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CASE STUDY

Environmental
Engineering

Degreaser Replacement at Ford Motor Company's Climate Control Division

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BACKGROUND

Ford Motor Company's Climate Control Division (CCD) recently completed a demonstration project with the Quality Environmental Management (QEM) Subcommittee of the President's Commission on Environmental Quality (PCEQ). The project demonstrated how pollution prevention and Total Quality Management (TQM) work together to reduce the environmental impact of a process, while at the same time providing a product that meets customers' needs. The pilot project undertaken by the CCD tested the replacement of Trichloroethylene (TCE) degreasers with aqueous degreaser units.

The CCD uses degreasers to remove oils and other contamination from aluminum heat exchangers found in radiators and heater cores. Heat exchangers are manufactured from stamped aluminum. In the stamping and assembly processes, oils are used to get the desired shape and fit. These processes deposit aluminum and dirt particles along with a surface oil residue. During assembly, heat exchangers are brazed to form an aluminum film which joins the different components of the part. To be brazed properly, the part must be as free of contamination as possible. Therefore, some sort of degreasing operation is required to decontaminate the part. Previously, TCE vapors were used to remove the oils and other contaminants from the part. **Figure 1** shows TCE vapor degreasing units previously used by CCD.

This degreasing process had many inherent problems. To begin with, TCE is a hazardous substance whose emissions are closely regulated. The TCE degreasers required close supervision

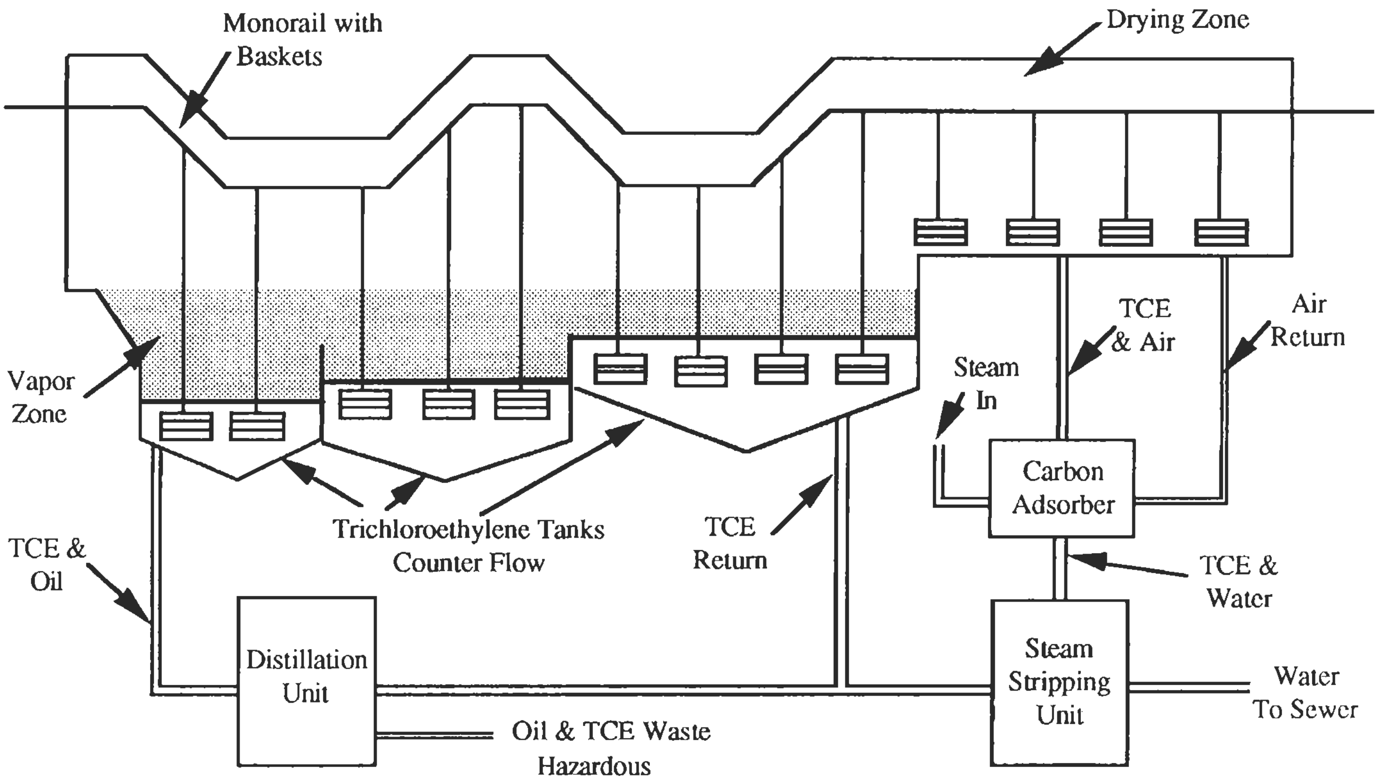

Figure 1. TCE Vapor Degreaser Unit

from a team of skilled operators. Additionally, the escape of TCE vapors from a degreaser almost always required a costly evacuation of the production facility and could potentially shut down operations for a number of hours. Finally, there were questions about TCE's effectiveness in removing contamination from the surface of the parts.

AQUEOUS DEGREASING SELECTION PROCESS

The CCD Advanced Engineering (AE) Staff designs and tests new processes and technologies that could improve existing operations, and it also develops manufacturing techniques for new products. AE is guided by a steering committee of representatives from its customer base, which includes CCD facilities worldwide, product engineering staff, manufacturing engineering staff, and division management. The steering committee sets the goals, priorities, and resource commitments for all AE Staff projects.

In early 1990 the AE Staff, along with the steering committee, realized that worker health and safety could be improved by replacing TCE degreasers with a less hazardous process. Such a substitution could also reduce environmental costs. As Ford corporate staff identified the sources of solvent releases in the U.S., the AE Staff realized that CCD's TCE degreasers accounted for a substantial portion of the entire company's chlorinated solvent emissions.

Investigation of a new brazing technique contributed to the replacement of TCE degreasers. In the new process, the surface of the heat exchangers degreased with TCE required additional preparations. Despite this, the new technique was attractive because it offered CCD a better, simpler braze compared to the current process, especially if an improved degreasing operation could eliminate much of the additional preparations. Finally, CCD anticipated that a new degreasing process would reduce production costs.

At the time of the initial decision to explore alternate degreasing techniques, the AE Staff integrated quality techniques into their project evaluation process through a process evaluation flow chart. They later realized they were also working on a pollution prevention project, aimed at lowering the toxicity of the degreasing process.

CCD's AE Staff committed an engineer to the project to decide which technology should be tested as a potential replacement for the TCE degreasers. As a starting point, CCD's degreasing operation was benchmarked against similar operations. Benchmarking researches techniques currently used by other companies involved in similar operations and establishes a scale for comparing and contrasting alternatives in order to identify areas of improvement. One can thus compare one's own process to others as well as learn what other experimenters have determined to be feasible processes. Benchmarking also offers the opportunity to avoid costly mistakes that others may have already committed. As can often be the case, the technique was limited by the fact that CCD competes for business against outside suppliers. As a result, it was often difficult to get detailed information about how competitors were undertaking a particular operation.

Even so, benchmarking helped identify a number of technologies that merited further investigation. For those technologies, prospective equipment and chemical suppliers were asked to submit further information about their products. Bench testing of available chemicals was also performed to ensure compatibility with the aluminum. Along with benchmarking, this initial testing led the engineer and the steering committee to choose aqueous degreasing for pilot testing.

Once aqueous degreasing was selected, the engineer had to select what type of cleaning process should be used. Three choices were available:

1. Immersion cleaning
2. Ultrasonic cleaning
3. High pressure spray cleaning

Immersion cleaning and ultrasonic cleaning were eliminated from the potential list because they were either incompatible with the heat exchangers or they were not yet a reliable technology.

High-pressure spray represented the best aqueous technology because most of its effectiveness derives from mechanical rather than chemical action.

Because pilot testing requires a production setting, CCD selected its Sheldon Road plant in Plymouth, Michigan to be the test site. This plant is within twenty miles of most of the company's research and engineering resources. Plant personnel would be involved with the equipment at their site, so they were asked to participate in the evaluation process. At this point, a Quality Action Team (QAT) was formed to facilitate the flow of information between individuals working on the project, including the Advanced Engineering Staff, the division representatives, the plant representatives, and the suppliers.

To ensure that the plant would not suffer financial detriment by hosting the pilot study, funds were allocated to cover any maintenance expenses and to pay the Sheldon Road employees to act as loaders and unloaders on the test apparatus. Because plants are held financially accountable for their operations, they are usually unwilling to take risks which may hurt profitability. But when division or corporate management is willing to bear the risk, company operations are more willing to try something new. Corporate assumption of financial risk has been used throughout Ford as a means to initiate a number of pollution prevention programs.

After selecting the high-pressure spray aqueous degreaser, a small-scale trial was conducted at an equipment supplier's facility. This trial validated the compatibility of the technology and also offered an opportunity to test some of the available cleaners in a "production type" system.

AE then conducted its own trials using a bench scale washer to replicate the production process. By setting up a bench-scale washer, CCD was able to avoid many of the expenses that could arise if a mistake occurred during production. The first advantage to working in bench scale is that the technology can be evaluated with a minimum investment. Should the technology prove inadequate, it can be abandoned at this point without a major loss. The second advantage of using bench-scale testing is that a wide variety of substances can be tested without incurring large costs, especially from wasted samples. What often happens is that a drum of material is purchased and a sample from it is tested. If the material is unsatisfactory, it must either be returned to the supplier (if they will accept it) or properly disposed, which is often rather expensive. But when bench-scale testing is performed, a five gallon pail of the material will normally be sufficient, and such small a quantities are often provided gratis by sales representatives. Testing then consumes all the material or leaves such a small volume of unused product that proper disposal is not difficult.

The aqueous degreasing program also requires a cleaner, so approximately a dozen different chemicals were evaluated for this purpose. The cleaners were divided into groups based on their pH. The three groups were:

- Strong alkaline cleaners ($pH > 13$)
- Moderate/mild alkaline cleaners ($7 < pH < 13$)
- Acidic cleaners ($pH < 7$)

Due to the incompatible, aggressive nature of the strong alkaline and acidic cleaners, both groups were eliminated from future consideration. Of the moderate/mild alkaline candidates, testing showed that the moderate alkaline cleaners provided the best part quality. The cleaners' performance was measured using five main parameters.

1. Oxide layer thickness — An oxide layer inhibits the brazing process; therefore cleaners which promoted oxide growth were eliminated.
2. Residual carbon contamination — This offers a measure of the amount of oil removed from the part. All cleaners tested exceeded the level of cleanliness that the vapor degreaser provides.
3. Aluminum surface attack — Etching removes a portion of the aluminum cladding, which can adversely affect brazing; therefore this property was kept to a minimum.
4. Surface wetability — Surface wetability offers a measure of how well water-based brazing materials will work. All attempts were made to maximize this parameter.
5. Oil rejection and treatability — All cleaners were evaluated to ensure that they formed unstable emulsions with the oil so that the oil could be recovered. Additionally, to make the aqueous system as simple as possible, the cleaners had to be dischargeable to the sewer system without further treatment.

After these five properties were used to decrease the number of cleaners, low volume production trials were performed to rank the remaining cleaners. With the ranking established, large volume trials were conducted until a suitable cleaner was found. These production trials demonstrated that the effectiveness of the cleaners is influenced by temperature, concentration, and time of contact.

Upon completion of the low-volume production trials, a pilot system was purchased. The pilot process was a scaled-down version of the production system. The degreasing unit featured three-stage processing, with individual stages for a pre-wash, a detergent wash, and an overflowing rinse. The equipment included blowers to minimize drag-out and cross contamination between stages. Attached to the prewash was an oil decant system capable of recovering more than 99% of the free oil without the use of chemicals. Finally, the system contained a drying unit to remove all moisture from the part. The pilot unit was capable of washing 100 radiators per hour, a fraction of the production level. The unit was installed at Sheldon Road in January of 1992, two years after the start of the project. As testing progressed, evaluation of cleaners continued. Some of the cleaners which performed well in small trials were unable to withstand production conditions and had to be eliminated. **Figure 2** is a schematic of the pilot system.

System characteristics of the pilot unit were monitored and recorded. These data were used to determine operating costs, chemical usage, control requirements, waste treatment issues, utility usage, and best operating practices. The data allowed AE to tell its facilities what was involved with the new process and predict the costs of operating a production unit. These data also confirmed that the basic goals of pollution prevention were achieved.

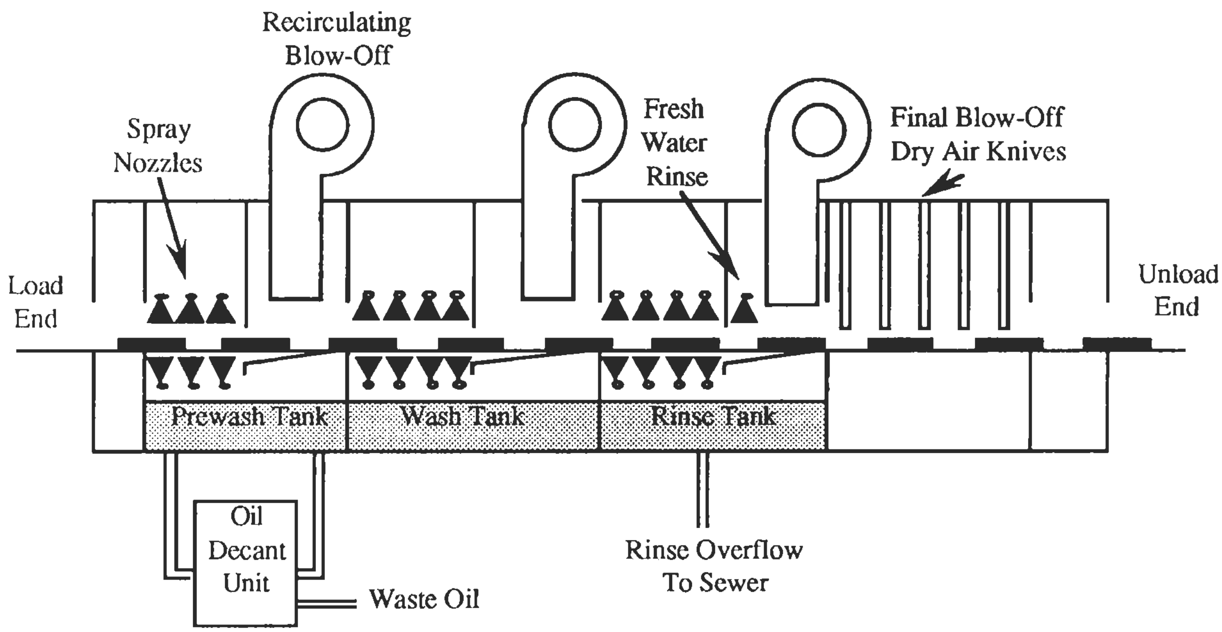

Figure 2. Pilot Aqueous Degreaser System

The pilot testing, completed in July 1992, demonstrated the success of aqueous degreasing. The aqueous system proved that it provided more cleaning at a lower cost than the TCE vapor degreasing system. By changing the process, a hazardous substance was removed from the plant, improving both health and safety as well as the plant's environmental impact. Plus, it was possible to recover the used oil for reclamation. Finally, the pilot work showed that aqueous degreasing is an easily controlled process.

The equipment used in the pilot process was returned to the manufacturer for retrofitting. After this, the machine entered full production at CCD's Connersville, Indiana plant. Monitoring will continue to provide long-term data on the process. Improvements will also be tested, including an examination of ultrafiltration to enhance emulsified oil recovery and decrease cleaner usage.

The President's Commission on Environmental Quality

Ford Motor Company joined the President's Commission on Environmental Quality in 1991 and was active on the Quality Environmental Management (QEM) subcommittee. The subcommittee was charged with developing procedures that companies can use to implement QEM. In order to carefully develop the procedures, twelve projects from eleven companies were solicited to act as demonstration projects. The leaders of these projects were required to describe their quality process and how they measured results. They were also asked to identify barriers and incentives to

QEM and pollution prevention. Ford selected the aqueous degreaser project when asked to provide a demonstration project.

The PCEQ had previously developed a theoretical flow chart outlining the procedures a company should use to undertake pollution prevention projects. The PCEQ flow chart, shown in **Figure 3**, closely resembles a standard Total Quality Management (TQM) flow chart. Because Ford had been using quality principles for a number of years, the process evaluation flow chart used by CCD AE also closely resembled the PCEQ flow chart.

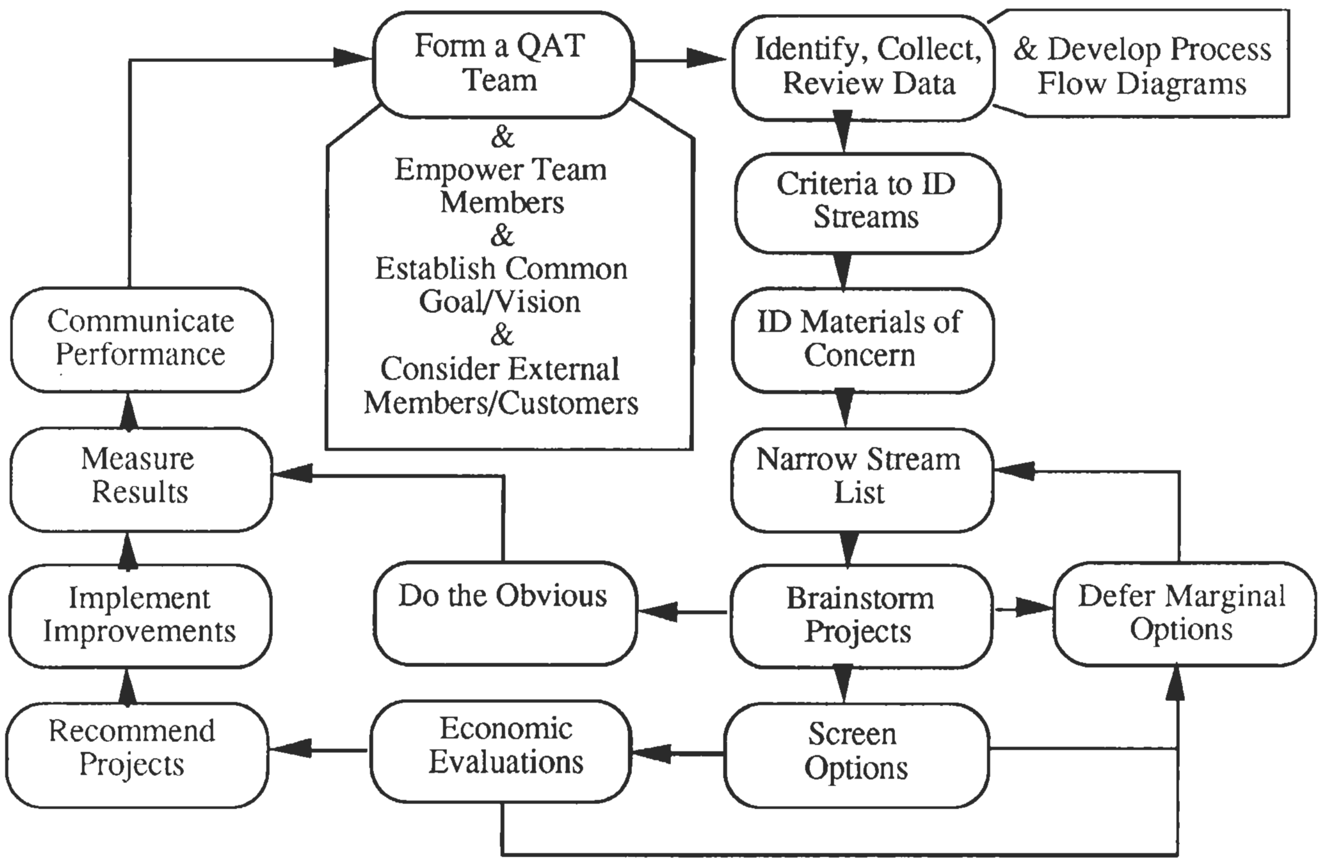

Figure 3. PCEQ Flow Chart

The PCEQ demonstration project began in the middle of the aqueous degreaser pilot project. Therefore much of the information gathered for the PCEQ was generated under normal conditions and not affected by the attention the PCEQ brought to the project. Because the PCEQ project at Ford was guided by the Chairman and Chief Executive Officer, Harold Polling, and the

Vice President for Environmental and Safety Engineering, Helen Petrauskas, resources that normally would not be available were dedicated to this project.

Forming cross-functional teams is the first step in any TQM endeavor. These teams are referred to by the PCEQ as Quality Action Teams (QAT). A QAT is supposed to use all the knowledge and resources available to team members. Ideally, this pooled insight helps the team avoid many of the pitfalls that can occur in projects relying on a narrow range of expertise. QAT members should include all stakeholders in a project, whether they are customers, engineers, product designers, vendors, or others.

Advanced Engineering normally forms QATs with representatives from vendors, the plants, the division, and other necessary resources such as the Research Laboratory. Due to the sensitive and technical nature of process modifications, public representatives usually do not participate in the decision-making process. But because of the attention brought to this project by the PCEQ, community members were invited to join the team. The State of Michigan Office of Waste Reduction Services and the Southeastern Michigan Council of Governments both provided representatives. The QAT was very pleased to have these representatives, who provided a community perspective and valuable technical assistance. By viewing the community as a customer, Ford has shown there is a great potential for mutual benefit in such projects.

The high-profile nature of this project undoubtedly energized the QAT. The enthusiasm of Helen Petrauskas especially encouraged others, reinforcing the belief that a project has a greater chance of success with the support of management. Experience seems to indicate that top management support is also critical to the success of pollution prevention projects.

Ultimately, Ford's experience with the aqueous degreaser project was combined with the eleven other projects to provide a blueprint for other companies to follow. One of the most important findings is that pollution prevention and TQM are complementary activities. A second finding is that a financial incentive such as pollution credits would hasten the pace of pollution prevention projects.

In January 1993, the PCEQ issued a report, entitled *Total Quality Management: A Framework for Pollution Prevention.* Using the experiences of Ford and the eleven other participating facilities, the report provides a guide for companies interested in developing their own pollution prevention programs using TQM. Included in **Appendix A** of this report is the PCEQ Executive Summary, which highlights the twelve projects and some of the key findings.

Key findings of the PCEQ were:

- TQM and pollution prevention are complementary concepts
- Pollution prevention can be achieved without large capital investments
- There is no universal method to measure progress in pollution prevention
- Systematic and rigorous analyses are the basis for any pollution prevention project, but flexibility is required in application
- Understanding the potential incentives and barriers to a pollution prevention project can add to the success of the project (PCEQ, pp. ix-x)
- "Management commitment is crucial to the success of a QEM system" (PCEQ, p. 16)

A successful pollution prevention program using TQM can achieve many benefits. The following positive results were illustrated by the twelve PCEQ projects:

- Potential cost savings
- Advances in technological innovation
- Increased public acceptance of the facility
- Improved relationships with regulators
- Increased recognition for individuals and teams
- Safer working conditions

However, before any pollution prevention project is undertaken, one should be aware of the following barriers to using pollution prevention with TQM:

- Resources for any project are limited
- Many may prefer business as usual
- Management and employees may be unaware of the benefits of pollution prevention
- Accounting systems do not measure environmental costs or values, so the true gains of any project may not be known
- Fear of compromising product quality or production efficiency
- Technological limitation (PCEQ, pp. 8-11)

The PCEQ project has identified a number of TQM tools and techniques that helped make the twelve projects successful. These tools and techniques, currently used in most TQM programs, include:

- Cause and Effect (or Fishbone) Diagrams
- Control Charts
- Histograms
- Pareto Charts
- Flow Charts

A complete description of the different tools and techniques as well as how to implement each are included in **Appendix B**.

REFERENCE

President's Commission on Environmental Quality (PCEQ), Quality Environmental Management Subcommittee. *Total Quality Management: A Framework for Pollution Prevention.* Washington, DC: Executive Office of the President,1993.

Discussion Questions

BUSINESS

- What costs should be attributed to an existing/proposed process and how should they be accounted for?

Direct	Indirect
- Environmental audits	- Liability
- Chemical/raw material costs	- Episodic events (i.e., plant shutdowns)
- Operating supplies	- Health and safety
- Waste	- Community image
- Utilities	- Changes in quality
- Labor	- Changes in costs of processes down the line
- Cleaning and maintenance	attributed to the process being evaluated

- At what point does a project which has many positive benefits but only marginal cost savings become good for the bottom line?
- What value does increased quality have when it does not increase the value to the customer?

NATURAL RESOURCES POLICY/POLITICAL SCIENCE

- Why should companies undertake pollution prevention activities if they only yield marginal to negative cost savings?
- What value does a cleaner environment have to a company?
- Who are the customers and stakeholders to a pollution prevention project?
- What can be done to encourage pollution prevention?
- Which is better: producing a few pounds of a hazardous waste or thousands of pounds of inert waste? (e.g., a few pounds of TCE per part vs. many pounds of water per part?)

ENGINEERING

- How clean is clean in terms of part cleanliness?
- How should cost projections be made?
- How valid are the results from a pilot study?
- How would you make an aqueous washer a closed system?
- Who should be included on a cross-functional team?
- Whose job is pollution prevention? The environmental engineer's? The production engineer's? Middle management's?

Ford Case Study Problem Set With Answers

1. How many parts can be processed in a year with the pilot unit if it averages 75 parts per hour? Assume production 50 weeks a year, 5 days a week and 24 hours a day.

Parts processed per year

$$= \frac{parts}{time\ period} \times time\ period$$

$$= \frac{75\ parts}{hour} \times \frac{24\ hours}{day} \times \frac{5\ days}{week} \times \frac{50\ weeks}{year}$$

$$= \mathbf{450{,}000\ parts\ per\ year}$$

Pilot Unit

2a. Calculate the total volume of water used by the pilot unit in one year. The tanks sizes are:

Pre-wash tank	650 gal.
Wash	500 gal.
Rinse	500 gal.

The tanks have to be drained and cleaned once a week. The rinse tank overflows at 7.5 gpm. Assume no evaporative loses.

Total Volume = *Volume of tank fills + volume of overflow*

$$= 82{,}500\ gal. + 2{,}700{,}000\ gal.$$

$$= \mathbf{2{,}782{,}500\ gal.}$$

Volume of tank fills

$$= \frac{number\ of\ fills}{year} \times Volume\ of\ tanks$$

$$= \frac{50\ times}{year} \times (650\ gal. + 500\ gal. + 500\ gal.)$$

$$= \mathbf{82{,}500\ gal.}$$

Volume of overflow = *overflow flow rate X time*

$$= \frac{7.5\ gal.}{min} \times \frac{60\ min}{hour} \times \frac{24\ hour}{day} \times \frac{5\ days}{week} \times 50\ weeks$$

$$= \mathbf{2{,}700{,}000\ gal.}$$

2b. Using the results from Question 1, calculate the volume of water used per part cleaned and the cost for cleaning each part. Assume that the cost for water including sewage is $2.25 per 1,000 gallons.

Volume of water,part)

$$= \frac{volume\ of\ water}{number\ of\ parts}$$

$$= \frac{2782500\ gal.}{450000\ parts}$$

$$= \frac{\mathbf{6.18\ gallons}}{\mathbf{part}}$$

Total water costs = *Total volume of water X Water rate*

$$= 2{,}782{,}500\ gal. \times \frac{\$2.25}{1000\ gal.}$$

$$= \mathbf{\$6260.63}$$

$$\frac{Cost\ of\ water}{part} = \frac{Volume\ of\ water}{part} \times Water\ rate$$

$$= \frac{6.18\ gal.}{part} \times \frac{\$2.25}{1000\ gal.}$$

$$= \frac{\mathbf{\$0.014}}{\mathbf{part}}$$

3. A detergent from Clean Brite is used in the wash tank at a initial concentration of 4% by volume. The detergent costs $20.00 per gallon. How much soap is required for each filling of the wash tank and at what cost? How much soap will be used in a year and at what cost? What will be the cost for the soap per part?

$$\frac{\text{Volume of soap}}{\text{filling}} = \text{Concentration soap X Volume of wash tank}$$

$$= 4\% \text{ X } 500 \text{ gal.}$$

$$= \frac{\mathbf{20\ gal.}}{\mathbf{filling}}$$

$$\frac{\text{Cost of soap}}{\text{filling}} = \frac{\text{Volume of soap}}{\text{filling}} \text{ X } \frac{\text{Cost of soap}}{\text{gallon}}$$

$$= \frac{20 \text{ gal.}}{\text{filling}} \text{ X } \frac{\$20.00}{\text{gallon}}$$

$$= \frac{\mathbf{\$400}}{\mathbf{filling}}$$

$$\frac{\text{Volume of soap}}{\text{year}} = \frac{\text{number of fillings}}{\text{year}} \text{ X } \frac{\text{volume of soap}}{\text{filling}}$$

$$= \frac{50 \text{ fillings}}{\text{year}} \text{ X } \frac{20 \text{ gal.}}{\text{filling}}$$

$$= \frac{\mathbf{1000\ gal.}}{\mathbf{year}}$$

$$\frac{\text{Cost of soap}}{\text{year}} = \frac{\text{Volume of soap}}{\text{year}} \text{ X } \frac{\text{Cost of soap}}{\text{gallon}}$$

$$= \frac{1000 \text{ gal.}}{\text{year}} \text{ X } \frac{\$20.00}{\text{gallon}}$$

$$= \frac{\mathbf{\$20000}}{\mathbf{year}}$$

$$\frac{\text{Cost of soap}}{\text{part}} = \frac{\text{cost of soap}}{\text{year}} \div \frac{\text{number of parts}}{\text{year}}$$

$$= \frac{\$20000}{\text{year}} \text{ X } \frac{\text{year}}{450000 \text{ parts}}$$

$$= \frac{\mathbf{\$0.044}}{\mathbf{year}}$$

4. What is the annual cost for water and chemicals when using the Clean Brite system? What is the cost per part?

$$\frac{\text{Total cost}}{\text{year}} = \frac{\text{total cost of water}}{\text{year}} + \frac{\text{total cost of chemicals}}{\text{year}}$$

$$= \frac{\$6260.63}{\text{year}} + \frac{\$20000}{\text{year}}$$

$$= \frac{\mathbf{\$26260.63}}{\mathbf{year}}$$

$$\frac{\text{Total cost}}{\text{part}} = \frac{\text{cost of water}}{\text{part}} + \frac{\text{cost of chemicals}}{\text{part}}$$

$$= \frac{\$0.014}{\text{part}} + \frac{\$0.044}{\text{part}}$$

$$= \frac{\mathbf{\$0.058}}{\mathbf{part}}$$

5. Squeaky Cleaners has heard about your project and they believe that they have a better detergent. Their detergent requires only four tank fills a year. The concentration of the detergent needs to be maintained at 2.00% by volume. Previous experience has shown that 250 parts can be washed with each gallon of this cleaner. The cleaner costs $7.00 per gallon. Compare the costs for the Squeaky Cleaner in terms of water, soap and total cost per part to the values calculated in Questions 3 and 4. Additionally, evaluate which cleaner would fulfill the goals of pollution prevention in terms of minimizing the amount of materials.

Volume of tank fills

$$= \frac{\text{number of fills}}{\text{year}} \times \text{volume of tanks}$$
$$= \frac{4\ \text{times}}{\text{year}} \times (650 + 500 + 500\ \text{gal.})$$
$$= \frac{\mathbf{6600\ gal.}}{\mathbf{year}}$$

Annual volume of overflow

$$= \text{flow rate of overflow} \times \text{year}$$
$$= \frac{7.5\ \text{gal.}}{\text{min}} \times \frac{60\ \text{min}}{\text{hr}} \times \frac{24\ \text{hrs}}{\text{day}} \times \frac{5\ \text{days}}{\text{week}} \times \frac{50\ \text{weeks}}{\text{year}}$$
$$= \frac{\mathbf{2700000\ gal.}}{\mathbf{year}}$$

Total annual volume

$$= \text{volume of tank fills} + \text{volume of overflow}$$
$$= \frac{6600\ \text{gal.}}{\text{year}} + \frac{2700000\ \text{gal.}}{\text{year}}$$
$$= \frac{\mathbf{2706600\ gal.}}{\mathbf{year}}$$

$$\frac{\text{Volume of water}}{\text{part}} = \frac{\text{total volume}}{\text{year}} \times \frac{\text{year}}{\text{part}}$$
$$= \frac{2706600\ \text{gal.}}{\text{year}} \times \frac{\text{year}}{450000\ \text{parts}}$$
$$= \frac{\mathbf{6.01\ gal.}}{\mathbf{parts}}$$

$$\frac{\text{Total water costs}}{\text{year}} = \frac{\text{total volume of water}}{\text{year}} \times \text{water rate}$$
$$= \frac{2706600\ \text{gal.}}{\text{year}} \times \frac{\$2.25}{1000\ \text{gal.}}$$
$$= \frac{\mathbf{\$6089.85}}{\mathbf{year}}$$

$$\frac{\text{Cost}}{\text{part}} = \frac{\text{volume of water}}{\text{part}} \times \text{water rate}$$
$$= \frac{\$6.01}{\text{part}} \times \frac{\$2.25}{1000\ \text{gal.}}$$
$$= \frac{\mathbf{\$0.014}}{\mathbf{part}}$$

Volume of soap required for each initial charge =

= percent soap X tank volume

= 2% X 500 gal.

= ***10 gal.***

Volume of soap required for 4 initial charges =

$$= \text{number of charges} \times \text{volume of soap per charge}$$

$$= \frac{4 \text{ charges}}{\text{year}} \times \frac{10 \text{ gal.}}{\text{charge}} = \mathbf{\frac{40 \text{ gal.}}{\text{year}}}$$

Volume of soap to maintain 2%

$$= \frac{\text{number of parts}}{\text{year}} \times \frac{\text{gal.}}{\text{part}}$$

$$= \frac{450000 \text{ parts}}{\text{year}} \times \frac{\text{gal.}}{250 \text{ parts}}$$

$$= \mathbf{\frac{1800 \text{ gal.}}{\text{year}}}$$

$$\frac{\text{Total volume of soap}}{\text{year}} = \text{Volume of soap for initial charges} + \text{Volume of soap to maintain concentration}$$

$$= \frac{40 \text{ gal.}}{\text{year}} + \frac{1800 \text{ gal.}}{\text{year}}$$

$$= \mathbf{\frac{1840 \text{ gal.}}{\text{year}}}$$

Annual cost of soap

$$= \frac{\text{Total volume of soap}}{\text{year}} \times \frac{\text{cost of soap}}{\text{gal.}}$$

$$= \frac{1840 \text{ gal.}}{\text{year}} \times \frac{\$7.00}{\text{gal.}}$$

$$= \mathbf{\frac{\$12800}{\text{year}}}$$

$$\frac{\text{Cost of soap}}{\text{part}} = \text{annual cost of soap / annual part production}$$

$$= \frac{\$12800}{\text{year}} \times \frac{\text{years}}{450000 \text{ parts}}$$

$$= \mathbf{\frac{\$0.029}{\text{part}}}$$

Total annual cost

$$= \text{Annual cost of water} + \text{Annual cost of soap}$$

$$= \frac{\$6089.85}{\text{year}} + \frac{\$12800}{\text{year}}$$

$$= \mathbf{\frac{\$18889.85}{\text{year}}}$$

Cost per part

$$= \text{total annual cost / annual part production}$$

$$= \frac{\$18889.85}{\text{year}} \times \frac{\text{year}}{450000 \text{ parts}}$$

$$= \mathbf{\frac{\$0.042}{\text{part}}}$$

The Squeaky Chemical system should be used because of its lower cost and lower requirements for water and chemicals.

Production Unit

6. Congratulations! The pilot aqueous degreaser was such a success that corporate management has approved the purchase of a production unit. The unit will be capable of cleaning 2,100,000 parts per year. The tank sizes are:

Pre-wash tank	1,400 gal.
Wash	1,250 gal.
Rinse	1,300 gal.

The tanks will be drained and cleaned four times a year. The rinse tank overflows at 7.5 gpm. The finance department has asked you to estimate the volume of water and soap used per year. Additionally, they want the cost of the water and soap per year and the total cost per year. Use the soap concentration of the Squeaky Chemical system.

$$\text{Annual volume of tank fills} = \frac{\text{number of fills}}{\text{year}} \times \text{volume of tanks}$$

$$= \frac{4\ \text{times}}{\text{year}} \times (1400 + 1250 + 1300\ \text{gal.})$$

$$= \frac{\mathbf{15800\ gal.}}{\mathbf{year}}$$

$$\text{Annual volume of overflow} = \text{flow rate of overflow} \times \text{year}$$

$$= \frac{7.5\ \text{gal.}}{\text{min}} \times \frac{60\ \text{min}}{\text{hr}} \times \frac{24\ \text{hrs}}{\text{day}} \times \frac{5\ \text{days}}{\text{week}} \times \frac{50\ \text{weeks}}{\text{year}}$$

$$= \frac{\mathbf{2700000\ gal.}}{\mathbf{year}}$$

$$\text{Total annual volume of water} = \text{volume of tank fills} + \text{volume of overflow}$$

$$= \frac{15800\ \text{gal.}}{\text{year}} + \frac{2700000\ \text{gal.}}{\text{year}}$$

$$= \frac{\mathbf{2715800\ gal.}}{\mathbf{year}}$$

$$\frac{\text{Total water costs}}{\text{year}} = \frac{\text{total volume of water}}{\text{year}} \times \text{water rate}$$

$$= \frac{2715800\ \text{gal.}}{\text{year}} \times \frac{\$2.25}{1000\ \text{gal.}}$$

$$= \frac{\mathbf{\$6110.55}}{\mathbf{year}}$$

Volume of soap required for each initial charge =

$$= \text{percent soap} \times \text{tank volume}$$

$$= 2\% \times 1250\ \text{gal.}$$

$$= \mathbf{25\ gal.}$$

Volume of soap required for 4 initial charges =

$$= \text{number of charges} \times \text{volume of soap per charge}$$

$$= \frac{4\ \text{charges}}{\text{year}} \times \frac{25\ \text{gal.}}{\text{charge}}$$

$$= \frac{\mathbf{100\ gal.}}{\mathbf{year}}$$

$$\textit{Volume of soap to maintain 2\%} = \frac{\textit{number of parts}}{\textit{year}} \times \frac{\textit{gal.}}{\textit{part}}$$

$$= \frac{2100000 \textit{ parts}}{\textit{year}} \times \frac{\textit{gal.}}{250 \textit{ parts}}$$

$$= \frac{\mathbf{8400\ gal.}}{\mathbf{year}}$$

$$\frac{\textit{Total volume of soap}}{\textit{year}} = \textit{Volume of soap for initial charges + Volume of soap to maintain concentration}$$

$$= \frac{100 \textit{ gal.}}{\textit{year}} + \frac{8400 \textit{ gal.}}{\textit{year}}$$

$$= \frac{\mathbf{8500\ gal.}}{\mathbf{year}}$$

$$\textit{Annual cost of soap} = \frac{\textit{Total volume of soap}}{\textit{year}} \times \frac{\textit{cost of soap}}{\textit{gal.}}$$

$$= \frac{8500 \textit{ gal.}}{\textit{year}} \times \frac{\$7.00}{\textit{gal.}}$$

$$= \frac{\mathbf{\$59500}}{\mathbf{year}}$$

$$\textit{Total annual cost} = \textit{Annual cost of water + Annual cost of soap}$$

$$= \frac{\$6110.55}{\textit{year}} + \frac{\$59500}{\textit{year}}$$

$$= \frac{\mathbf{\$65610.55}}{\mathbf{year}}$$

7. Compare the unit production costs for the water, the soap, and the total with the values for the pilot unit using Squeaky Chemical's soap. Comment on any trends.

Pilot unit

$$\textit{Unit cost of water} = \frac{\mathbf{\$0.014}}{\mathbf{part}}$$

$$\textit{Unit cost of soap} = \frac{\mathbf{\$0.029}}{\mathbf{part}}$$

$$\textit{Total unit cost} = \frac{\mathbf{\$0.042}}{\mathbf{part}}$$

Production Unit

$$\text{Unit cost of water} = \frac{\text{cost of water}}{\text{year}} / \text{production rate}$$

$$= \frac{\$6110.55}{\text{year}} X \frac{\text{year}}{2100000 \text{ parts}}$$

$$= \frac{\mathbf{\$0.003}}{\mathbf{part}}$$

$$\text{Unit cost of soap} = \frac{\text{cost of soap}}{\text{year}} / \text{production rate}$$

$$= \frac{\$59500}{\text{year}} X \frac{\text{year}}{2100000 \text{ parts}}$$

$$= \frac{\mathbf{\$0.028}}{\mathbf{part}}$$

$$\text{Total unit cost,} = \frac{\text{total cost}}{\text{year}} / \text{production rate}$$

$$= \frac{\$65610.55}{\text{year}} X \frac{\text{year}}{2100000 \text{ parts}}$$

$$= \frac{\mathbf{\$0.031}}{\mathbf{part}}$$

All these costs decrease because the initial charges of chemicals are spread over more processed parts.

8. The toxicology department uses an analytical system called the toxicology index to rate the toxicity of chemicals in the environment. The system involves multiplying the total quantity of a substance used in the process by a weighting factor for that particular substance. Compare the toxicology index of the aqueous production process with a TCE unit of the same capacity. What does the toxicology index indicate about pollution prevention?

The density of water is 8.3 lbs. per gallon and of the soap is 8.0 lbs. per gallon. The TCE production unit uses 1.8 X 10^6 lbs. of TCE annually. The toxicology numbers are:

Substance	**Weighting factor (lbs.$^{-1}$)**
TCE	16
water	1
soap	1.2

Note: The weighting factors were developed only for this problem set. In consulting practice, toxicity evaluations are considerably more complicated.

TCE Unit = *Tox Number X Wt. of TCE*

$= 16 \text{ lbs.}^{-1} \times 1.8 \times 10^6 \text{ lbs.}$

$= \mathbf{2.88 \times 10^7}$

Aqueous Unit = *Tox Number of Water X Wt of Water + Tox Number of Soap X Wt of Soap*

$= 1 \text{ lbs.}^{-1} \times 2715800 \text{ gal} \times \frac{8.3\text{lbs.}}{\text{gal.}} + 1.2\text{lbs.}^{-1} \times 8500 \text{ gal} \times \frac{8 \text{ lbs.}}{\text{gal.}}$

$= \mathbf{2.26 \times 10^7}$

$$\text{Percent Difference} = \frac{\text{TCE Unit}}{\text{aqueous unit}}$$

$$= \frac{2.88 \times 10^7}{2.05 \times 10^7}$$

$= \mathbf{127\ \%}$

One can see that even though the aqueous process produces more waste, the difference in toxicity more than compensates. Therefore, it is possible to make a process change which both results in cost savings and reduces environmental impacts.