is technically and economically feasible, and to handle all waste in an environmentally sound manner. Treatment or disposal will be on-site whenever practicable, or at other DuPont sites with suitable waste management facilities as a first choice if it becomes necessary to send waste off-site."

At the corporate level, waste reduction goals have been articulated. These are:

- reduction of hazardous waste by 35% from 1990 to 2000.
- reduction of toxic emissions to the air (from U.S. sites) by 60% from 1987 to 1993.
- reduction of emissions of the EPA's special list of 17 hazardous chemicals by 50% from 1988 to 1995.

DuPont has also committed to goals for reducing or eliminating CFC production, energy consumption, carcinogenic air emissions, and toxic discharges to landfill.

DuPont has established a corporate level core competency group to provide vision and determine goals for waste reduction. The Environmental Stewardship Core Competency of the Safety, Health, and Environmental Excellence Center (SHEEC) is directly accountable to the Vice President of Safety, Health, and Environmental Affairs. Among SHEEC's responsibilities are:

- establishing guidelines for waste reduction goals
- tracking wastes and waste reductions
- implementing the Responsible Care Codes
- administering environmental excellence awards and compensations
- auditing sites for compliance with regulations and company policy
- training for waste reduction

At Chambers Works, the site staff has replicated Mr. Woolard's commitment, and has adopted similar waste reduction goals for the site. The staff has established a task team to develop the site commitment, achieve consensus among all operating areas of the plant, organize the program at the site level, and implement the Responsible Care codes. The team consists of plant staff members, environmental professionals, supervisors, R&D people, and line workers. It has developed and maintains a six-month action plan for implementing long-term waste reductions. The plan, which is updated frequently, is also concerned with eliminating unplanned releases.

The site commitment has been replicated in each of the five operating areas and has worked its way down to the line organizations. Some line organizations have adopted ongoing waste reduction efforts, and some have been pursuing them for years. Some of these facilities are featured in the project assessments. What they have in common are a willingness to abandon old ways of thinking about waste and the ongoing participation of cross-functional groups of people in waste reduction activities.

The experience at Chambers Works so far reveals that driving the commitment downward gets harder the closer one gets to the line organizations. The ongoing demands of production, maintenance, safety, and so on seem to compete with waste reduction. The successful facilities are those that have made the paradigm shift that views all of these demands as complementary, and not competing, activities.

Waste Stream Selection

The EPA includes waste stream selection in its chartering phase under "Do preliminary assessment", whereas DuPont devotes three discrete steps to waste stream selection. In both methodologies, waste steam selection involves data collection and prioritization of the waste streams. Both methods suggest collecting the minimum amount of information needed to prioritize the streams.

The primary tool offered by the EPA for prioritizing waste streams is a formal ranking and weighting procedure. In practice, the amount of data to be collected is proportional to the number of criteria used to prioritize the waste streams. For example, collecting data about waste costs requires information about the cost of treating the waste, the cost of product lost to waste, handling costs, and transportation costs. For large sites with many waste streams, formal ranking and weighting can be too time-consuming to be practical. Moreover, much of this effort will be duplicated during the assessment phase.

An alternative tool for prioritizing wastes is offered by the DuPont methodology, and is known internally as "Know Your Waste"[10]. The method requires a production area or site to identify all wastes streams and to collect sufficient information about them to permit prioritization. It suggests the creation of flow diagrams or material balances to help quantify previously unaccounted for losses and emissions.

Once the major streams have been identified, they are prioritized into "do now" and "do later" streams by cross-site, cross-disciplinary teams without formal ranking and weighting. This tool is similar to one offered by the EPA for screening waste reduction options.

Of course, the group which identifies the waste streams to work on should also be empowered to allocate resources for waste assessments upon those streams. An important criteria for selection of "do now" streams is waste minimization potential. This was true for the brainstorming teams that chose the candidates for the 15 assessments. This is probably why most of the assessments in the Chambers Works project identified options that would significantly reduce waste while producing high economic returns. The Responsible Care Codes take "Know Your Waste" a step further by including input from employees and the community during waste stream prioritization.

Other tools for prioritizing waste streams can be considered. For example, Pareto diagrams are a simple way to rank waste streams by volume. Smaller waste streams could be given high priority if they are particularly toxic or for anticipated regulatory imperatives. A Pareto analysis for a typical chemical plant is likely to show that the top 20% of the waste streams account for more than 80% of the total waste volume. Of the 15 assessments included in the Chambers Works project, 13 addressed waste streams that were among the top 20% for each operating area, and among the top 20% for each disposal medium.

Assessment Phase

DuPont actually combines its assessment and implementation phases, whereas the EPA methodology expands the assessment phase into four discrete steps. In the assessment phase of the Chambers Works project, the project team performed the tasks listed under "Do detailed assessment", "Define pollution prevention options", and "Do feasibility analysis" of the EPA methodology.

Some general observations from the assessment phase of the Chambers Works project are summarized below:

- Assessments should be quick, uncomplicated, and structured to suit local conditions. Otherwise, they're viewed as annoyances intruding upon the day-to-day concerns of running a production process.
- Assessment teams should be kept small, about six to eight people, to encourage open discussion during option generation.
- Including at least one line-worker on an assessment team provides insight into how the process really operates.
- Including at least one person from outside the process on an assessment team provides a fresh perspective.
- Area inspections and brainstorming meetings are valuable tools during the assessment phase.
- It's important to determine the source of a waste stream, as opposed to identifying the equipment that emits it, before the option generation step.

- Overly structured methods for screening options do not overcome group biases and are regarded as time-wasters by most teams.

What follows is a task-by-task analysis of the assessment phase of the Chambers Works project.

Assessment teams

The formation of interdisciplinary assessment teams at the process area level was considered a good approach and is probably the reason why all of the project assessments identified at least some good waste minimization options. The teams numbered from six to ten people, and typically included supervisors, production people, engineers, chemists, and operators. The operators provided valuable input in most of the assessments. They see things that are not part of written procedures, and know better than anyone else what happens during day-to-day process operation.

Particularly helpful was the inclusion of people from outside of the process on each assessment team. Outsiders provide an objective view. Their presence promotes creative thinking because they don't know the process well enough to be bound by local conventions. Appointing outsiders as assessment team leaders could be a way of capitalizing on the fresh perspectives they provide.

In the Chambers Works project, project team members led the assessment teams. This provided two advantages. First, doing assessments became easier as project team members gained experience. Second, project team members were able to share ideas generated in earlier assessments with participants in the later assessments. The accumulated learnings of the project team are the basis for the information in Section 5: *Waste Reduction Opportunities for Organic Chemical Processes*.

Data collection

For each assessment, some combination of the following kinds of information proved useful during the assessment phase:

- Operating procedures
- Flow rates
- Batch sizes
- Waste concentrations within streams
- Raw material and finished product specs
- Documentation on process changes
- Information about lab experiments or plant trials

The project team feels it is important to obtain or generate a material balance before the area inspection. The material balance proved to be the most useful single piece of documentation. In most cases, having sufficient data to compile a material balance was nearly all the data that was required for an assessment.

Energy balances were not considered to be useful because of a bias in the waste stream selection. Energy consumption was rated low as a criterion for selecting the streams, and few of the options generated during the assessments had a significant impact upon energy consumption. However, energy costs were included in calculations for economic feasibility. Similarly, water balances were not considered useful, but water costs were included in the calculations for economic feasibility.

Area inspection

All 15 of the project assessments included an area inspection by members of the assessment teams. These proved to be a useful team-building exercise, and provided everyone with a common grounding in the process. Outside participants would probably have had trouble understanding the discussions during the subsequent brainstorming meeting without these inspections.

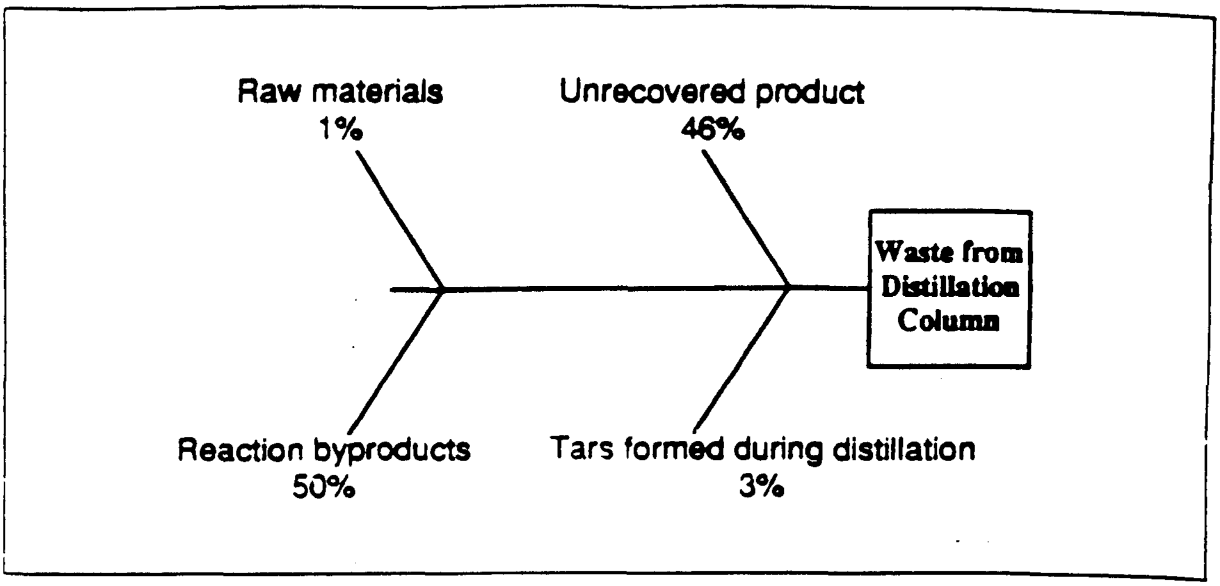


Figure 4–3. Sources of Waste

The experience that outsiders bring to the site inspections can sometimes result in a breakthrough. On one inspection, an outsider noticed a waste stream similar in composition to the raw material used by another Chambers Works process. She is now conducting an independent assessment on this waste stream to determine if it can indeed be used as a feed stock for the other process.

Option generation

Options were generated at brainstorming meetings of the assessment teams. The project team concluded that the best format for these meetings is to freely collect ideas, and to avoid discussion of them beyond what is necessary to understand them.

It is important to determine the true source of the waste stream before the option generation part of the assessment phase. Impurities from an upstream process, poor process control, and many other factors may all combine to contribute to waste. Unless these sources are identified and their relative importance established, option generation can focus on the piece of equipment that emits the waste stream and which may in fact produce only a small part of the waste. As Figure 4–3 shows, one of the project assessments examined a waste stream that had four sources. Two of these sources were responsible for about 97% of the waste. But because these sources were not identified beforehand, roughly equal numbers of options addressed all four sources. Fortunately, the causes of the waste came to be well understood before the assessment was completed. But knowing the major sources of the waste beforehand would have saved time by allowing team members to concentrate on them.

Several tools might be provided to help identify the actual source of the waste. A material balance provides a good starting point. A cause-and-effect "fishbone" diagram such as that in Figure 4–3 can help identify the sources of waste and indicate where to look for reductions. Sampling to identify components of the waste stream can provide clues to their sources. Control charts, histograms, and scatter diagrams can depict fluctuations in waste stream components and thus provide more clues.

The value of brainstorming meetings was demonstrated by at least one of the "retrospective" project assessments. A group was developing an option that would have reduced waste, and had actually begun to procure the required equipment. Later, another option that eliminated the waste stream entirely was identified and implemented. The wasteful procurement might have been avoided if a good cross-section of people from the process had been brought together for brainstorming.

Option screening

The EPA methodology offers several tools for option screening. These include such simple methods as categorizing and simple voting, as well as the more rigorous weighted-sum rating and ranking method. Five of the assessments performed rating and ranking of options using the weighted-sum method described in Section 2. These exercises were very time-consuming, and four of the five assessment teams did not find them useful. For those assessments, it would have been better to apply one of the simpler tools. The one team that did find the weighted-sum method helpful had a very complicated process with many options.

The assessment teams uncovered some possible pitfalls with the weighted-sum method. The method is designed to provide an objective measure of an option's worthiness. In practice, some teams incorporated local biases into the weights assigned to the criteria or the rankings they gave to an option. Thus, options which outside observers subjectively considered to be innovative and promising sometimes didn't fare well when ranked against more conventional, "popular" options.

On several occasions, an option ranked at or near the top of the list because it scored high in every criteria except probability of success or safety. But an unsatisfactory score in either of these two criteria is enough to reject an option, no matter what its other merits are.

The high scores achieved by some impractical options probably indicates that the assessment teams used too many weighted criteria.

Another problem with the ranking and weighting is that many options could not be evaluated on the fly. Some options had to be better defined or required laboratory analysis. This made it difficult to rank them at a meeting.

Often, the options that were worth pursuing were obvious to many team members before the ranking exercise began. These people tended to view the subsequent exercise as a waste of time.

The weighting and ranking meetings were not entirely fruitless. Often the discussions about each option provided a good basis for determining its technical and environmental feasibility.

One of the simpler tools offered by the EPA is to classify options into three categories: implement immediately, marginal or impractical, and more study required. This is similar to a DuPont tool designed to quickly identify the best options for further evaluation. It prescribes placing all of the generated options into four categories:

- Do now
- Do later
- Insufficient knowledge
- (Apparently) impractical

The terms "do now" and "do later" do not refer to timing but to the waste reduction value of an option. A do-now option is one with high waste minimization potential or high chance of success. The do-later options have lower waste reduction potential and perhaps longer implementation times. The do-later options should be reconsidered after the do-now options have been implemented. The "insufficient knowledge" options require additional study before they can move into one of the other categories. The "impractical" options, while not dismissed outright, have very low waste reduction value or chance of success.

Many other tools can be used to quickly screen options. These include cost/benefits analysis, simple voting, and listing option "pros" and "cons".

Feasibility analysis

The economic analysis portion of the assessment is the most difficult and time-consuming part of the assessment. The use of long-term economic indicators as prescribed by both the EPA's total cost assessment and the DuPont methodology, while necessary, is a source of potential problems. Estimating investment, cost savings, and revenue changes is within the competence of the people who will actually be doing the analysis at the area level. The difficulties arise when dealing with the other factors required for calculating net present value (NPV). These include multiyear estimates of inflation, taxes, tax depreciation, fixed costs, selling expenses, working capital, etc. Most chemists and engineers do not perform enough NPV calculations to become expert in the method. Computers have helped to simplify the calculation of NPV, but not the determination of the factors cited here.

Section 2 contains a description of how the project team determined the economic feasibility of selected options. That description includes a "short-cut" method which standardizes the assumptions about the factors needed to calculate NPV, and simplifies the calculation to terms familiar to the people who perform assessments. The short-cut method provides good results for a minimum of effort. Frequently, the project team had to evaluate an option with only a rough idea of its waste reduction potential. Determining the precise waste reduction through lab testing or plant trials is expensive and time-consuming. To select the best options during the assessment phase, the project team had to make quick estimates of waste reduction potential. The short-cut method was a great help in these situations.

In calculating NPV, DuPont uses only actual costs and then considers the impact of such "soft costs" as safety or regulatory compliance. The EPA method encourages the assignment of dollar values to these soft costs to improve the attractiveness of waste reduction options. But determining actual values for future liability and intangibles is difficult at the organizational level where most assessments are done. Most assessment teams can identify the "soft" costs and benefits associated with an option, and these can be factored into the final decision to implement or not implement. In practice, using the DuPont or EPA methods made no real difference in determining option feasibility in the 15 assessments. However, it is conceivable that the choice of method might make a difference for marginal options.

The economic feasibility part of the assessments uncovered several possible pitfalls associated with either methodology:

- failure to consider non-waste minimization improvement options
- overestimating sales, savings, or waste minimizations
- underestimating additional operating costs
- underestimating required capital investment
- taking credit for cost savings that merely shift the costs to other areas of the plant

WRITE ASSESSMENT REPORT

Writing the assessment reports in Section 3 was difficult for those processes that had committed to waste reduction before the start of the project's assessment phase. This is because the typical waste assessment is done informally. No report is written at the end of assessments, and only the most promising options are investigated in depth. Documentation about past reduction efforts is, of course, available. But lost are the waste reduction options that were suggested and rejected. Because waste reduction is an iterative process, it would be useful to capture those options for reconsideration in a future assessment.

For this reason, the project team feels that assessment reports are a useful part of the assessment process. However, writing reports such as those in Section 3 is time-consuming. A list of the generated options, a summary of the pros and cons of each, and the feasibility results may be all that is necessary.

Implementation

Several assessment reports in Section 3 describe a variety of waste reduction implementations. Some of these consisted of stepwise changes to the process, each incrementally reducing the amount of waste. Such changes can often be made without large capital expenditures, and can be accomplished quickly. This is a common approach to waste reduction. Because expenditures are small, facilities are willing to make the changes without extensive study and testing. Several iterations of incremental improvement are often sufficient to virtually eliminate the waste stream. Other implementations require large capital expenditures and do require laboratory testing, piloting, allocating resources, and capital, installation, and testing.

Many of the waste reductions described in the Chambers Works project assessments were performed as part of ongoing process improvements, and were classified as such. For example, a major upgrade to a process control system might be considered by people at the area to be a "process improvement", even though it resulted in a significant waste reduction. It's important for an organization to take full waste reduction credit for such improvements.

It is felt that implementations should be performed at the lowest organizational level possible. Several project assessments describe implementations in which operators and mechanics played a major role in reducing large waste streams. Many smaller waste streams can escape the notice of the site team. But at the area level, they can be reduced as part of ongoing process improvement programs.

Product Life Cycle

An important feature of the DuPont methodology is that it considers the environmental impact of products from the design phase, through manufacture and use, to final disposal. The DuPont methodology step called "Organize to Facilitate Waste Minimization" covers the design of new products and processes, as do the Responsible Care Codes. DuPont has developed a method for designing more environmentally friendly processes, and has shared it with the process industries[12]. Chambers Works has developed guidelines for reducing product and process waste by building pollution prevention into the research and development of new products. Wastes generated during manufacturing are addressed by the DuPont waste reduction program, well-described in this report. The final disposal of DuPont products and packaging is addressed by the Responsible Care Codes for Product Stewardship. In short, DuPont attempts to build pollution prevention into each stage of a product's life cycle.

The EPA prescribes a more holistic approach to product life cycle issues. Although not specified as a step in the EPA methodology, the *Facility Pollution Prevention Guide* recommends the use of life cycle analysis (LCA). The guide does not provide much information about how to perform a life cycle assessment, but the subject has been covered in the open literature.[13,14] The virtue of LCA is that it considers the complete environmental impact of a product during the earliest stages of design and development. In practice, LCA is perceived as being difficult, time-consuming, and expensive. Moreover, LCA is not always free from bias given the speculative nature of the many assumptions it requires as assessment inputs.

The point is that more tools should be offered for addressing product life cycle issues. LCA seems best suited for the design of new products. For established products, the approach taken by DuPont may be more appropriate.

Conclusions

The EPA methodology has already evolved from a how-to for conducting assessments to a comprehensive pollution prevention program. It will no doubt evolve again as experience with its application grows. Joint projects between EPA and industry, such as the Chambers Works project, provide a wealth of real world input to future iterations. The increasing volume of technical literature on the subject of methodologies will also be influential. The EPA seems well-placed to develop what will be recognized as an industry standard for pollution prevention methodologies.

An important strength of the current methodology is its recognition that pollution prevention requires the participation from all levels of the organization. It contains well-articulated prescriptions around management commitment.

In prescribing the expanded cost inventory, the EPA is asking the right question, i.e., how does one accurately value the benefits of pollution prevention? Unfortunately, the expanded cost inventory is full of ambiguities and is difficult to apply. Economic feasibility evaluations are often performed at the process area level, and by people who are unable to place a value upon future liability or intangible benefits. As this report has noted, such evaluations are already difficult. Having people attempt to estimate dollar values for such intangibles as "improved public image" seems too much to ask. Other methods are easier. These include the subjective consideration of soft costs/benefits during option evaluation.

The EPA *Pollution Prevention Guide* rightly prescribes flexibility in the choice of assesment tools to suit local circumstances. However, the DuPont members of the project Team believe that the tools featured by the guide in dedicated chapters and appendixes exhibit a bias toward the more formal and rigorous assessment tools. Such featured methods as the total cost assessment, life cycle analysis, and weighted-sum rating and ranking all have simpler counterparts. The DuPont team members feel that the more rigorous tools work best when applied to very complex problems with many factors to consider. But most problems addressed at the process area level are amenable to quicker, less formal methods. Application of the formal methods to the typical process-level assessment does not ensure elimination of group biases, and tends to dampen the enthusiasm of the busy people who participate in such assessments.

The Chambers Works project uncovered several key learnings that may be helpful to other pollution prevention efforts:

- A successful waste reduction program requires the commitment of the entire organization. An important strength of the DuPont methodology is its "cascading commitment" approach in which the commitment to pollution prevention is made by the top management and then replicated at all levels of the organization. Over time, this approach integrates pollution prevention into the corporate culture, and empowers individual facilities to implement waste reductions. Today, pollution prevention is taking hold and growing roots at facilities across Chambers Works.
- Vision is important for successful waste reduction. During the Chambers Works project, the project team observed that what the successful facilities have in common is a vision of a process that becomes ever better in terms of productivity, quality, and waste reduction. At those facilities where wastes were eliminated, people already knew that they wanted to reduce waste and had general ideas about how to do it.
- Success breeds success. A waste reduction methodology should provide for quick, early results to provide examples and encouragement to others. This can be accomplished by keeping the assessment phase simple and flexible.

Methodology Refinement

Process Improvement Programs and Pollution Prevention

Many businesses in DuPont have adopted formal process improvement programs to achieve such goals as greater capacity, shorter cycle times, and higher quality. Indeed, many of the pollution prevention success stories occurred at facilities which were really pursuing these goals. One of the strengths of the DuPont process improvement methodology is that it recognizes "visioning" as a discrete and ongoing activity that underlies the entire effort. At a high level, business teams create a vision of a nimble, flexible organization able to quickly meet new competitive challenges. At the facility level, people create a vision of a world-class process that is appropriate for their circumstances and their role within the high-level vision.

The ideal pollution prevention program would combine the commitment enjoyed by the DuPont waste minimization methodology with the visioning that is a part of the process improvement methodology. And it would be simple to allow facilities to achieve quick successes. The key determinants of success for any pollution prevention program is organization-wide commitment, vision, and visible success. If these ingredients are present, it almost doesn't matter which prescriptive methodology an organization adopts.

Methodology Upgrade

An upgraded methodology would begin by identifying the building blocks upon which a successful pollution prevention program might be based. These are depicted in Figure 4–5. At the base of the pyramid are the four "stakeholders" in pollution prevention: community, employees, stockholders, and customers. All have a role to play in the methodology.

The commitment to pollution prevention, in which policies and goals are articulated, is built upon interactions with the four entities at the base of the pyramid.

With the commitment in place, a vision can be created to provide a road map for meeting the goals. A vision depicts a future-state process or organization that meets the pollution prevention goals, and is accompanied by a general, evolutionary plan for achieving the vision.

Figure 4–5. Building Blocks of a Successful Pollution Prevention Program

With the vision in place, an analysis of the organization or facility can be performed. The vision influences the option generation activity, and helps to resolve ambiguities about the relative merits of waste reduction options. The extent to which an option advances the facility toward the future state becomes a criterion by which the option is evaluated.

The results of implementations cycle back to the interaction with the stakeholders. Through this interaction, the goals and the vision are upgraded to achieve additional waste reductions. Continual iterations of the methodology advance an organization toward the state of "no waste" at the top of the pyramid.

A suggested methodology is presented in Figure 4–6. One unique feature is that it requires all of the steps to be performed at all organizational levels. This concept is illustrated in Figure 4–7. Most methodologies consist of a series of steps, the first few of which are performed at the highest levels of the organization, and the last of which are performed at the line organization. But the new methodology could prescribe that each step of the plan be performed at each level of the organization.

The activities recommended for each step would consider the limited time and resources available for pollution prevention. Instead of prescribing "how-tos", the methodology would provide a variety of tools from which local sites can choose. The hope is that waste reduction opportunities will be identified quickly, leaving more time for people to perform the implementations that actually reduce waste.

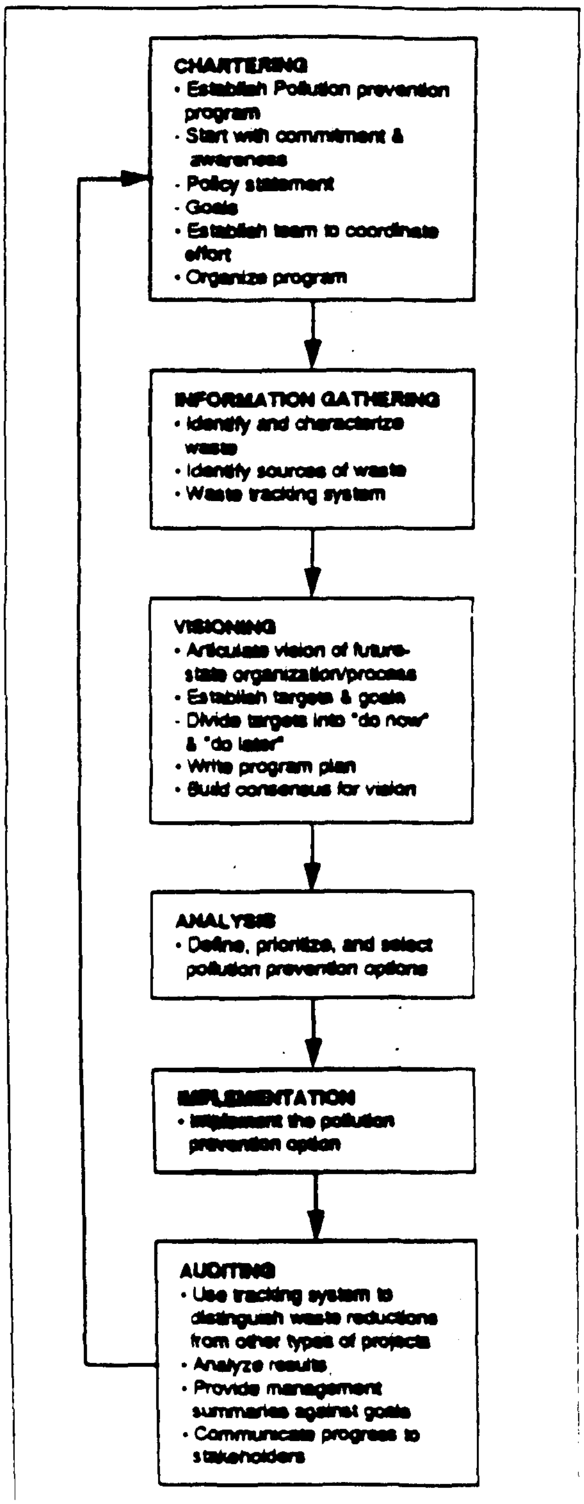


Figure 4–6. Upgraded Methodology

A Common Plan for All

An upgraded methodology could have people at all levels of the organization working to the same plan. At the corporate level, a company commits to a pollution prevention program and creates a vision to depict a future-state corporation that meets the pollution prevention goals. During the analysis phase, options to advance the company toward the vision are generated. Such options might include tools that help sites establish their pollution prevention goals, recognition programs for environmental excellence, provisions for pollution prevention training, etc.

The facility level is where wastes are generated and where waste reductions will occur. Chartering at this level involves, among other things, forming an interdisciplinary pollution prevention team. In those facilities that have established a formal process improvement program, that program's core team can double as the pollution prevention team provided they are given appropriate training. The facility team then creates a vision of a future-state process that makes high-quality products with a minimum of waste. The options generated during the assessment phase are evaluated in part for the extent to which it advances the facility toward the vision.

The facility level implementations provide the feedback that the rest of the organization needs to develop new goals and update their visions. Thus, pollution prevention becomes a perpetual effort to achieve ever greater levels of environmental excellence.

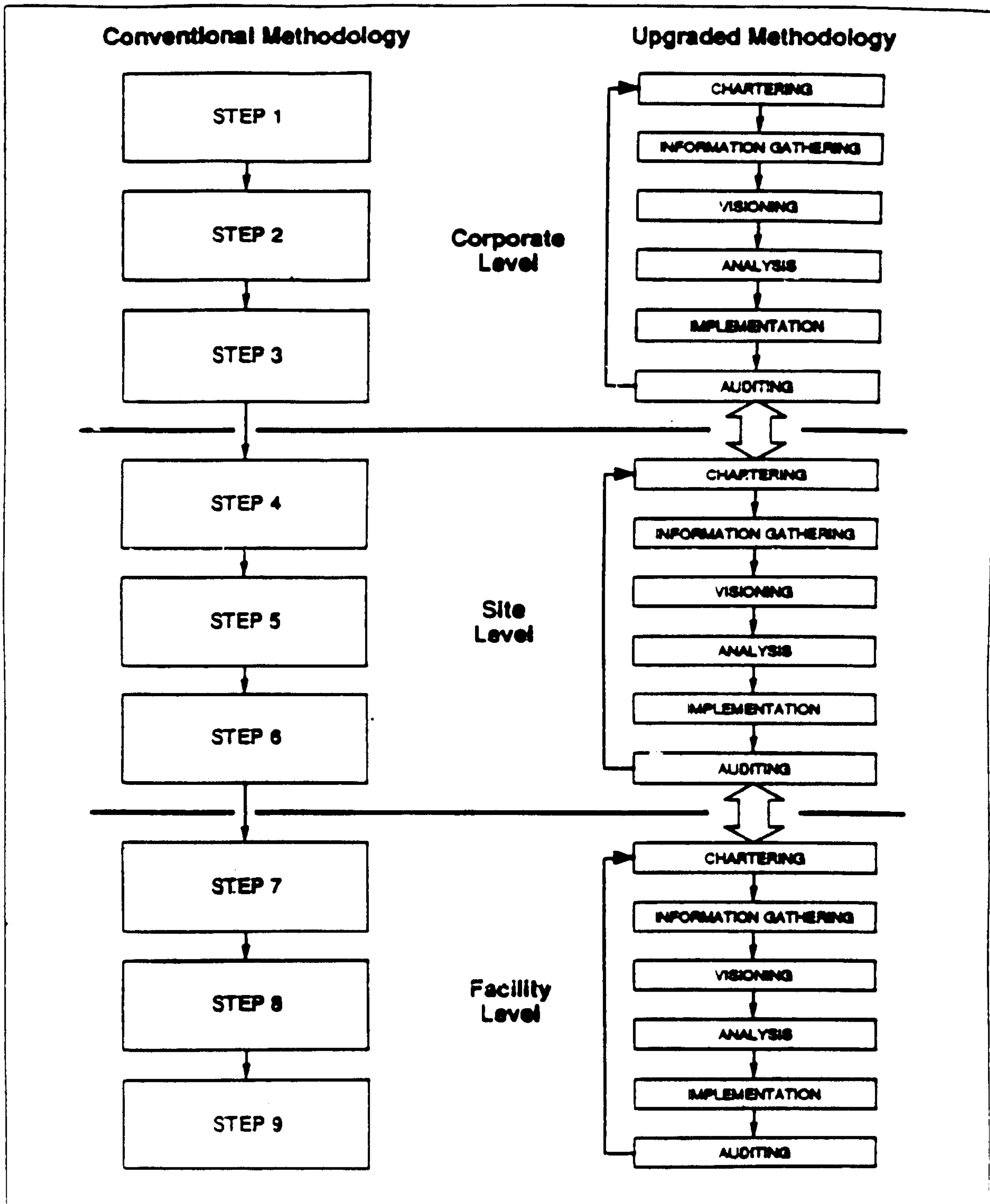


Figure 4–7. Comparison of Conventional and Upgraded Methodologies

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SECTION **5**

Waste Reduction Opportunities for Organic Chemical Processes

The Chambers Works Waste Minimization Project examined 15 waste streams from the DuPont site in Deepwater, New Jersey. Scores of people with diverse skills and experiences generated well more than a hundred options for reducing these streams. Some of the options were duplicates of each other, generated by assessment teams working on separate but similar processes. Some were "blue sky", futuristic suggestions thrown out at brainstorming meetings as much to stimulate thought as to identify immediate reductions. But nearly all of them were generated by people who actually work the processes every day. Taken together, these options represent a body of practical experience that can benefit others throughout the chemical processing industries.

This section compiles those options that are of general interest to industry, and augments them with options gleaned from a post-assessment search of the technical literature. They are grouped by four waste stream types:

1. Solvent Wash Waste
2. Solvent Waste (other than solvent wash waste)
3. Waste Incurred from Reaction Byproducts
4. Tar Waste

The information in this section is offered to stimulate thought during the assessment phase of a waste reduction effort. It is not an exhaustive compilation of possibilities, and its inclusion here cannot be regarded as an endorsement of an option's viability in any particular situation. Your organization should independently evaluate the suitability of these or any other options for its own needs and circumstances.

Solvent Wash Waste

Cleaning of equipment is one of the most common areas of waste generation. Much literature exists on the reduction of solvent wash waste from metal cleaning and degreasing applications as well as from various applications in the paint industry. This section focuses on the chemical industry's reduction of solvent wash waste (i.e., vessels and associated piping requiring clean-out). However some of the waste minimization techniques presented in this section can be applied to other industries (and, in fact, were derived from literature on other industries' wash waste reduction techniques).

Three of the fifteen case studies presented in Section 3 of this report focus on solvent waste reduction. These are:

- Case Study 6: Polymer Vessel Washout
- Case Study 12: CAC Process
- Case Study 15: Distillation Train

Waste minimization options from the three case studies were combined with information from the technical literature. Figure 5–1 presents a fishbone chart of some alternatives for reducing solvent wash waste. The options are neither all-inclusive nor applicable to all situations.

Discussion of Options

The first 10 options are grouped under the Operating Procedures category. For the most part, they can be implemented quickly and at little or no cost.

- *Clean equipment manually.* Manual cleaning could reduce the amount of solvent used because:
    - the manual washing may be more efficient than an automated wash system
    - personnel can vary the amount of solvent needed from wash-to-wash depending on the condition of the equipment (cleanliness)

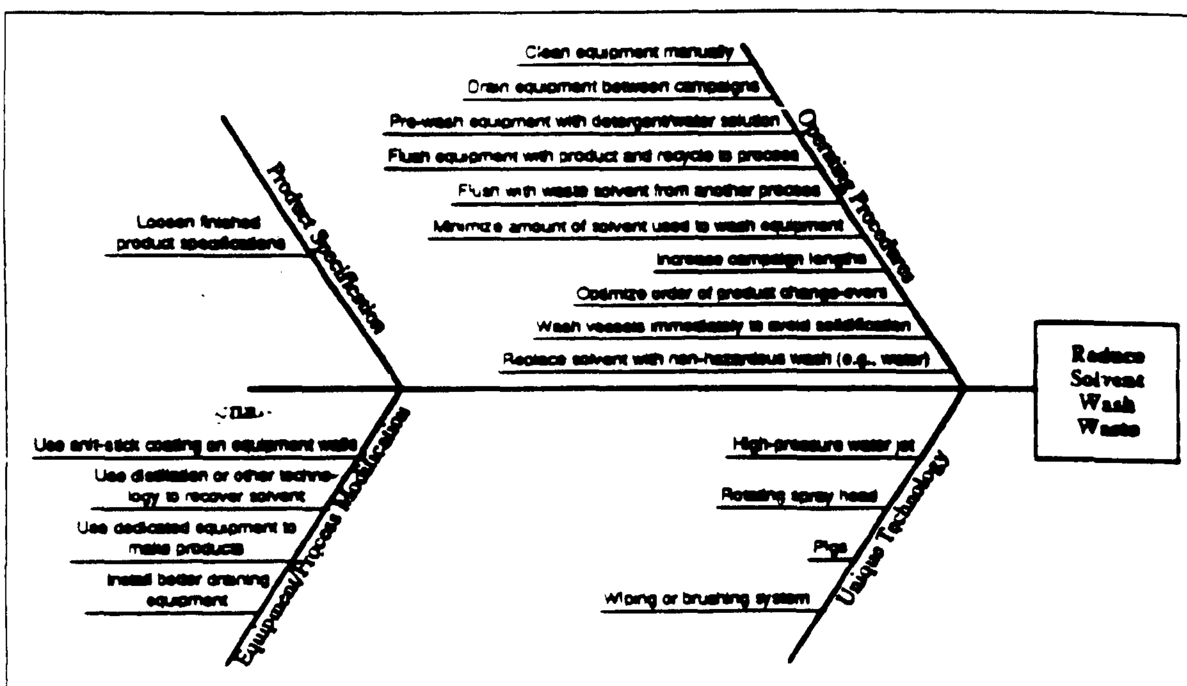

Figure 5–1. Solvent Wash Waste Reduction Options

A variation of this option could involve personnel entering the equipment and wiping the product residue off the equipment interior walls with hand held wipers or spatulas[1] which would minimize or eliminate the necessity of a subsequent solvent wash. The safety aspects of this option, particularly the nature and extent of personnel exposure, should be thoroughly reviewed before implementation.

- *Drain equipment between campaigns*. Better draining would lessen the product residue on the equipment walls and thereby minimize or eliminate the solvent used in a subsequent wash. This could be accomplished by simply increasing the time between the end of a production batch or cycle and the start of the washout procedure. This option was adopted in Case Studies 12 and 15. In Case Study 15, to facilitate draining of a packed distillation column, a slight positive pressure is maintained (with nitrogen) on the column for 24 to 48 hours. The residual product is thereby "swept" off the packing, and accumulates in the bottom of the column.

- *Prewash equipment with a detergent/water solution*. This option has to do with performing a prewash on the contaminated equipment using a soap and water solution[2]. This step would minimize or eliminate the solvent needed in a subsequent wash step.

- *Flush equipment with product and recycle to process*. This option applies to situations where two or more different products are produced in the same equipment. A small reserve of the next product to be campaigned can be withheld from a previous similar campaign and then be used as a flush for the equipment. The contaminated product (which had been used as flush) can then be reworked or reprocessed to make it acceptable for use. This option was adopted in Case Study 12.

- *Flush with waste solvent from another process*. Instead of using a fresh solvent, a waste solvent from another process on the plant can be used for the equipment flush. This procedure would reduce the plant's total waste load.

- *Minimize amount of solvent used to wash equipment*. This option was adopted in Case Study 15. Many times, a process will be started up and a procedure written calling for a certain volume of solvent flush to clean out the equipment set between batches or cycles. The procedure often times goes unchallenged. Often, the amount of solvent used for the flush can be minimized[1] with no change in the resulting cleanliness of the equipment.

- *Increase campaign lengths*[1]. By careful scheduling and planning, product campaign lengths can be increased thereby reducing the number of equipment washouts needed.

- *Optimize order of product changeovers*[1]. Many times, specifications for products produced in the same equipment are different. One set of specifications may be more stringent than another. Through careful planning and inventory control, product changeovers can be made from products with tighter specs to those with looser specs.

- *Wash vessels immediately to avoid solidification*[1]. Often times, product residue will dry and thicken or harden in the equipment between solvent washouts. By immediately washing out vessels between campaigns, the residue is more easily removed when it does not have the opportunity to set on equipment interior walls.

- *Replace solvent with non-hazardous wash.* Solvent wash can be replaced by a less hazardous or non-hazardous (i.e., water) flush material. Another variation of this option would be to replace the solvent with a less volatile solvent thus reducing fugitive emissions. The solvent could then be recovered and recycled.

The next group of options belong to the Unique Technology category. These usually involve capital investment. The costs incurred during waste reduction associated with the new technology must result in a sizable return on investment to justify the capital cost.

- *High-pressure water jet.* This option was adopted in Case-Study 6. The new cleaning system involves a special nozzle and lance assembly which is connected to a high-pressure water source and inserted through a flange at the vessel bottom. All solvent waste is eliminated. Product removed from the equipment walls can be separated from the water and recovered for further waste reduction. Even in those processes where water cannot be introduced into the equipment, an alternative exists. Vessels can be cleaned with solid carbon dioxide (dry ice) particles suspended in a nitrogen gas carrier. The solid CO_2 cleans in a manner similar to that of sand blasting, but evaporates, leaving only the material removed from the equipment.

- *Rotating spray head®.* A rotating spray head can be used to clean vessel interiors. This system would minimize solvent use by allowing solvent to contact all contaminated surfaces in an efficient manner.

- *Pipe-cleaning "pigs".* These are pipe cleaning mechanisms made of any number of materials. They are actuated by high-pressure water, product, or air. Pigs remove residual buildup on pipe walls thereby minimizing or eliminating subsequent washing.

- *Wiping or brushing system.* A system of wipers or brushes that would clean off residual product. (Perhaps analogous to a car wash except on interior vessel walls as opposed to the outside of a car.) This system would be appropriate for situations where the product hardens on the vessel walls. The wipers or brushes would then dislodge the material which would subsequently fall to the vessel bottom. This would not be appropriate for viscous material that would adhere to the brushes or wipers then have to be washed off; this could create as much, if not more waste, than the original situation.

Any options falling under the Product Specification category would usually not involve capital expenditures. Investigation, perhaps including R&D efforts, would probably have to take place before any product spec changes could be incorporated so that finished product quality would not be adversely affected.

- *Loosen finished product specifications.* Loosening finished product specs would allow higher levels of impurities or cross-contamination of products which would allow reduction or elimination of solvent wash. This option was adopted for Case Study 15.

The final five options fall under the Equipment/Process Modification category. Options in this category usually involve significant capital costs. Options for implementation are chosen such that the resulting waste reductions are large enough to support the large capital expenditures.

- *Use anti-stick coating on equipment walls.* Application of an anti-stick agent, such as Teflon®, to equipment interior walls would enable easy removal of leftover residue. The subsequent flush could then be accomplished with less solvent resulting in less waste.

- *Use distillation or other technology to recover solvent*[1,4]. Recycle and reuse of solvent can reduce waste significantly. Depending on the situation, there are several processes that can be considered for recovery. A non-inclusive list includes crystallization, filtration, membrane separation, distillation, and wiped-film evaporation. Ultrasonics, which involves an extremely high level of mixing, should also be considered. For small volumes, sending the solvent to a commercial recovery operation may be considered. The purchase or rental of a mobile solvent recovery process[5] may also be cost-effective.

  Initially, Case Study 6 selected the use of distillation to recover solvent wash waste. But as source reduction option was subsequently investigated, and proved to be a better alternative.

- *Use dedicated equipment to make products*. This option eliminates the necessity of having to wash out equipment between production campaigns thus eliminating the flush solvent waste stream. Case Study 15 adopted this option, installing second pipeline for dedicated transfer of raw material to the distillation process.

- *Install better draining equipment*. During the design of a new process, flush solvent waste can be significantly minimized by designing equipment to facilitate better draining. This would include vessels that contain sloping interior bottoms and piping arrangements with valved low points or valves that drain back into the main vessels. In Case Study 12, drainage valves were installed at strategic "low point" locations on the process equipment. A movable, insulated collection vessel was designed and built by facility personnel. After a product campaign, the residue is drained from each equipment section into the collection vessel. The collected material is then reintroduced into the process during the product's next campaign.

Solvent Waste (other than solvent wash)

Solvents are commonly used in the chemical industry as carriers to dissolve and dilute reactants or products, or as washing agents to wash out impurities from products. Often, it is necessary to isolate the finished product from the solvent at the end of a production cycle or after a washing cycle. A major source of waste exists in the use and isolation of the solvent. Other times, product is sold in solution with a solvent. Many customers are requiring manufacturers to look into ways of replacing or eliminating the solvents used in this manner.

Five of the case studies examined in Section 3 of this report focused on solvent waste (other than solvent flush) minimization. These are listed below:

- Case Study 1: Specialty Alcohols
- Case Study 2: Organic Salt Process
- Case Study 4: Diphenol Ether Process
- Case Study 9: CAP Isomers Process
- Case Study 11: Specialty Surfactant

Waste minimization options from the five case studies were combined with information from the technical literature. Figure 5–2 presents a fishbone chart of some alternatives for reducing solvent waste. The options are neither all-inclusive nor applicable to all situations.

Discussion of Options

The first category of waste minimization options is chemistry. Any options falling into this category usually involve significant technical research before being adopted. Such areas as safety and product quality have to be investigated prior to any change.

- *Replace solvent with a less hazardous material.* This option was adopted in Case Study 11. In this study, the chlorofluorocarbon, which served as a solvent for dissolving the surfactant product, has been replaced with water.

- *Develop new chemistry that minimizes or eliminates solvent.* Waste reductions can

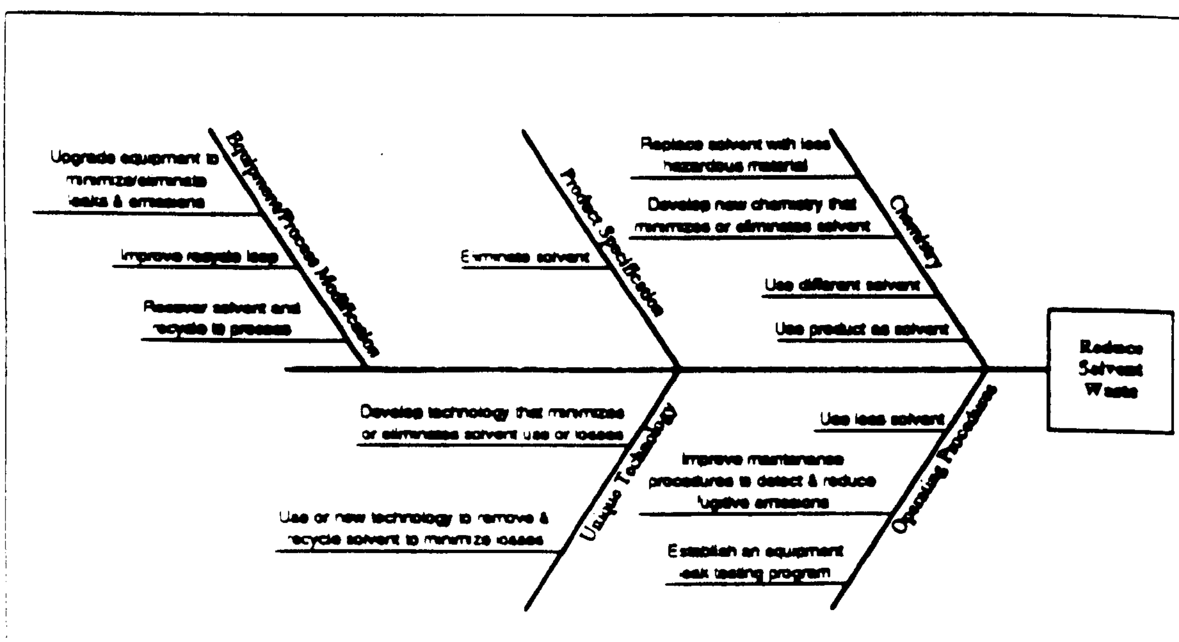

Figure 5–2. Solvent Waste Reduction Options

result from the development of new chemistry that eliminates the necessity of using solvent as a carrier for solids, or eliminates the need for a solvent wash. This type of "breakthrough" option should always be sought and considered in a waste minimization program.

- *Use different solvent*. Use of a less hazardous or non-hazardous solvent or use of a similarly hazardous solvent that would require less volume would all be waste minimizing options. A typical example would be the use of a high boiling solvent. VOC would be reduced and the company would save on solvent costs.

- *Use product as solvent*. This option is currently under investigation for Case Study 9. In that process a stabilizer used to prevent dechlorination is slurried in a solvent and then added to the distillation column reboiler. The solvent finally leaves the process as a significant portion of a tar waste stream. The waste minimization strategy is to use the product as the carrier component of the stabilizer. The product would then be removed from the product stream during the distillation. This option would eliminate the solvent.

The next three options fall under the Operating Procedures category. These options usually do not require any capital investment and can be implemented quickly.

- *Use less solvent*. Many times processes are started up and run unchallenged under a certain set of operating procedures. The procedures may have been developed in a laboratory and sized up for production scale. Investigation may reveal that lessening the amount of solvent used in the process may not affect the process or product. Such a reduction would probably result in a corresponding waste reduction. In Case Study 4 this option was explored but not adopted due to safety concerns.

- *Improve maintenance procedures to detect and reduce fugitive emissions*. Fugitive emissions (emissions from valves, gaskets, pump seals, fittings, etc., in a process) can be significant if gone undetected. Routine testing for fugitives coupled with an action plan for reduction or elimination of the emission can reduce the air emission waste stream from these sources significantly.

- *Establish leak testing program*. This option refers to equipment and piping leaks. Establishment of a routine leak detection program coupled with an action plan for reduction or elimination of the leak would result in significant waste reductions.

Options from the Product Specification category would usually not involve capital expenditures. They do require investigation to ensure that product quality is not adversely affected. This category contains one option.

- *Eliminate solvent*. Elimination of solvent, either the solvent wash or the solvent added to the product (whatever is applicable), would completely eliminate the associated wastes. Case Study 1 adopted this waste minimization option. This study featured a process that included a solvent wash for removing impurities, but continuous improvements in the as-made purity of the product eliminated the need for the solvent wash.

Options from the Unique Technology category usually involve capital investment, and require a sizable return on investment to justify the cost. This category contains two options.

- *Develop technology that minimizes or eliminates solvent use or losses*. Wastes can be minimized or eliminated with the development of new technology.

- *Use new technology to remove and recycle solvent to minimize losses*. Some new technologies to explore might include extraction, wiped-film evaporation, and membrane separation.

The final three options fall under the Equipment/Process Modification category. Options in this category typically involve significant capital expenditures. Options for implementation are chosen such that the resulting waste reductions are large enough to support the large capital expenditures.

- *Upgrade equipment to minimize or eliminate leaks and emissions*. Upgrading could require significant replacement of old equipment or merely repair of existing equipment.

  For example, steam jets for dropping pressure in distillation columns could be replaced with mechanical vacuum systems, such as liquid-ring vacuum pumps. Another example would be the repair of leaky or faulty equipment, pipes, and valves.

- *Improve recycle loop*. This option refers to processes that already employ a solvent recovery/recycling system. Improvement could include installing larger or higher tech equipment or simply making the current system more reliable or more efficient. In Case Study 2, this option was adopted. Startup solvent wastes are generated from a solvent recovery distillation column during startup before the column reaches its operating temperature and pressure. These wastes will be reduced by channeling the startup wastes to a holding tank until the column has reached its operating temperature and pressure. The startup wastes will then be reintroduced to the system after the column has attained steady-state conditions.

- *Recover solvent and recycle to process*. This option calls for waste reduction by the installation of a recovery/recycling process such as distillation, separation, filtration, crystallization. For a small operation that cannot justify the costs of installing such a process, a mobile solvent recovery process[5] may be a viable option.

Waste from Reaction Byproducts

Most processes that involve chemical reactions also involve side reactions which produce byproducts. The byproducts end up as waste downstream. The costs associated with the byproducts consist not only of the increasing disposal costs, but also the cost of raw materials and product yield. Many times, inexpensive changes can be made to decrease byproduct formation. However, when these are exhausted some more detailed, expensive changes can be implemented with high returns.

Six of the case studies in Section 3 of this report dealt with reduction of byproducts. These are listed below:

- Case Study 1: Specialty Alcohols
- Case Study 2: Organic Salt Process
- Case Study 3: Nitroaromatics
- Case Study 4: Diphenol Ether Process
- Case Study 8: Monomer Production
- Case Study 14: SAC Process

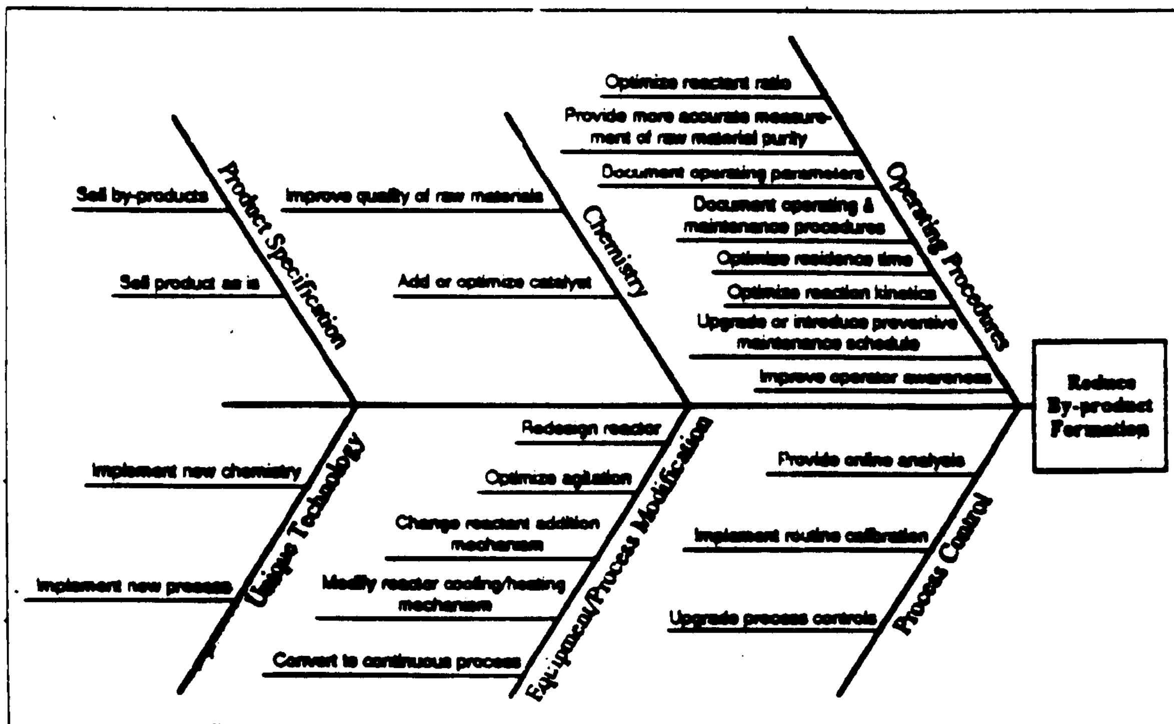

Figure 5-3. Reaction Byproducts Waste Reduction Options

Waste minimization options from the six case studies were combined with information from technical literature. Figure 5–3 presents a fishbone chart of some alternatives for reducing byproduct formation. The options are neither all-inclusive, nor applicable to all situations.

Discussion of Options

The first category of options is Operating Procedures. Any option falling under this category usually does not require any significant capital expenditure. The options can often be implemented quickly.

- *Optimize reactant ratio*. Optimization of the reactant ratio can reduce the excess constituents that may be involved in side, byproduct forming reactions. This option will also increase production yield. This technique was adopted in Case Study 2.

- *Provide more accurate measurement of raw material purity*. This can be accomplished by either providing an upgraded measurement device, or by changing the measurement technique. By knowing the accurate raw material purity, the reactants can be added in the appropriate amounts thus reducing excesses and under-additions. This in turn reduces constituents available for side reactions and byproduct formation. This option will also increase production yield. Although explored in Case Study 4, this option was not adopted because in this particular situation, byproducts constituted a very small portion of the waste stream.

- *Optimize operating parameters*. Many times, processes are operated within a range of operating conditions. Narrowing this range, or even changing the range altogether, may help to reduce the byproducts.

- *Document operating and maintenance procedures*. Documentation of good work practices, both operational and maintenance, will ensure that they are performed correctly. This could include modified or narrower operating ranges, calibration methods and cycles, and maintenance procedures.

- *Optimize residence time*. A common cause of byproduct formation is a reaction time that is either too short or too long. In such cases, increasing or decreasing reactor residence time may reduce byproducts. Among the options examined in Case Study 3 is one that would reduce feed rates to increase residence time.

- *Optimize reaction kinetics*. Optimizing reaction kinetics, (temperature and pressure) can reduce byproduct formation. This option was demonstrated in Case Study 14.

- *Upgrade or introduce preventative maintenance (PM) schedule*. Preventative maintenance can identify and correct problem areas that cause waste formation. This includes process parameter measurement and control equipment and raw material feed systems, as well as reactor functionality (agitators, baffle integrity, etc.).

- *Improve operator awareness*. Making operators aware of the need to reduce waste can, in fact, result in waste reductions. Education as to how waste can be controlled, (i.e., through better control of process parameters, good housekeeping practices, etc.) can lead to significant waste reductions.

The next three options fall under the Process Control category. These options are ones related to the measurement and control of process parameters, raw material feed rates, or reaction conversion rates. Byproduct formation, often times, can be minimized by good process control.

- *Provide online analysis*. Online analysis and control of process parameters, raw material feed rates, or reaction conversion rates can significantly reduce byproduct formation and waste. If online analysis and control is too costly, more frequent operator checks or manual sampling and control will also serve to enhance control of the process and thus reduce waste. Online analysis was examined in Case Study 3. In this situation, the reaction mass exiting the reactor was to be measured for acidity in order to control raw material feed rate. It was theorized that this control scheme would minimize reaction byproduct formation.

- *Implement routine calibration*. Routine calibration of process measurement and control equipment can minimize inaccurate parameter set-points and faulty control.

- *Upgrade process controls*. Upgrades of process parameter measurement and control equipment to ensure more accurate control within perhaps a narrower range, can help to reduce process conditions that contribute to byproduct formation. This option was selected for Case Study 8. In this case, the upgraded control system will be costly, but is expected to reduce waste generation significantly as well as increase product yield. These combined factors justify the high capital cost.

The next category of options is chemistry. Options falling into this category generally involve a certain amount of R&D work not only to come up with the change, but also to ensure safety and product quality.

- *Improve quality of raw materials*. Providing high-quality raw materials with minimum impurities can reduce waste. This option could entail working with vendors to provide higher quality materials or providing some online means of ensuring optimal raw material properties. For example, in Case Study 14, an online pH meter was installed to ensure that the pH of the incoming raw material is at an optimal level. Process adjustments are made to correspond to any deviations.

- *Add or optimize catalyst*. The addition of a catalyst, or optimization of the amount or type of catalyst, may minimize side reactions and improve reaction conversion. Changes in the chemical makeup of a catalyst, the method by which it is prepared, or its physical characteristics (size, shape, porosity, etc.) can substantially improve catalyst life and effectiveness.[6]

The following four options fall under the Equipment category. Options under this category usually involve significant capital expenditures. Options for implementation are usually chosen so that the resulting waste reductions are large enough to support the large capital expenditures.

- *Redesign reactor*. Reactor design plays an important role in whether or not byproduct formation is a problem. Reactors should be designed so that "dead spots" are avoided, there is good heat transfer to the reaction mass, and there is adequate residence time. Reactor size and shape, agitation device, baffles, a plug-flow versus continuous stirred reactor, etc., all have an effect on the efficiency of the reaction and, thereby, the formation of byproducts. This option was considered in Case Study 3 but was deemed to be too costly.

- *Optimize agitation.* Increasing agitation or changing agitation mechanisms many times results in better contact of the reactants, resulting in a more efficient reaction with less byproduct formation. Such modifications to the reactor as adding or improving baffles, installing a higher-r.p.m. motor on the agitator(s), or using a different mixer blade or multiple impellers can improve mixing. Some examples of various mixing mechanisms include impellers, jet mixers, and mixing pipe tees, as well as the utilization of the impeller of a pump to mix. Improvement of reactor agitation was chosen as a top option in Case Study 3.
- *Change reactant addition mechanism.* Improving the way in which reactants are added in a reaction process is another way in which byproduct formation can be inhibited. This usually means adding the reactant or reactants in a way that promotes better contact of all the reaction components. Traditional feed methods can be replaced with spargers or other distribution systems. Adding a compound to a pump impeller containing the other reaction compounds or adding a reactant into a pipe mixing tee should also be considered to promote better distribution.
- *Modify reactor cooling/heating mechanism.* Modification of the mechanism for cooling or heating a reactor can also limit byproduct formation and increase product yield. Avoidance of hot or cold spots in the reactor should be considered in making the choice of mechanisms. Heat-up and/or cool down times should also be considered.
- *Convert to continuous process.* The startups and shutdowns associated with batch processes are a common source of wastes and byproduct formation. Converting a process from batch to continuous mode would reduce these wastes. This option may require modifications to piping and equipment.

Options in the Product Specification category do not require capital expenditure, although development and marketing efforts are usually necessary. Both of the following options appear in several of the case studies in Section 3.

- *Sell byproducts.* It's worth considering whether a market can be identified for a byproduct.
- *Sell product as is.* Loosening product specifications, if accepted by the customer, could allow the product to be sold without the prior removal of byproducts thus eliminating the associated waste. Sometimes, however, this could simply move the waste problem from one area to another. The entire process and product loop requires examination prior to adoption of this option.

Waste minimization alternatives in the Unique Technology category are long-term projects that require capital investment. The savings associated with the resulting waste reduction would, of course, have to be large enough to justify the capital cost.

- *Implement new chemistry.* An existing process may involve chemistry that can be significantly upgraded or changed due to newer findings and technology. The new chemistry could result in significant waste reductions and should be considered.
- *Implement new process.* An existing process that was installed before waste minimization was considered could be replaced with a newer, environmentally friendly process. One such example is the use of ultrasound techniques that enable a reaction to proceed at lower temperatures, thus reducing tar and/or byproduct formation. Another example is a laser system that enables reactions to proceed at lower temperatures because selection of the proper frequency enables activation of the specific chemical bond of interest[7].

Tar Waste

Many distillation processes build up tar waste in the column bottoms. The distillation process is used to purify components in a crude product stream which was produced in an upstream reaction process. Typical analyses of tar streams vary drastically from process to process. A starting point for investigating waste minimization options should be determining the major components and causes of the tar waste stream. There are three major contributions to tar:

1. If byproducts or impurities are present in the crude product stream from the upstream reaction process, they may significantly contribute to the tar waste load.
2. Another major component of the tar may be thermally decomposed or polymerized product or raw material. The thermal decomposition or polymerization may have occurred in the distillation column's reboiler because of high-temperatures.
3. Additives such as stabilizers and inhibitors that have been added to the distillation process or to the upstream process may also significantly contribute to the waste load.

After the composition of the waste stream has been determined, the direction of the option generation session is more clearly defined. The previous section, "Reduce Byproduct Formation" deals with all the options related to byproduct and impurity reduction. The options presented below focus mainly on reduction of tars formed as a result of thermal decomposition and polymerization as well as reduction of additives.

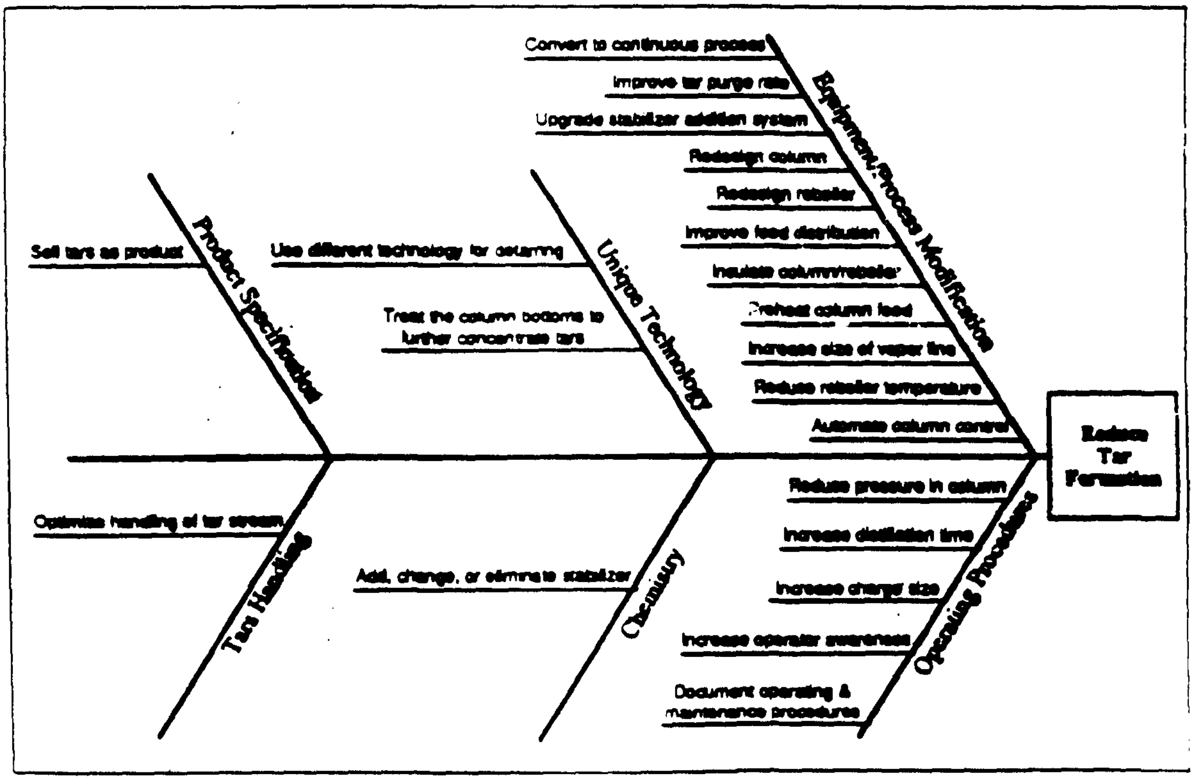

Figure 5-4. Tar Waste Reduction Options

Six of the case studies in Section 3 of this report dealt with reduction of tars. These are listed below:

- Case Study 3: Nitroaromatics
- Case Study 5: CAP Purification
- Case Study 8: Monomer Production
- Case Study 9: CAP Isomers Process
- Case Study 10: Wiped-Film Evaporator
- Case Study 14: SAC Process

Waste minimization options from the six case studies mentioned above were combined with information from the technical literature to come up with the waste minimization alternatives shown in Figure 5–4. The options are neither all-inclusive nor applicable to all situations.

Discussion of Options

The first category of options is Equipment/Process Modification. Options under this category usually involve significant capital expenditures. Options for implementation are usually chosen because the resulting waste reductions are large enough to support the large capital investment.

- *Convert to continuous process*. The startups and shutdowns associated with batch processes are a common source of wastes and byproduct formation. Converting a process from batch to continuous mode would reduce these wastes. This option may require modifications to piping and equipment.

- *Improve tar purge rate*. Continuous distillation processes require a means of removing tar waste from column bottoms. Optimizing the rate at which tars are purged may reduce waste. An automatic purge that controls at the lowest possible purge rate is probably best. If an automatic purge is not possible, then there are other ways to improve a manually controlled or batch-operated tar purge. If a batch purge is used, more frequent purges of smaller quantities may reduce overall waste.

  Some processes that purge continuously may purge at excessively high rates to prevent valve-plugging. More frequent cleaning, or installing a new purge system (perhaps with anti-stick interior surfaces) would permit lower purge rates. This option was chosen as one of the top alternatives in Case Study 3. The nitroaromatics process has difficulty maintaining low purge rates because at low flows, the valve and flow-meter become plugged with tar. To avoid plugging, the process runs at higher flow rates. Area personnel are now exploring a new flow-meter and valve that would be sensitive enough to permit lower flow rates without plugging.

- *Upgrade stabilizer addition*. Many distillation processes use stabilizers which reduce the formation of tars as well as minimize unfavorable side reactions. The stabilizers not only wind up as large components of the tar waste stream but also typically make the waste stream more viscous. The more viscous the waste stream, the more saleable product the waste stream carries with it. Upgrade of the stabilizer addition system would allow for less stabilizer to be added in the process. Upgrades may include continuous versus batch addition of stabilizer (adopted in Case Study 9) or continuous or more frequent analysis of the presence of the stabilizer coupled with automatic addition or enhanced manual addition of the stabilizer.

  Optimization of the point of addition, column versus reboiler, is another area to be explored along with method of addition. One inventive option generated at the Case Study 5 brainstorming session was to put the stabilizer in a packed column, separate from the process distillation column. Process material would then be circulated through the packed column containing the stabilizer.

Stabilizer typically consists of a solid material slurried in a solvent used as a carrier. Options for waste reduction also focus on selective reduction of one of the two components. Addition of the stabilizer in powder form eliminates the solvent. Use of product as the carrier component was selected as one of the best options in Case Study 9.

- *Redesign column.* Many of the case studies evaluated this option in some fashion. A better design may include changes in size or packing. The focus is on making the column more efficient for the particular process.
- *Redesign reboiler.* Depending on the process, a better design may include use of a different heat source in the reboiler to limit thermal degradation of materials, a better agitation system to allow more efficient use of the stabilizer, or a different reboiler design altogether (i.e., smaller, larger, different shape). Case Study 5 looked at two options focusing on redesign of the reboiler: 1) installation of spargers in the still to circulate the stabilizer, and 2) installation of an external heat source to replace the current heating coils.
- *Improve feed distribution.* The effectiveness of feed distributors (particularly in packed columns) needs to be analyzed to be sure that distribution anomalies are not lowering overall column efficiency.[6]
- *Insulate column and/or reboiler.* Good insulation is necessary to prevent heat losses. Poor insulation requires higher reboiler temperatures and also allows column conditions to fluctuate with weather conditions[6].
- *Preheat column feed.* Preheating the feed should improve column efficiency. Supplying heat in the feed requires lower temperatures than supplying the same heat to the reboiler, and it reduces reboiler load. Often, the feed is preheated by cross-exchange with other process streams[6].
- *Increase size of vapor line.* In low pressure or vacuum columns, pressure drop is especially critical; installing a large vapor line reduces pressure drop and decreases the reboiler temperature[6].
- *Reduce reboiler temperature.* Several techniques could be used to reduce reboiler temperature such as de-superheating steam, using lower pressure steam, and using an intermediate heat transfer fluid.
- *Automate Column Control.* For a given distillation process, there is one set of operating conditions that is "optimum" at any given time. Automated control systems are capable of responding to process fluctuations and product changes swiftly and smoothly, minimizing waste production.

The next category of options is Operating Procedures. Typically the options in this category can be done in a relatively short amount of time for little or no capital cost.

- *Reduce pressure in column.* Reduction of the pressure in a column allows the distillation to be run at a lower temperature. This option was evaluated in Case Study 3.

- *Increase distillation time*. This option would be considered for a batch process where extending the distillation time would allow more product to be extracted from the tar waste. This option was explored in Case Study 8. It was not chosen because the more concentrated tars at the bottom of the reactor would become too thick to remove easily. A way of easily removing the thick tars would have to be implemented along with this option.

- *Increase charge size or campaign size*. Tar waste streams usually carry with them a certain amount of product. Increase in charge size (batch size) could possibly reduce the tar waste stream if the tars are removed from the still bottom after every charge. Also, in the case of a campaign where the tars are removed at the end of a campaign, increasing the charges per campaign can lessen the number of tar clean-outs per year thus resulting in less tar waste. This option was explored in Case Study 5.

- *Increase operator awareness*. Making operators aware of the need to reduce waste can, in fact, result in waste reductions. Education on how waste can be controlled can lead to significant waste reductions.

- *Document operating and maintenance procedures*[5]. Documentation of good operating practices, both operational and maintenance, will ensure that they are performed correctly. This could include modified or narrower operating ranges, calibration methods and cycles, and maintenance procedures.

The next two options fall under Unique Technology. Options in this category usually involve a significant amount of capital investment and R&D effort. Most of the case studies examined in this report looked at some sort of new technology for minimizing the waste.

- *Use different technology for detarring*. Some other means of purification of a crude product stream may reduce the tar formation. The types of technology may include crystallization, membrane separation, extraction, filtration, or the use of a wiped-film evaporator.

- *Treat the column bottoms to further concentrate tars*. Treating the tar stream from the bottom of a distillation for further removal of product may be a viable option. In Case Study 10, a wiped-film evaporator will be installed to further concentrate the tar waste stream. Other methods should also be investigated such as extraction and crystallization.

One option falls under the Chemistry category. Options in this category require significant R&D research by chemists and engineers to ensure adequate product quality as well as process safety.

- *Add, change, or eliminate stabilizer*. This option focuses on increasing or optimizing the addition of stabilizer. This could also mean using a different stabilizer that requires smaller quantities to provide the same stabilizing effect. Since the stabilizer represents such a large portion of the waste stream, emphasis in this area should be given. Case Studies 3, 9, and 5 focused on this area.

Any options falling under the Product Specification category would usually not involve capital expenditures. Investigation, perhaps including R&D efforts, would probably have to take place before any product spec changes could be incorporated so that finished product quality would not be adversely affected.

- *Sell tars as product.* Selling tars to be made into a useful product is a way of eliminating the stream as a waste. This option may be difficult to implement, especially if the tars contain a hazardous component.

The Tars Handling category contains one option.

- *Optimize handling of tar waste stream.* In several of the processes used in the case studies, the tars from the bottoms of the distillation column had to be thinned with a solvent to make them pumpable. Often times this solvent is product from the process. The added solvent adds to the volume of the waste stream. In Case Study 14, tars were pumped from the process equipment into a tank truck for transportation to the on-site incinerator. In the past, trucks were dispatched to the incinerator only when full. During the several days it took to fill the truck, the tar waste solidified which would make it difficult to handle at the incinerator. Hot product was therefore added just prior to the discharge of the truck to thin the waste. To rectify this situation. the area is now discharging the trucks on a daily basis. The material in the trucks stays warm enough to enable adequate handling at the incinerator.

In Case Study 9, low boiler product was added to a tar waste collection tank as a solvent to thin the tars. Two options were explored to minimize the need for addition of this solvent: 1) Use of an already existing waste stream from another process to thin the tars. 2) The addition of acid to the tar waste stream to make it water soluble. The stream could then be mixed with water and disposed of at the wastewater treatment plant.

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