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Project Summary

Demonstration of Alternative Cleaning Systems

Dean M. Menke, Gary A. Davis, Lori E. Kincaid, and Rupy Sawhney

This report represents the first demonstration of cleaner technologies to support the goals of the 33/50 Program under the EPA Cooperative Agreement No. CR821848. It focuses on substitutes for solvent degreasing processes that eliminate the use of chlorinated organic solvents. The substitute technologies were 1) an aqueous wash system; 2) a no-clean technology; and 3) a hot water wash system. Technical, environmental, and economic evaluations were performed to determine the merits of the substitutes as they were implemented by Calsonic Manufacturing Corporation, the project's industry partner. A national environmental impact evaluation was also performed to estimate the potential impacts on the nation's environment if entire industrial sectors were to implement the substitutes.

The demonstration strongly supports the implementation of the alternative technologies. The implementation of the cleaning process alternatives either improved or did not affect the performance of subsequent process steps or the quality of the products. The aqueous wash system reduced cleaning cycle times by 50% and part reject rates by nearly 77% with improved cleaning characteristics. The no-clean alternative had no effect on either production or part reject rates. The substitutes significantly reduced the quantity of toxic chemicals used and released. The traditional processes released 1,1,1-trichloroethane (TCA) to the air, as well as generated a TCA hazardous waste stream; the substitutes generate either a non-hazardous wastewater discharge (aqueous and hot water wash systems), or a volatile organic compound air emission (no-clean technologies). Each alternative offered significant financial advantages as compared to the traditional solvent degreasing systems when the economics were evaluated using activity-based cost accounting.

The national environmental impact evaluation compared the life-cycle environmental impacts of traditional chlorinated solvent systems to the alternatives. The evaluation suggests that significant reductions in life-cycle chemical emissions will occur with the implementation of alternative cleaning systems. Generally, for the aqueous wash systems, the shift would mean increased wastewater loads and oily pollutant discharges to POTWs. The nation's POTW infrastructure, in aggregate, can handle these increased loads. The shift in waste stream composition, however, must be evaluated on a case-by-case basis.

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

Introduction

The "Cleaner Technology Demonstrations for the 33/50 Chemicals" project is a cooperative agreement between the U.S.

Environmental Protection Agency (EPA), National Risk Management Research Laboratory (NRMRL, formerly Risk Reduction Engineering Laboratory) and the Center for Clean Products and Clean Technologies (Center) of The University of Tennessee. The research of this project supports the voluntary pollution prevention initiatives of the 33/50 Program, while having applications within a broad range of industries. This report represents the first demonstration project to be completed under the EPA NRMRL project.

Objectives

The overall objective of this project was to evaluate substitutes for the 33/50 chemicals in order to encourage reductions in their use and release. This report focuses on substitutes for solvent degreasing processes that eliminate the use of the 33/50 chlorinated organic chemicals. In this study the Center worked directly with an industry partner, Calsonic Manufacturing Corporation (CMC) of Shelbyville, TN, to demonstrate substitute feasibility.

To meet the project objective, technical, environmental, and economic evaluations of solvent degreasing substitutes were evaluated. A fourth evaluation, a national environmental impact evaluation, was performed to estimate the impacts to the nation's environment if entire industrial sectors were to implement similar alternatives to solvent degreasing. Within each evaluation, the following objectives were established:

1. Technical Evaluation
   - evaluate the effect of a substitute on process and product performance as compared to the 33/50 chemicals
2. Environmental Evaluation
   - evaluate the potential for reduction in releases and off-site transfers of the 33/50 chemicals in the production process or product stage
   - compare the overall life-cycle environmental attributes of the substitute as compared to the 33/50 chemicals
3. Economic Evaluation
   - evaluate the total cost of the substitute as compared to the 33/50 chemicals
4. National Impact Evaluation
   - evaluate the national environmental impact of replacing the 33/50 chemicals with the substitute

Methodology

Data required to perform the technical, environmental, and economic evaluations were collected through data request tables, site visits, and interviews with CMC employees. Data request tables, completed by CMC and during site visits, allowed for the collection of process information including capital costs, operating and maintenance costs, utilities consumption, and production data. Similar data were requested for both the solvent degreasing systems (historic data) and alternative systems (current data). Questions concerning generation rates and disposal costs of waste (hazardous and non-hazardous) and waste water accompanied the data request tables, as well as questions concerning permitting requirements and costs. These questions were also directed at operations both before and after the process changes.

Site visits and interviews allowed Center staff to become familiar with the operations of CMC, ask specific questions to complete and clarify the data request tables, and to maintain a working contact with CMC. An extended site visit near the completion of this project was conducted to observe the day-to-day operations of the process lines under investigation in order to extend the traditional economic evaluation by using activity-based cost accounting.

The national impact evaluation utilized the knowledge of CMC's process changes to identify and evaluate potential changes on a national scale if entire industrial sectors were to implement similar solvent degreasing alternatives. to CMC's. Toxic Release Inventory (TRI) data and information from various literature sources were used to develop a life-cycle evaluation of chlorinated solvent degreasing and its alternatives.

CMC'S Chlorinated Solvent Substitutes Program

CMC is located in Shelbyville, TN, with several sister companies throughout the U.S. and the world. CMC employs approximately 800 persons, and has more than 430,00 ft^2 of manufacturing area divided between two sites, three buildings. CMC manufactures automotive parts, including heaters, blowers, cooling units, motor fans, radiators, auxiliary oil coolers and exhaust systems.

To meet internal protocols to eliminate 1,1,1-trichloroethane (TCA) from its manufacturing processes, CMC initiated a number of changes to eliminate solvent degreasing applications. These changes included an aqueous wash system, a no-clean process which employs an evaporative lubricant to eliminate the need for solvent degreasing, and the application of a hot water wash to remove forming oils. Technical, environmental, and economic evaluations were performed for the aqueous wash and no-clean alternatives to determine their merits. The merits of the hot water wash system were presented as supplemental information to the aqueous wash alternative. An introduction to these process changes, and the manufacturing lines which utilize them, is presented below.

The Radiator Line and Aqueous Wash System

Radiators are designed to hold a large volume of water and antifreeze in proximity to a large volume of air to allow efficient heat transfer from the fluid to the air. CMC manufactures the tube-and-fin type of radiator core, consisting of a series of long tubes extending between a top tank and bottom tank of the radiator. In this type of configuration, fins are placed between the tubes; air passes between the fins and around the outside of the tubes, absorbing heat from the fluid in the tubes.

CMC manufactures the tubes and fins of the radiator core from aluminum stock. Tubes are formed from aluminum rolls at a tube-forming station with the assistance of a forming/cooling fluid, cut to length, and sent to assembly. To form the fins, rolls of aluminum are lubricated with a forming (napthenic) oil, fed through fin corrugators, cut to length, and sent to assembly. The tubes, fins, and prefabricated endplates are assembled in a jig to complete the radiator core.

Following assembly, the cores are cleaned by a conveyor aqueous wash system to remove the forming oils, cutting oils, coolant, and other soils. The aqueous wash process begins with a water wash, intended to remove the majority of the contaminants, followed by a heated detergent bath, and completed by a hot water rinse. Effluent from the aqueous wash process is sent to a wastewater treatment plant at the facility for pretreatment prior to discharge to the local sewer system. After the aqueous wash, the radiator cores continue on the conveyor for flux application, drying, and brazing. Final assembly includes nylon fluid tanks and leak testing.

The current aqueous wash system was adapted in 1991. Previously, five batch vapor degreasers were used to clean the assembled radiator core, one located at each fin corrugation and assembly station. Under this scheme the radiator core was an assembly of corrugated fins (process above) and prefabricated tubes and endplates supplied by another company. These assemblies were then cleaned in one of the five vapor degreasers, using 1,1,1-trichloroethane as the degreasing solvent. The use of TCA resulted in releases of TCA to the air from the process, releases to water (wastewater) from solvent carry over on parts to subsequent process units, and a hazardous waste stream of spent TCA. CMC sent this hazardous waste stream to an off-site recycling facility. To eliminate these waste streams and improve the cleaning process, CMC implemented the aqueous wash system.

The Condenser Line and No-Clean Technology

CMC manufactures condensers for use in automobile air conditioning systems. The condenser consists of a serpentine tube on which fins have been mounted. Compressed vapor passes through the tube; air passing around the fins and between the tubes removes heat from the compressed vapor. The cooled vapor condenses and runs into a receiver-dryer. CMC manufactures the fins from rolls of aluminum, and bends and cuts the tubes from rolled aluminum-tube stock.

In 1993 CMC converted its fin manufacturing process from a conveyor solvent degreasing process using TCA to an "evaporative" oil, no-clean process. In this no-clean system, rolls of aluminum are lubricated with a low-boiling-point oil and fed through a fin corrugator. The fin then passes through fin driers to evaporate the oils. CMC operates four fin corrugator stations in the condenser line. In the current system the corrugated fin is conveyed through the now empty vapor degreasing chambers, then cut to length and sent to assembly.

The Converter Line and Hot Water Wash System

Catalytic converters are automobile exhaust units which consist of a ceramic substrate and wire mesh encased in a metal shell. CMC assembles converters from shells, flanges, ceramic substrates, and wire mesh separators supplied by other manufacturers. After receiving these materials, CMC cleans the metal shell halves and flanges in a conveyor hot water wash system to remove cutting and lubricating oils left by the manufacturer. The wash system consists of a hot water spray zone, followed by a second hot water spray (rinse) zone and a drying oven. After cleaning, the ceramic substrate and wire mesh separator are inserted in the two shell halves, which are then welded together with the flanges, to form the converter unit. Each catalytic converter is leak-tested using an air-based pressure-decay system. The converters then continue along the process train to be incorporated into the exhaust system.

Until December 1993, CMC used a conveyor vapor degreaser with TCA as the degreasing solvent. The current equipment used in the hot water wash system was converted by CMC from an obsolete muffler washing system and a defunct paint spray booth and curing oven.

Results of the Technical, Environmental, and Economic Evaluations

Over the last four years CMC has implemented a number of changes to eliminate TCA from its cleaning processes. Efforts to accomplish this goal included the installation of an aqueous wash system (detergent) which replaced five solvent degreasers on a radiator manufacturing line, the replacement of a petroleum-based lubricant with an evaporative lubricant that does not require cleaning for subsequent processing on a condenser manufacturing line, and the installation of a hot water wash system to replace a solvent degreaser on a catalytic converter manufacturing line. These changes, along with similar changes on other process lines, eliminated the use of TCA as a cleaning solvent within CMC's manufacturing facility. Total elimination of TCA from cleaning processes was accomplished by November, 1994.

The technical, environmental, and economic evaluations performed in this study were completed using CMC's historic records, information obtained from site visits and interviews with CMC employees, the on-line TRI data base, and literature searches. The radiator and condenser manufacturing lines were the main focus of the research. The merits of the hot water wash system were presented as supplemental information to the aqueous wash alternative. The environmental analysis of CMC was expanded to evaluate the national environmental impacts if entire industry sectors were to implement similar process changes.

Technical Evaluation

The technical evaluation analyzed the merits of the alternative cleaning systems (both the aqueous wash and the no-clean, evaporative lubricant systems) by comparing the rates of production (i.e., cycle time required to clean one part) and the part reject rates between the old and new processes. Both historic data and interviews with CMC quality control staff established the results shown in Table 1.

A significant decrease in cycle time was experienced with the implementation of the aqueous wash system in the radiator line; cycle time to clean one radiator unit was decreased by 50%. The process bottleneck, which was the solvent degreasing application, has now shifted away from the cleaning operation, and employee attentions can be focused upon other operations to further optimize the manufacturing process.

A significant decrease in the parts reject rate for the radiator line was also experienced after the implementation of the aqueous wash system. This decrease, over 76%, is predominantly attributed to the improved cleaning characteristics of the aqueous wash system. The production and part reject rates for the condenser line, though not statistically evaluated due to data limitations, were evaluated through employee interviews. These interviews established that the implementation of the no-clean process alternative had little effect on either rate.

Environmental Evaluation

The changes in chemical releases and transfers to the environment from CMC's manufacturing facilities due to the implementation of the alternative processes included the following:

1. elimination of TRI reporting requirements of TCA hazardous waste emissions, from each process line;
2. the creation of a state-regulated VOC air emission for the condenser line; and
3. the creation of a waste water stream for the radiator line.

These changes are summarized for the radiator and condenser manufacturing lines in the following table (Table 2). It is assumed that air releases and hazardous waste transfers are the only TCA emissions from CMC processes. Therefore,

Table 1. *Summary of the Technical Evaluation Results*

Line	*Cycle Time*	*Part Reject Rate*
Radiator	*50% decrease was experienced after aqueous wash implementation*	*76% reduction in part reject rate due to aqueous wash system*
Condenser	*no significant change*	*no significant change*

Table 2. *Summary of Environmental Evaluation Results*

Line	Total Waste Generation per Year: Solvent Degreasing Operations		Total Waste Generation per Year: Alternative Systems Operations	
Radiator	*171,500 lb*	*TCA consumed*	*22,100 lb*	*detergent consumed*
	114,900 lb	*TCA haz. waste transfers*	*2.0 million gal*	*wastewater generated*
	56,600 lb	*TCA air releases*	*10,800 lb*	*non-haz., oily waste transfers*
	(1990)		*64,780 lb*	*non-haz. wastewater treatment solids transfers*
			(1992)	
Condenser	*121,500 lb*	*TCA consumed*	*12,200 lb*	*evap. lub. consumed*
	14,400 lb	*petroleum lub. consumed*	*12,200 lb*	*VOC air releases*
	75,400 lb	*TCA haz. waste transfers*	*(1994)*	
	46,100 lb	*TCA air releases*		
	(1992)			

based on TCA consumption rates and line-specific hazardous waste generation estimates, the air releases were estimated. Other line-specific information was drawn directly from purchasing records.

Though eliminating the use and hazardous waste disposal of TCA, the hot water wash system of the converter line was not quantitatively evaluated in this analysis. However, a qualitative evaluation of this system is presented throughout the evaluations of the report.

Though the aqueous wash system of the radiator line generates two million gallons of wastewater per year, overall chemical consumption, when compared to the solvent degreasing system, has greatly decreased. The consumption rate of 2,640 gal/yr of detergent is minimal when compared to the 15,840 gal/yr (171,700 lb/yr) of TCA previously consumed. The evaporative lubricant system of the condenser line has similar advantages; the release of 12,200 lb/yr of VOC-lubricant is an order of magnitude less than the 121,500 lb/yr of TCA released by the degreasers.

These data clearly show the trade-off issues that must be considered when choosing between alternative cleaning systems. For the radiator line, releases of the toxic, ozone-depleting chemical TCA were eliminated, but a larger volume, low-toxicity wastewater stream was generated. Although hazardous waste management requirements have been eliminated for this line, permitted discharge requirements set by the local publicly owned treatment works (POTW) must still be met. For the condenser line, hazardous waste and TCA were once again eliminated. Air releases decreased substantially, suggesting less potential employee exposure; complete data on the relative toxicity of TCA and the mineral-spirit-based VOCs emitted by the evaporative lube, however, are not available. This is one of the reasons CMC is now switching to a non-petroleum based evaporative lube.

Economic Evaluation

Two economic evaluations were completed for the analyses of the alternatives. The first evaluation used a traditional method focusing on direct costs. The second method utilized activity-based costing to more accurately allocate overhead costs to the appropriate products and processes. Finally, a hybrid of these methods was used to more accurately represent the costs and benefits of the alternatives. Tables 3 and 4 summarize the results of traditional and hybrid economic analyses for the radiator and condenser manufacturing lines, respectively.

Table 3 shows that the hybrid method identified additional direct costs associated with the solvent degreasing units of the radiator line that would have been part of an overhead cost factor in a more traditional analysis. These results illustrate very clearly that traditional cost analyses are not adequate to fully estimate the benefits of pollution prevention projects. By properly allocating through ABC that would normally be part of an overhead factor, this study demonstrates the costs-benefits of the aqueous wash system, benefits beyond traditional costing techniques are realized.

The results of the economic analysis for the condenser line did not change the final conclusions since the evaporative lube system had clear advantages even with traditional cost methods. By using the hybrid approach, however, the cost savings due to the implementation of this alternative were even greater.

National Environmental Impact Evaluation

The environmental evaluation of CMC's process changes was used to estimate the potential environmental impacts of the alternatives to solvent degreasing if entire industrial sectors were to implement similar changes. This evaluation utilized the life-cycle concept to evaluate the potential environmental impacts which could result throughout the life cycle of the chemicals used in the traditional and alternative processes. The elimination of chlorinated solvents from materials and parts degreasing could significantly impact the national emissions of these chemicals from their production, use and disposal. The implementation of the alternative systems, though having associated releases and transfers of other chemicals, could significantly decrease the environmental impacts now associated with the life cycle of solvent degreasers and the solvents used.

Replacing chlorinated solvent degreasers could substantially reduce the use of approximately 499.9 million lb of chlorinated chemicals in materials and parts degreasing applications. In addition to the direct use and disposal emissions that would be reduced, an estimated 460,000 lb of solvent emissions from production facilities could also be reduced. This 460,000 lb estimate is based on the quantity of the chlorinated solvents currently produced, the emissions from these production processes, and the distribution of the chemicals to solvent degreasing applications.

Table 3. *Comparison of Hybrid and Traditonal Analyses-Radiator Manufacturing Line*

	Hybrid Analysis		*Tradition, Direct Cost Analysis*	
Analysis	*Solvent System*	*Aqueous Wash System*	*Solvent System*	*Aqueous Wash System*
Payback		*2.4 yr*		*11.6 yr*
NPV (5-yr)	*$2,584,150*	*$1,514,260*	*$660,580*	*$808,280*
NPV (10-yr)	*$5,725,530*	*$3,073,640*	*$1,464,270*	*$1,508,720*
NPV (15-yr)	*$9,547,510*	*$4,762,870*	*$2,442,090*	*$2,147,930*

Notes:
1. *i = interest rate/period = 4%.*
2. *the capital investment of the aqueous wash system was depreciated (straight-line) over seven yr.*
3. *assumptions: inflation rate of zero and equal costs/yr.*
4. *dollar values represent costs.*

Table 4. *Comparison of Hybrid and Traditional Analyses-Condenser Manufacturing Line*

	Hybrid Analysis		*Tradition, Direct Cost Analysis*	
Analysis	*Solvent System*	*Evaporative Oil System*	*Solvent System*	*Evaporative Oil System*
Payback		*0.27 yr*		*0.45 yr*
NPV (5-yr)	*$1,089,550*	*$219,660*	*$619,750*	*$99,930*

Notes:
1. *i = interest rate/period = 4%.*
2. *the capital investment of the aqueous wash system was depreciated (straight-line) over 7 yr.*
3. *assumptions: inflation rate of zero and equal costs/yr.*
4. *dollar values represent costs.*

The implementation of an aqueous wash alternative has unique emissions of its own. Detergents, a mixture of surfactants, builders, chelators, and other ingredients, have associated chemical production releases and transfers. Emissions from production of commonly used ingredients (e.g., ethoxylated alcohols, alkylbenzene sulfonates, EDTA, and tetrapotassium pyrophosphate) include ethylene, ethylene glycol, benzene, glycol ether, and a variety of acids. An estimate of the quantity of detergent ingredients applied to industrial applications was not available, and therefore an estimate of the production releases which could be allocated to the industrial use of detergents was not possible. However, order-of-magnitude calculations show that life-cycle releases and transfers could be significantly reduced with the implementation of the aqueous alternative.

A second issue to address when considering the life-cycle attributes of aqueous wash systems is the proper management of the water waste stream. Pretreatment of the wastewater from aqueous systems may be required to adequately remove oils, greases, biological oxygen demand (BOD), and suspended solids. The conclusions from the national environmental impact evaluation indicated that the infrastructure of wastewater treatment facilities is sufficient to handle the increased wastewater flow and load if entire industry sectors shifted from solvent to aqueous systems.

Conclusions

The demonstration strongly supports the implementation of the alternative technologies. The implementation of the cleaning process alternatives either improved or did not affect the performance of subsequent process steps or the quality of the products. The aqueous wash system reduced cleaning cycle times by 50% and part reject rates by nearly 77% with improved cleaning characteristics. The no-clean alternative had no effect on either production or part reject rates. The substitutes significantly reduced the quantity of toxic chemicals used and released. The traditional processes released 1,1,1-trichloroethane (TCA) to the air, as well as generating a TCA hazardous waste stream; the substitutes generate either a non-hazardous wastewater discharge (aqueous and hot water wash systems), or a volatile organic compound air emission that is much less no-clean technology. Each alternative offered significant financial advantages as compared to the traditional solvent degreasing systems when using activity-based cost accounting and compared to the traditional solvent degreasing systems.

The national environmental impact evaluation compared the life-cycle environmental impacts of traditional chlorinated solvent systems versus the alternatives. The evaluation suggests that significant reductions in life-cycle chemical emissions will occur with implementation of alternative cleaning systems. Generally, for the aqueous wash systems, the shift would mean increased wastewater loads and oily pollutant discharges to POTWs. The nation's POTW infrastructure, in aggregate, can handle these increased loads, however, the shift in waste stream composition must be evaluated on a case-by-case basis.

Dean M. Menke, Gary A. Davis, Lori E. Kincaid, and Rupy Sawhney are with the University of Tennessee, Knoxville, TN 37996-0710
***Diana R. Kirk** is the EPA Project Officer (see below).*
The complete report, entitled "Demonstration of Alternative Cleaning Systems," (Order No. PB95-255741; Cost: $27.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
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U.S. Environmental Protection Agency
Cincinnati, OH 45268

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