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REPLACING SOLVENT
CLEANING WITH
AQUEOUS CLEANING

Prepared for

Office of Environmental Engineering
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Prepared by

Air and Energy Engineering Research
Laboratory
Research Triangle Park NC 27711

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REPLACING SOLVENT CLEANING WITH AQUEOUS CLEANING

By

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Washington, D.C. 20460

ABSTRACT

This report documents actions taken by Robert Bosch Corporation, Charleston, SC, in replacing the cleaning solvents CFC-113 and trichloroethylene (TCE) with aqueous solutions. Bosch has succeeded in eliminating all CFC-113 use and so far has eliminated two thirds of their TCE usage. Their goal is to be completely free of chlorinated cleaning solvents by the end of 1995.

These changes in cleaning have not only responded to the environmental goals of the Montreal Protocol and EPA's 33/50 program but have also resulted in improved cleaning at dramatically reduced costs. An early key decision was to replace their aging, large central degreasing stations with a multitude of small cleaning units, each designed and dedicated for cleaning just one part at one step in the product assembly process. This strategy demanded reassessment of each cleaning step and the identification of apparatus and chemistry for optimizing each aqueous replacement. This report summarizes the actions taken to achieve aqueous cleaning of four typical component parts, previously cleaned with chlorinated solvents. The report provides quantitative comparisons of cleaning performance and costs of the old chlorinated (1988) and the new aqueous (1992) cleaning methods. For each of these components, the new aqueous cleaning step matched or exceeded the cleanliness levels of the old, chlorinated cleaning methods and did so at similar or lower costs.

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ACKNOWLEDGMENT

The author wishes to acknowledge the cooperation and support of the Robert Bosch Corporation, Charleston, South Carolina, in the preparation of this report. The initial and primary contact person at Bosch was Roland K. De'ssaure, a manufacturing engineer in the Automotive Group. He arranged the initial project presentation at Bosch and fielded many questions and requests over the following months. Wolfgang A. Hasper, Unit Manager, Industrial Engineering, contributed valuable cost and performance data. Steve Bledsoe, Manager, Engineering Services, provided guidance with respect to the corporate outlook on the company's environmental responsibilities and goals.

UNITS

The majority of the data reported here are in English units, the primary units used by both the vendors in rating equipment and Bosch in their process descriptions. These English units have been retained to simplify communication with most of the intended readership. For those few readers preferring metric units, multiplying factors for converting from the English units used in this report to their metric equivalents are given in the table below.

METRIC CONVERSION FACTORS (Approximate)				
Symbol	When You Know Number of	Multiply By	To Find Number of	Symbol
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	30.5	centimeters	cm
		MASS		
lb	pounds	0.454	kilograms	kg
		VOLUME		
gal	gallons	3.79	liters	L
		PRESSURE		
atm	atmospheres	98.1	kilopascals	kPa
psi	pounds per square inch	6.89	kilopascals	kPa
		TEMPERATURE (Exact)		
°F	degrees Fahrenheit	5/9 (after subtracting 32)	degrees Celsius	°C

SECTION 1

INTRODUCTION

Several factors now strongly favor industrial cleaning of metal surfaces based on chemicals other than chlorinated solvents:

1. The Copenhagen amendments to the Montreal Protocol have established January 1, 1996 as the deadline for the phaseout of production of Class I substances*. These include the solvents 1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113), methyl chloroform (1,1,1-trichloroethane, abbreviated TCA), and carbon tetrachloride.

2. The CAA also requires all products manufactured after May 15, 1993 with TCA or other Class I substances to display a label announcing that fact along with the warning that these solvents are destructive to the ozone layer [Federal Register, Vol. 58, No. 27, p. 8162, Thurs., Feb. 11, 1993].

3. The costs of these chemicals have skyrocketed, and the costs of most other chlorinated solvents may follow the same pattern.

What are the options available to a manufacturer now using chlorinated cleaning solvents and facing these realities? Many industrial leaders have already responded to this crisis and found acceptable answers. This report describes one such set of solutions carried out by Robert Bosch Corporation in Charleston, SC. They eliminated their use of CFC-113 (544,000 lbs. in 1988) and reduced their consumption of trichloroethylene (TCE) from 133,000 lbs. in 1988 to 43,000 lbs. in 1992. As graphed in Figure 1, the reduced use of chlorofluorocarbon (CFC) alone has returned a major dollar savings in chemical costs. Table 1 compares the annual operating costs for all chemicals and electric power used in cleaning for the years 1988 and 1993. The 1988 values represent the usages before the introduction of any

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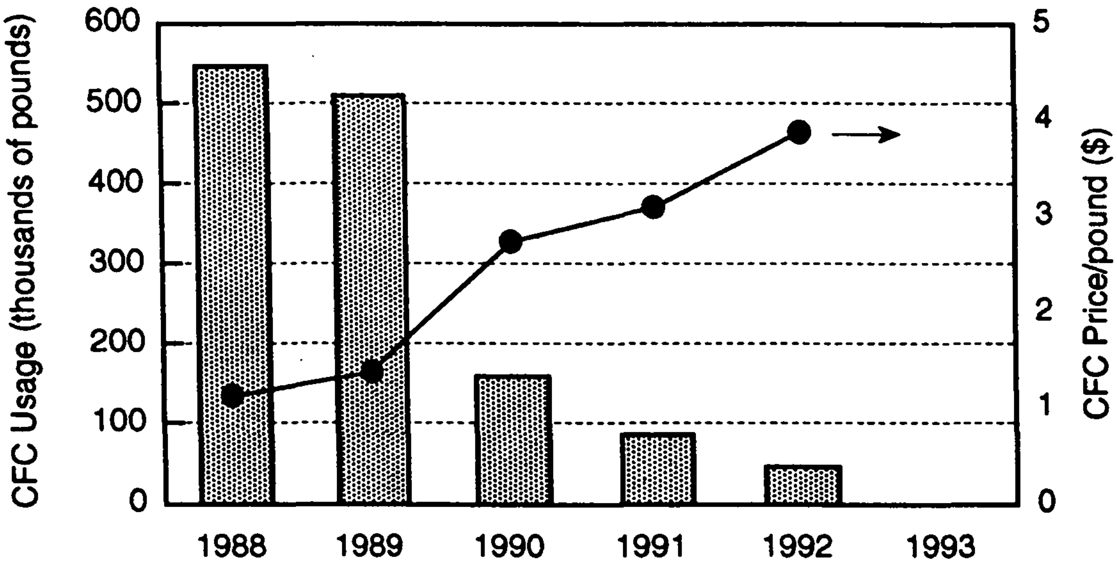
*A Class I substance is a substance listed in Section 602(a) of the Clean Air Act (CAA) Amendments of 1990 plus any subsequent additions. Typically it includes substances having ozone depletion potentials of 0.2 or greater.



CFC Usage (1000s of lbs.)	544	510	160	86	45	0
Price/pound ($)	1.1	1.35	2.71	3.08	3.86	
Annual Cost (1000s of $) (Usage x Price/pound)	598	689	434	265	174	0

Figure 1. Reduction in CFC usage and costs.

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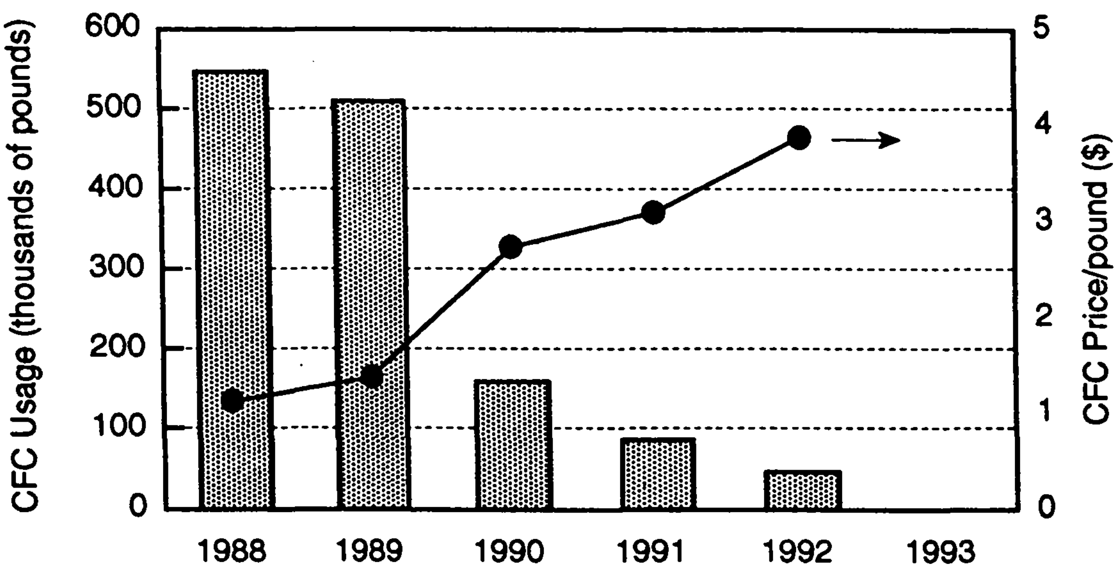

	1988	1989	1990	1991	1992	1993
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Figure 1. Reduction in CFC usage and costs.

TABLE 1. NONLABOR ANNUAL OPERATING COSTS, ALL CLEANING STEPS

	1988			1993		
	TCE	CFC	Total	TCE	H_2O/Additive	Total
Solvent Loss, ($)	50,000	600,000	650,000	16,000	6,000	22,000
Electric Power, ($)	53,000	47,000	100,000	33,000	8,000	41,000

aqueous replacement technology. The low solvent costs estimated for 1993 ($22,000) reflect primarily the elimination of all CFC solvent cleaning. Also, TCE costs were reduced from $50,000 to $16,000. Not only have the chemical costs been dramatically reduced, but electric power costs have also gone down. Reduced power costs were realized because of the switch from a few large central cleaning stations to many small, dedicated cleaning units, each customized for cleaning just one component type.

Bosch's goal now is to eliminate all TCE-based operations by the end of 1995 and thus achieve a chlorinated-solvent-free operation. The objective of this report is to provide the details of how these goals and cost savings have been achieved so that others can learn from these experiences. What has proven successful at Bosch may transfer directly to other sites in the same industrial category and to other industries with similar cleaning problems.

The report begins in Section 2 with a brief corporate profile of Robert Bosch GMBH and, in particular, the manufacturing plant in Charleston, SC. Section 3 contains a discussion of general cleaning problems at Bosch, Charleston, and describes their philosophical approach in finding suitable replacement technology for CFC-113 and TCE cleaning. Section 4 reviews the details of converting the cleaning of four typical parts from chlorinated solvents to aqueous cleaning. The steps of both the 1988 cleaning process (chlorinated solvents) and the 1992 cleaning process (the aqueous replacement process) for each component type are listed. The performance (cleaning adequacy as assessed by visual inspection and extraction tests) and relative costs of the 1988 and 1992 processes are compared.

SECTION 2

SITE/ORGANIZATION DESCRIPTION

The Robert Bosch Corporation, with corporate offices in Broadview, IL, is a US subsidiary of Robert Bosch GMBH, Stuttgart, Germany. The parent company is a large, worldwide conglomerate with annual sales of about 20 billion dollars and employees numbering about 160,000. Sales of the US subsidiary are a little over one billion dollars per year. It employs over 5,000 people spread among eight business segments. Robert Bosch, Charleston is a manufacturing plant in the Automotive Group, which is the largest subdivision of the Robert Bosch Corporation.

The Charleston plant has been operating since 1973. It currently operates with about 600,000 ft^2 of manufacturing space and employs approximately 1,700 people, 350 of whom are support personnel and engineers. The plant has a heavy engineering emphasis in support of its assembly and test functions.

The primary products produced at Robert Bosch, Charleston, are gasoline fuel injectors, antilock brake systems, and diesel fuel pumps. They are sold to manufacturers such as Ford and General Motors. This activity is listed under Standard Industrial Code (SIC) 3714, motor vehicle parts. Nationwide, this SIC is one of the top three in terms of total TCA (1,1,1-trichloroethane) emissions and is probably number one in terms of the number of facilities emitting TCA. Robert Bosch, Charleston, however, does not and has not used TCA. Their metal parts have been cleaned with CFC-113 and trichloroethylene (TCE). Since all CFC-113 use has now been eliminated, its parts do not require a Class I substance label. Nonetheless, the organization has made the decision to phase out the use of all chlorinated solvents by the end of 1995, including TCE. This decision is partly based on being a good community citizen and supporting the U. S. Environmental Protection Agency's (EPA's) 33/50 program,* but also on the improved cleaning efficiency and product performance spawned by the replacement cleaning technologies. Eliminating chlorinated solvents has been good for both Charleston's environment and product quality.

The primary Robert Bosch contacts in the preparation of this report were Roland De'ssaure, Manufacturing Engineer [(803) 760-7637] and Wolfgang Hasper, Unit Manager, Industrial Engineering [(803) 760-7659] who contributed most of the information reported here. The details and data summaries originated with them and their coworkers. They are justifiably proud of their success in solving their cleaning problems and are willing to share their experiences with others facing similar problems.

Eliminating chlorinated solvents on the production floor required a large team effort. Table 2 lists those playing primary roles. The team begins with the Vice President/Plant Manager, a necessary team member. From the start, Bosch management supported the solvent replacement team. Equally important, management recognized that set-backs would occur. All management asked was that the team do its best. The team included both planners and users of the solvent replacement strategies, and other support personnel as shown by the variety of skills represented in Table 2. In-house plating personnel contributed their specialized skills for the chemical selection.

Changeovers to nonchlorinated solvents began in earnest early in 1990, and continue today. By the end of 1992, all CFC use had been eliminated by adopting one of the process changes reported in Section 4. The 1992 processes described in Section 4 are themselves continually being reevaluated and improved. Certain steps in the replacement processes described in Section 4 are no longer current, having been superseded by newer steps. Additional upgrades will continue to be introduced.

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*The EPA's 33/50 program is a voluntary pollution prevention initiative to reduce the 1988 national pollution releases and off-site transfers of 17 toxic chemicals by 33% by the end of 1992 and by 50% by the end of 1995. TCE is one of the 17 target chemicals on the 33/50 list. Bosch, Charleston, has already met its 1995 TCE goal.

TABLE 2. THE BOSCH SOLVENT REPLACEMENT TEAM

J. Moulton	VP/Plant Manager
T. Smith	Production Manager
F. Skibba	Production Manager, Heat Treatment
R. Dessaure	Process Engineer
M. Carpenter	Process Engineer
P. Amarendran	Process Engineer
W. Hasper	Process Engineer
S. Bledsoe	Process Engineer
G. Boatright	Environmental Officer
C. McNeely	Quality Gauging
J. Evans	Quality Gauging
H. Marano	Purchasing, Capital and Chemicals
D. Root	Solvent Recovery
T. Walker	Facility
J. Bays	Production Supervisor, Heat Treatment
C. Nunnally	Plant Chemist
J. Kochanowski	Metallurgist
S. Grant	Assistant Plant Chemist
B. Adkins	Production Setup
C. Cyran	Production Setup
C. Branch	Production Operator
T. Langley	Setup
T. Fontenot	Supervisor, Contamination Test
A. Gadson	Operator, Contamination Test (3 shifts)
B. Garderson	Operator, Contamination Test (3 shifts)
M. Davis	Operator, Contamination Test (3 shifts)
J. Mingoia	Sp. Equip. Mechanic
S. Bugarin	Sp. Equip. Mechanic
M. Adair	Sp. Equip. Mechanic

SECTION 3

CLEANING OPERATIONS AT BOSCH, CHARLESTON

PARTS BEING CLEANED

Most of the parts cleaned at Bosch, Charleston are for two assemblies, a fuel injector and an antilock brake system. The cleaning processes associated with these products are typical of all Bosch cleaning processes and will be discussed here.

The fuel injector assembly, for example, consists of several component parts. Some parts are cleaned more than once during the assembly process, resulting in over 30 separate cleaning operations. The parts to be cleaned consist of mild steel, stainless steel, plastic, and rubber. Contamination to be removed typically includes metal chips and fibers, grinding coolants, shop dirt, chemical residues, fingerprints, etc.

Cleaning operations at Bosch include both gross cleaning and precision cleaning. Gross cleaning is carried out on the open production floor, and precision cleaning is done in the Class 10,000 cleanroom where final assembly takes place. Inadequate cleaning can compromise product performance and cause failure. Part cleanliness is thus more than just a cosmetic consideration. While the cleaning requirements are less than those of the semiconductor or disk drive industries who worry about submicrometer-size particles, part cleanliness at Bosch means more than simple washing or scrubbing in soap and water. Particles larger than about 25 micrometers (μm) are of concern and are targets for removal by the cleaning process.

PREVIOUS SOLVENT CLEANING TECHNOLOGY

In 1988, all cleaning operations for manufacturing were performed using either CFC-113 or trichloroethylene (TCE). Typically these cleaning steps were carried out in large centrally located degreasers (Figure 2). Eight units used TCE; seven used CFC-113. These degreasers were off-the-shelf, commercially available units, and all

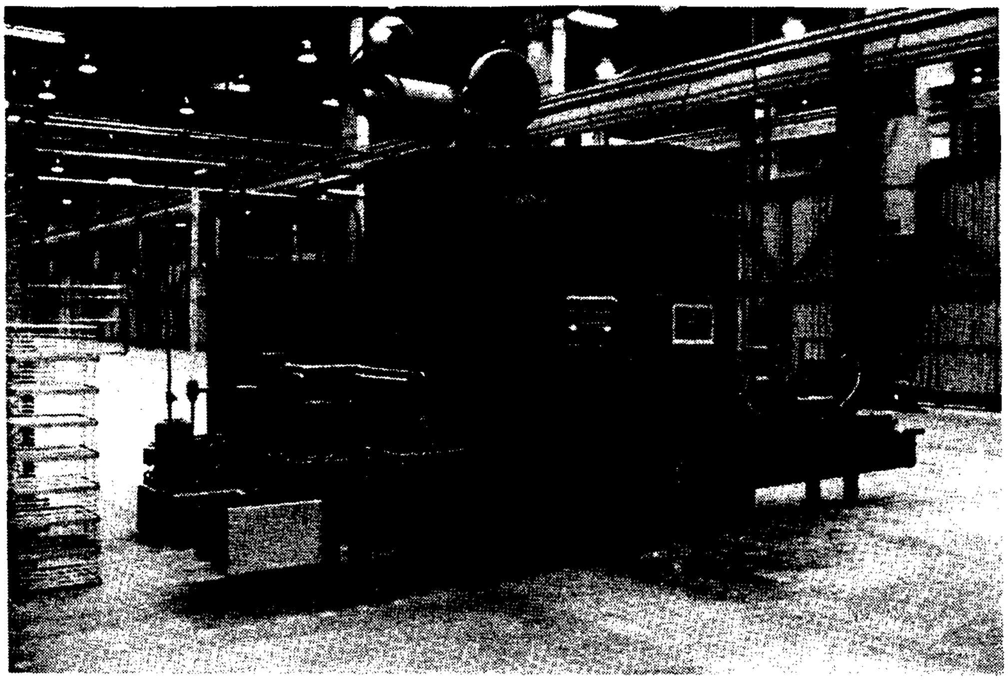


Figure 2. TCE vapor degreaser.

included some form of solvent recovery. The units used combinations of sprays and ultrasonic agitation to dislodge the contaminants, in addition to vapor degreasing.

Both the TCE and the CFC units acted as general purpose cleaning stations for the various cleaning steps required in manufacturing. Parts passed through the cleaning stations in their order of arrival. Throughput time for baskets containing a total of 60-100 lbs. of parts was typically about 40 minutes.

In this operating mode, solvent consumption in 1988 was 544,000 lbs. of CFC-113 and 133,000 lbs. of TCE.

COSTS OF PREVIOUS TECHNOLOGY

Costs of cleaning using CFC-113 and TCE fall into five categories: capital, solvent, operating expenses, maintenance, and waste disposal. Waste disposal depends on site location, as do labor and energy costs. Capital equipment and chemicals, while less site-specific, change with time--quite rapidly over the last few years (Figure 1).

The capital costs of centrally located vapor degreasers of the size pictured in Figure 2 averaged $250,000. When replacing these units, Bosch chose not to resell them as operating used equipment but to scrap them.

At $1.10/lb., the 1988 cost for CFC-113 solvent was $600,000. The cost for TCE was $50,000. By prorating plant power costs, the cost of power for operating all the cleaners was estimated to be $100,000/yr. Operating labor requirements in the three-shift operation averaged one man/cleaner/shift or $75,000 per year per cleaner per shift.

Maintenance costs were minor on the central cleaners. The equipment had little time down for either scheduled or unscheduled maintenance. Waste disposal costs were also small for the CFC-113 central cleaners, most of the losses being dragout and vapor losses to the atmosphere. The TCE degreasers also had some atmospheric losses, but about 92% of the vapor was recovered for reuse.

OPTIONS FOR REPLACING CHLORINATED SOLVENTS

Options considered for replacing the chlorinated solvents included "no clean," using other organic solvents, aqueous (water-based) cleaning and supercritical carbon dioxide. The most desirable option considered by Bosch, Charleston, in replacing chlorinated solvent cleaning, was the "no clean" option. For the "no clean" option, the cleaning step is examined to decide if it is absolutely necessary. Sometimes the cleaning step can be eliminated with only minor changes, or no changes, in the rest of the manufacturing process. The cleaning step is simply omitted. Successful replacement of a chlorinated solvent clean with a "no clean" is a fairly rare event, but has large benefits in reduced costs and cycle time.

An example of this type of process change at Bosch involved the replacement of solvent cleaning of a part between two machining steps. In the "no clean" replacement process, the oil-based lubricant is centrifuged off the parts, eliminating the wash and rinse cycles formerly used. This eliminated a waste stream, reduced the cycle time, chemical usage, and floor space needed. This "no clean" replacement resulted from a suggestion by shop-floor manufacturing personnel.

For all those operations for which "no clean" was not feasible, Bosch, Charleston, decided to bypass interim alternatives, such as the hydrochlorofluorocarbon solvents. They also decided not to revert to the hydrocarbon cleaners of earlier years (although the cleaning of the polyamide coil discussed in Section 4 remains a temporary exception). The Bosch decision was to immediately address the long-term environmental issues associated with cleaning and develop cleaning methods that would be as permanent as could be conceived under present knowledge and regulations. The interim solutions were abandoned as "not buying time but wasting time."

The next option considered was aqueous cleaning. Aqueous cleaning with deionized water has proven very effective, especially when customized for one specific cleaning step on a specific part. The costs of deionized water cleaning become affordable when used in the limited quantities required by small, dedicated cleaning stations that incorporate multiple reuses before discharge. Bosch team members decided that parts cleaning could best be done with small custom cleaners dedicated to one or a few cleaning steps, which is a major switch from the large central cleaners of 1988. This switch eliminated any possibility of cross contamination, shortened cycle times, and allowed better matching of each cleaning process to the specific part and contaminants. The switch from large central cleaners to small custom units has improved part cleaning efficiency and reduced solvent losses. This fresh approach of introducing single function washers for critical cleaning tasks was made easier by the fact that much of the existing cleaning equipment was 10 years old and in need of replacement. Particles larger than 500 μm were being generated in some of these units. Retrofitting or modifying this existing equipment would be both expensive and short-sighted. Selecting new, customized equipment, however, required careful analyses of many cleaning steps. While this process was lengthy and demanding and continues even today, improvements in product yield and quality that accompanied the early efforts have convinced Bosch that this approach is best for them.

The team reviewed other options for replacing chlorinated solvents, but did not choose them for testing. Some, like supercritical carbon dioxide cleaning, sounded exotic and expensive and not production-ready. The primary reason for dismissing other options, however, was that aqueous replacement technology had more advantages and fewer potential problems.

CLEANING PROCESS SELECTION

Cleanliness Criteria

Bosch, Charleston uses two tests to judge the cleanliness of the parts and the effectiveness of the cleaning techniques. The first is a visual inspection. Contaminants inspected for include fibers, dust, and machining debris. In the second test, lots are periodically audited by a five-minute ultrasonic extraction of one basket of parts from the lot in petroleum distillate. The particles released during the extraction are collected on a 2" filter with a 5 μm pore rating and weighed to assess cleanliness.

Control charts plotting reject rates from both the visual inspection and the extraction test monitor the efficiency of the cleaning process. (Figure 4, p. 21, shows a typical chart of part rejection based on visual inspection.)

Supporting tests may be carried out in a vendor's facility, but vendor data have generally played a minor role in the replacement team's decisions. Time lapses between vendor cleaning and evaluation at Bosch hinder this approach. New process evaluation at Bosch is typically done on production equipment made available for tests during off hours. Either an existing production unit is modified or adopted to a new process, or a prototype production unit is ordered from a vendor. Modifications and fine tuning are then carried out on the production scale units before the new process is incorporated into an ongoing production line.

Hardware Selection

Solvent replacement selection at Bosch has always started with the selection of the cleaning process and associated hardware, such as ultrasonics, high-pressure spray, or turbo washing, rather than the selection of a cleaning solvent or fluid. The argument for this approach is that there are hundreds of chemicals to choose from but only a handful of cleaning processes.

To rapidly identify suitable aqueous cleaning hardware, Bosch first investigated off-the-shelf washing stations. If off-the-shelf units proved ineffective or were not available, Bosch retrofitted existing equipment or engineered custom units of their own design. In one application, they converted a low-pressure spray washer to high pressure; in another, a high-pressure unit was modified to use water instead of CFC-113. A turbo washer has also proved very successful in aqueous cleaning of certain parts, but no single piece of hardware solved all cleaning problems.

Drying following wash and rinse was a particularly sensitive issue for Bosch. Functional requirements typically require that all water be removed before the next operation. Removal of water by heating the parts often produced unacceptable spotting. Centrifuging at room temperature after aqueous cleaning has now become the part drying technique almost universally adopted by Bosch. The centrifuges used provide the option of warm air circulation during the spinning, but this drying assistance has not often been necessary.

Chemistry Selection

Compatibility of a chemistry with a part is determined by Bosch's chemical and metallurgical laboratories. These tests for chemical compatibility and absence of part degradation take 24 to 96 hours and are conducted before introducing any chemical into production. Safety considerations (flammability or toxicity) cause some solvents to be eliminated from consideration. The production floor itself then becomes the laboratory for final acceptance tests. Causes of rejection include poor cleaning in production and objections from production personnel regarding solvent odor or part appearance after cleaning.

All but one replacement solution adapted to date has consisted of deionized water alone or deionized water containing an alkaline cleaner. The specific additives and surfactants used in the cleaning steps were selected to be compatible with the part being cleaned, the soil being removed, and the cleaning equipment used. These decisions involved experimenting with various proprietary products to confirm rust protection and satisfactory soil removal.

For instance, oil-based lubricants are used for machining the parts. The parts are cleaned in aqueous systems with chemistries that allow the removed oil to separate from the water. Oil is removed from the tanks in most operations by skimming or gravity separation in holding tanks, and is subsequently shipped off-site in sealed containers for disposal.

Parts cleaned by an aqueous replacement method typically had a different feel and appearance than when cleaned with a chlorinated solvent. They looked duller and often had a different color, and some visible water spots. These obvious differences worried production personnel who were slow to accept the new cleaning process until they adjusted to the new acceptance tests and received assurances from the Quality Gauging Department that the new cleaning process was adequate. Only after a transition period, which varied from part to part and was as long as six months, did production personnel accept ownership of the new cleaning apparatus. Until this confidence built, all breakdowns, equipment, and performance problems were immediately passed back to the replacement team. Once transfer of ownership was completed on one part, acceptance for other parts developed more easily and quickly.

SECTION 4

CONVERSION PLANS AND PERFORMANCE OF FOUR CLEANING STEPS

This section reviews the details of the conversion of four parts from TCE- or CFC-113-based cleaning steps to aqueous cleaning. The four parts selected are described in Table 3 and typify Bosch cleaning operations that have been switched out of CFC or TCE cleaning. These four cleaning steps were chosen because they show the wide variety of options available and results possible when ingenuity is applied to solvent replacement. Each part is discussed separately in the following sections, which summarize the steps taken to select a specific aqueous replacement process, and compare before and after cleaning performance and operating costs.

PART A

Figure 3 shows two process flows for cleaning Part A. The one in the left column is the 1988 process based on TCE and CFC-113. The other is the 1992 aqueous process developed to replace the 1988 chlorinated solvent process.

The process flow consists of two stages, one before an annealing heat treatment--the "soft" stage of the process flow--and a "hard" stage following the heat treatment. This machine and anneal sequence typifies many Bosch-processed parts.

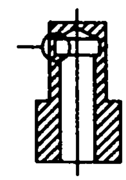
The 1988 Cleaning Sequence

The 1988 cleaning sequence following the soft machining consisted of three separate operations, labeled with a solid square in Figure 3. The initial step was a cycle through a central degreaser (Figure 2). Four other parts were also cleaned in this degreaser. From the TCE degreaser, Part A received a low-pressure

TABLE 3. REPRESENTATIVE COMPONENTS FOR CLEANING

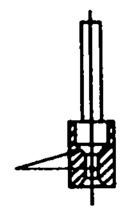
1. Part A

   Composition: 440C steel.
   Size and shape: Approximately 1/2" diameter, cylindrical, 1" long.
   Special cleaning challenge: Internal recess (see circle).
   Contamination to be removed: Metal chips, grinding media, shop dirt, cleaning chemical residues, fibers.
   Measurement of cleaning effectiveness: Visual inspection (100%), extraction testing for particles, statistical process control (SPC) charts.



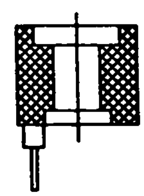
2. Part B (Subassembly)

   Composition: 304 steel.
   Size and shape: 3/4" pin, 1/16" diameter.
   Special cleaning challenge: Internal bore (see arrows).
   Contamination to be removed: Grinding media, shop dirt, cleaning chemical residues, fibers.
   Measurement of cleaning effectiveness: Visual inspection (100%),; extraction testing for particles; SPC



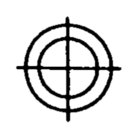
3. Part C (Coil)

   Composition: Polyamide 66
   Size and shape: 1-1/4" high, 3/4" diameter
   Contamination to be removed: Fibers, soldering splatter, contamination generated from shipping
   Measurement of cleaning effectiveness: Visual inspection (audit only); extraction testing for particles; SPC



4. Part D (O-Ring)

   Composition: Viton B
   Size and shape: 1/2" ring made of 1/32" stock
   Contamination to be removed: Metal fibers, filler material, plastic contamination, contamination generated from shipping
   Measurement of cleaning effectiveness: Extraction testing for particles; SPC



1988	1992
Soft	
□ Soft machine ↓ ■ Immersion ultrasonic cleaning TCE ↓ ■ Solvent low pressure spray ↓ ■ Vibratory Immersion CFC ↓ □ Heat treat	□ Soft machine ↓ ■ Turbo wash aqueous (wash time: 15 min; drain time: 2 min); (5% detergent: 150 °F) ↓ ■ Turbo rinse deionized water (130 °F); rinse time: 15 min; drain time: 2 min ↓ ■ Spray rinse/air blow-off (0.2% detergent) ↓ □ Heat treat Qty/day: 42,000 Cycle time, 2 baskets (1,300 pcs): 18 min (same for wash and rinse)
Hard	
■ Immersion ultrasonic cleaning TCE ↓ □ Auto deburr ↓ ■ Ultrasonic immersion CFC ↓ □ Visual inspect/extraction	■ Immersion ultrasonic cleaning TCE* ↓ □ Auto deburr ↓ ■ High-pressure spray wash aqueous (deionized water; 2,000 psi; 4 min/tray) ↓ ○ Centrifugal dry (6 min, 2 trays) ↓ □ Visual inspect/extraction Qty/Day: 42,000

□ = Noncleaning
■ = Wash
○ = Dry

*Turbo washer (aqueous) introduced 10/93.

Figure 3. Cleaning sequences for Part A.

(8-10 atmospheres) solvent spray with a petroleum distillate (flash point of 104 °F). This spraying unit was dedicated to processing Part A ; no other parts were cleaned in this sprayer. The final cleaning step before annealing was immersion in CFC-113. The parts fed into the bath through a spiral chute and were lifted from the bath on a track that was mechanically vibrated to provide agitation and complete cleaning.

After each of the heat treatment and deburring steps, the parts again passed through the central degreaser. They then were subjected to 100% microscopic inspection for contamination. Lots were also audited by the ultrasonic extraction test. The cleaning effectiveness of the 1988 process was not satisfactory. Reject rates ranged from 4 to 6.3 percent. Therefore, the motivation to change stemmed from both performance and environmental issues.

The 1992 Cleaning Sequence

To begin the replacement of the chlorinated solvents, the team sent samples of dirty parts to six vendors of aqueous cleaning equipment. These parts were evaluated by the visual inspection and ultrasonic extraction tests when they were returned. By these tests, a turbo washer with a proprietary detergent proved most successful for this processing step. Turbo washing implies turbulent washing in a vigorously stirred solution, the agitation being supplied by a high-speed impeller. This high-energy feature is physically and economically feasible in a small, dedicated unit.

The decision was made to further evaluate aqueous cleaning in a turbo washer. A series of in-house metallurgical and chemical laboratory tests confirmed that the turbo washed parts exhibited no dimensional or chemical changes. The component surfaces appeared to have retained the properties needed for operation in the final assembly. No residue or altered texture could be detected.

With manufacturing compatibility established and rough cost estimates favoring the aqueous process, the decision was made to switch the cleaning to the turbo washer. Prototype units were ordered and introduced into production. Primary fine tuning on the production floor consisted of trial and error adjustment of the detergent concentration. Reducing the formation of foam is typically an important factor in selecting detergent concentration. Five percent was the optimum detergent concentration to produce a balance between effective cleaning and water spotting, foam formation, or residues.

The new 1992 process consisted of two cycles, a wash cycle in the aqueous detergent solution and a rinse cycle in deionized water alone (Figure 3). In the initial manufacturing version, two units, each with 160 gallons capacity, were used for the wash and rinse cycles. The initial process also included an insurance rinse, called the "spray rinse/air blow-off" in Figure 3. This additional step was carried out in a machine already available at Bosch and became part of the initial replacement sequence. Subsequent plans assume that all three "wash" steps in the soft portion of the 1992 process can be compressed into one step in one apparatus. However, the wash cycle fluid is currently filtered to only 25 μm while a 3 μm pore size is used for the rinse water filter.

The cleaning steps in the "hard" portion, previously ultrasonic TCE and CFC baths, were replaced with aqueous turbo washing (effective 10/93) and a high-pressure (2,000 psi) wash followed by a centrifugal drying step. The custom modification of the washer was performed in-house by Bosch personnel and included the incorporation of a redesigned manifold with five high-pressure pumps. Adding point-of-use filters immediately upstream of the spray nozzles was also important. This modified washer proved more effective in eliminating debris from the deburring operation than the CFC ultrasonic immersion step it replaced. An alkaline aqueous cleaning solution is used in the turbo washer. The high-pressure washer now uses just deionized water, although the initial protocol called for an additive.

A rotary disk skimmer is incorporated in the design adopted to separate oils from the wash solution. This feature, in addition to filtration of the wash solution, means cleaning solution replacement occurs only once a week. The oils are collected in a container and sent out as waste for disposal; the wash water is treated and discharged to the city sewer system.

Performance Comparisons

Visual inspection has been the primary criterion for assessing cleanliness. All components are 100% visually inspected for residue, rust, fibers, dirt, in addition to machining defects and burrs. By this criterion, the aqueous process clearly outperforms the 1988 chlorinated solvent process. Figure 4 shows that rejection rates from visual inspections before the heat treat step have dropped to almost zero from the nearly 40 percent rate that was characteristic of the 1988 process. Previously, the high humidity months from June to August always correlated with high rejection rates at visual inspection because of rust. This high incidence of rust would disappear during the winter months. The 1992 process has eliminated the phenomenon. Bosch chemists believe that water vapor condensed under surface particles at high humidity and formed hydrochloric acid (HCl) with residual chlorinated solvent. The HCl corroded the metal, producing rust spots. Eliminating the chlorinated solvent stopped the acid formation.

Rejects from the visual inspection after the cleaning steps of the hard processing sequence were also significantly reduced with the 1992 process (Figure 5). Two types of rejects are plotted in Figure 5, those attributed to metal chips and those attributed to other particulate contamination. Rejects from both sources are detected by microscopic inspection. The first five months of the 1992 process (months eight to twelve in Figure 5) included a manually operated crank for moving parts under the high-pressure spray. Automating this motion (1/93 in Figure 5) further reduced the reject rate.

At the end of the hard processing sequence, extraction tests were also done on an audit basis. By 1992, the filter used to collect extracted particles had been changed to a 2" diameter with a 3 μm pore rating. Particles on the filter are now counted optically on an optical imaging system (rather than by weighing). Thus, direct quantitative comparisons between the 1988 and 1992 processing sequences are not appropriate. Reject rates because of extraction audits have not changed between the two processes; however, extraction tests continue to be secondary criteria,

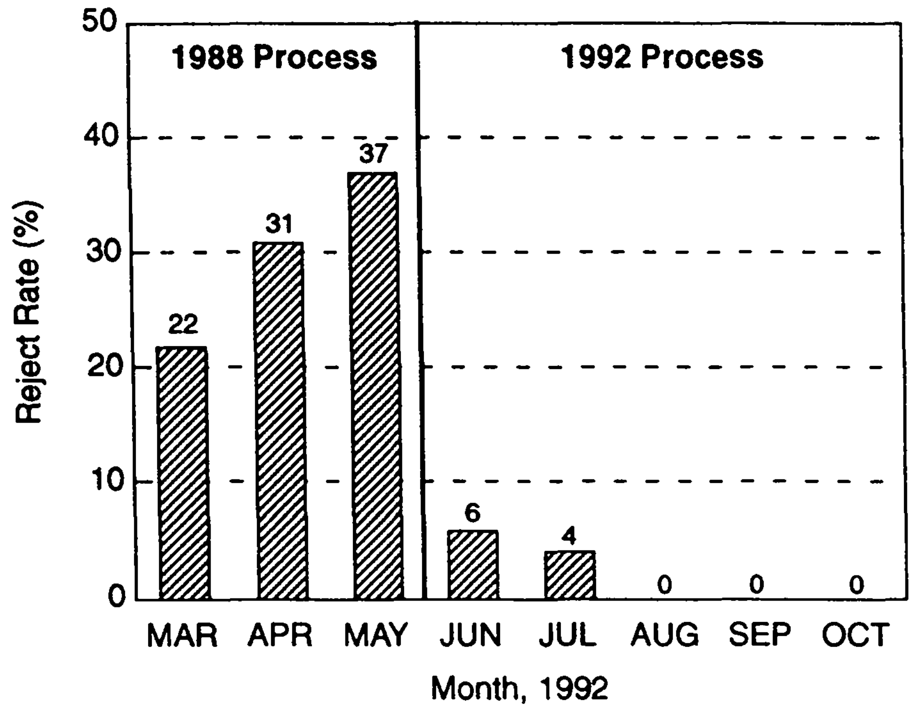


Figure 4. Reduced rejection rate before Part A heat treatment (soft stage) brought about by the switch to the 1992 cleaning process.

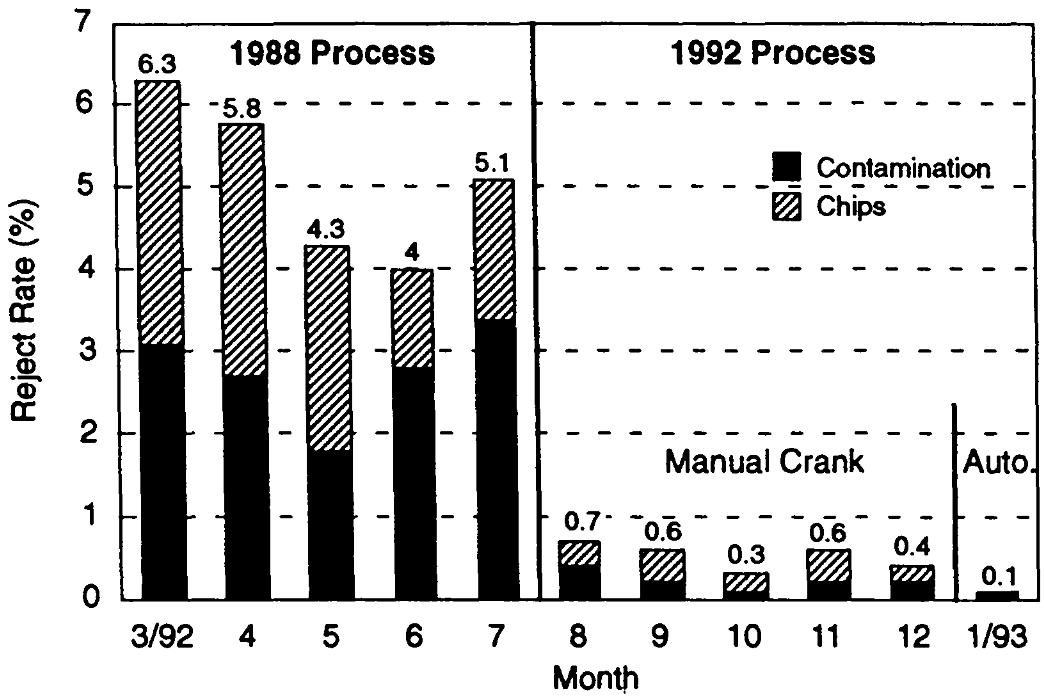


Figure 5. Reduced rejection rate at Part A visual inspection (hard stage) brought about by the switch to 1992 cleaning process.

depending as they do on variables such as part orientation and the condition of the extraction fluid.

Cost Comparisons

A comparison of two types of costs for cleaning is in Figure 6--prorated nondepreciated capital costs and annual labor costs of operation. The prorated nondepreciated capital costs represent the initial capital cost of the cleaning equipment divided among the different part types cleaned by that equipment. In 1988, many different parts were cleaned in the same equipment. The capital costs in Figure 6 represent the fractional use of the equipment. Similarly, labor costs represent the costs of operator labor for cleaning just Part A. All of the cleaning equipment used in the 1992 process of Figure 3 is dedicated to cleaning one component. No other parts are cleaned in this equipment. Cost comparisons for solvent/chemical use and utility power have not been broken down according to part but were presented in Figure 1 as total annual costs for site cleaning operations.

The data in Figure 6 show the 1992 aqueous process to be less expensive in terms of both capital and operating labor costs. The combination of the cost savings and the reduced reject rates of the 1992 aqueous process confirms that chlorinated solvent replacement has been a smart business move for Bosch besides being an environmentally responsible action.

PART B, 304 STAINLESS STEEL SUBASSEMBLY

The subassembly is also a stainless steel component machined at Bosch. Only the post annealing cleaning sequence is depicted in Figure 7. The description of the cleaning steps associated with the soft machining steps has been omitted (they are similar to those for Part A). The 1988 cleaning sequence following annealing consisted of four steps and used both TCE and CFC-113. This cleaning sequence resulted in virtually reject-free parts. The 1992 aqueous replacement process has matched the cleaning performance of the 1988 process and has done so at lower capital and operating costs.

Prorated, Nondepreciated Capital Costs, No Price Index Adjustment

1988			1992		
Soft					
		Footprint* (ftxft)			**Footprint (ftxft)**
TCE ultrasonic	$ 50,000	17x21	Turbo wash		4x5
Low pressure solvent spray	140,000	8x7	Turbo rinse	$70,000	4x5
Vibratory CFC	38,000	8x10	Spray rinse		3x4
Hard					
		Footprint (ftxft)			**Footprint (ftxft)**
TCE ultrasonic	$ 50,000	17x21	Turbo wash	$35,000	4x5
CFC ultrasonic	$50,000	15x22	High-pressure spray	50,000	5x4
			Centrifugal dry	6,000	2.5x2.5
Total	$328,000		Total	$161,000	

Prorated, Operating Labor Costs - 1992 dollars

TCE ultrasonic	0.2 man year	Turbo wash	
Low pressure solvent spray	0.5 man year	Turbo rinse	0.5 man year
Vibratory CFC	0.5 man year	Spray rinse	
TCE ultrasonic	0.2 man year	High-pressure spray	0.5 man year
CFC ultrasonic	0.5 man year	Centrifugal dry	
Total	1.9 man years/shift ($143,000)	Total	1 man year/shift ($75,000)

*Footprint: the dimensions of the floor space occupied by the equipment.

Figure 6. Comparison of cleaning costs in Part A.

1988	1992
□ Auto deburr	□ Auto deburr
↓	↓
■ Immersion/agitation in petroleum distillate	■ High-pressure spray aqueous (4 min/tray)
↓	↓
■ Immersion ultrasonic aqueous	○ Centrifugal dry
↓	↓
■ Immersion ultrasonic TCE	□ Visual inspection
↓	
■ High-pressure spray CFC	Qty/day: 42,000 Parts/tray: 300
↓	
□ Visual inspection	

□ = Noncleaning
■ = Wash
○ = Dry

Figure 7. Cleaning sequences for Part B.

The 1988 Cleaning Sequence

The first of four wash steps in the 1988 cleaning sequence was immersion with agitation in a tank of in-house design. The cleaning solvent for this step was a petroleum distillate. An aqueous ultrasonic bath was next, followed by ultrasonic cleaning in TCE in one of the central degreasing units. The fourth step was a high-pressure spray wash with CFC-113. This high-pressure cleaning step appeared to be critical to the success of the cleaning operation, and high pressure became the focus of the replacement search. Ultrasonics alone did not clean the part adequately; the large mechanical forces that are characteristic of high-pressure spraying seemed necessary for satisfactory cleaning.

The 1992 Cleaning Sequence

Solutions other than water were considered for the high-pressure spray. The group of candidates included many commercially available semiaqueous solvents such as terpenes, and some petroleum distillates. The fire and explosion hazards associated with high-pressure spraying of these flammable solvents discouraged further development. Certain semiaqueous solvents were declared objectionable because of odors or greasy residues left on parts. Water became the fluid of choice for replacing CFC-113 in high-pressure spraying, having both safety and flexibility in its favor.

The 1992 cleaning sequence chosen is a one-step exposure to high-pressure water containing a wetting agent and a rust inhibitor. Bosch engineers converted one high-pressure CFC unit to a high-pressure water sprayer and initiated a series of exploratory cleaning trials. Variables in the test matrix included type of cleaning agent, pressure, temperature, nozzle-to-part distance, and exposure time. From these test results, an acceptable cleaning recipe and sprayer design were developed for the in-house modified unit. The single nozzle of the original hand-held spray equipment was replaced by five manifolds, positioned for maximum part coverage and sized to match the total fluid flow of the original single-nozzle design.

Bosch then contracted with an equipment supplier to build a custom, automated production unit meeting the design specifications determined by Bosch's in-house work. This arrangement proved highly successful as the equipment supplier could use both the clean part specifications, in terms of visual inspection and extraction tests, and the technical guidance provided by the Bosch prototype experiments. Preacceptance tests at the equipment supplier's site led to initial minor modifications. Additional changes in chemical additives and cycle times were made on the production floor at Bosch. The nozzle material was also changed to tungsten carbide to reduce particle generation due to erosion of the nozzle by the high-pressure water. Two months separated initial introduction into production and full production acceptance.

Performance Comparison: Chlorinated Solvents vs. High-pressure Aqueous Spray

The cleaning performance of the 1992 high-pressure aqueous cleaning sequence has matched that of the 1988 chlorinated solvent cleaning sequence. The 1988 cleaning sequence worked very well with virtually no cleaning-related rejects by visual inspection. The 1992 process performs similarly.

Cost Comparison: Chlorinated Solvents vs. High-pressure Aqueous Spray

Figure 8 contains prorated nondepreciated costs of capital equipment for both the 1988 and the 1992 cleaning sequences. It also includes estimates of prorated annual labor costs for both sequences. Labor costs for the automated 1992 process are dramatically lower than those of the 1988 process, which was primarily a manual process. As before, no breakdown of power and chemical solvent costs by part has been made. Table 1 contains these costs for all cleaning operations.

Prorated, Nondepreciated Capital Costs, No Price Index Adjustment

1988		Footprint* (ftxft)	1992		Footprint (ftxft)
Agitation in petroleum distillate (in-house dip tank)	$0	3x3	High-pressure aqueous spray	$160,000	10x7
Ultrasonic immersion, aqueous	50,000	17x21	Centrifugal dry	6,000	2.5x2.5
Ultrasonic immersion, TCE	50,000	4.5x4.5			
High-pressure spray, CFC-113	100,000	5x5			
			Total	$166,000	
Total	$200,000				

Prorated, Operating Labor Costs - 1992 Dollars

Dip tank	0.25 man year	High-pressure aqueous spray, Centrifugal dry	0.25 man year
Ultrasonic immersion, aqueous	0.25 man year		
Ultrasonic immersion, TCE	0.20 man year		
High-pressure spray, CFC-113	0.75 man year		
Total	1.45 man years/shift ($109,000)	Total	0.25 man year/shift ($19,000)
(manual)		(automated)	

*Footprint: the dimensions of the floor space occupied by the equipment.

Figure 8. Cleaning cost comparisons for Part B.

PART C, INDUCTION COIL

The induction coil is an assembly containing several materials, including polyamide 66. This part differs from Parts A and B discussed earlier not only in composition but also in that it is a part fabricated outside the Bosch, Charleston plant. The part is received ready for assembly without additional machining or other processing except cleaning. Cleaning of the coil is essential. Otherwise, contaminants from the coil will interfere with the operation of the product.

The 1988 Cleaning Sequence for Coils

Figure 9 shows the outside origin of the coil by the label "warehouse" before cleaning for assembly. The 1988 cleaning step was ultrasonic cleaning in CFC-113.

The 1992 Cleaning Sequence for Coils

The 1992 process differs from the 1988 process in the substitution of the ultrasonic cleaning fluid and the apparatus in which the cleaning is carried out. The ultrasonic cleaning fluid in the 1992 process is a petroleum distillate, and the apparatus used is a dedicated ultrasonic bath modified to be compatible with the petroleum distillate operation (the commercial unit was designed as an aqueous bath). The key modifications needed to make the ultrasonic unit compatible with the petroleum distillate operation were: (1) the addition of cooling coils, (2) an exhaust line for improved ventilation, and (3) improved bath filtration. A centrifugal drying step has also been added in the 1992 process. The centrifugal drying apparatus includes a pump and filters for reusing the removed cleaning fluid.

The decision to use a petroleum distillate in an ultrasonic bath was based primarily on expediency and represents the only instance in which Bosch used an interim replacement solution before developing the long-term replacement. The reason for this action was to achieve the corporate goal of CFC-free operation by the end of 1992. Replacement of the CFC used for cleaning the coil was the final step in achieving that goal. The petroleum distillate was known to be compatible with the coil and was an easy action to implement in order to achieve a CFC-free plant.

1988	1992
□ Warehouse ↓ ■ Immersion ultrasonic cleaning (CFC) ↓ □ Assembly	□ Warehouse ↓ ■ Immersion ultrasonic cleaning (petroleum distillate) ↓ ○ Centrifugal dry ↓ □ Assembly

□ = Noncleaning
■ = Wash
○ = Dry

Figure 9. Cleaning sequences for Part C, a purchased induction coil.

Developing an aqueous cleaning process, while thought to be feasible and the likely long-term solution, was perceived as a more difficult, longer task because of drying and spotting problems.

Ultrasonic cleaning with the petroleum distillate did allow Bosch, Charleston to meet their deadline for CFC-free operation. Developing a suitable cleaning process for the coil that is not based on a volatile organic compound (VOC) is now underway. However, the cost justification for this next replacement task is not nearly so compelling as with CFC-113 replacement. With CFC replacement, some payback times (time required for the savings in cleaning costs to exceed the cost of the new equipment) were about one month. No such dramatic results will accompany the replacement of petroleum distillates.

Performance Comparisons Between Coil Cleaning Sequences

Coil cleanliness is checked by visual inspection audits (one tray out of 10-20 trays is visually inspected). The visual inspector looks for fibers, dirt, and other foreign matter. However, the primary measure of part cleanliness is the extraction test with a petroleum distillate. Based on the extraction tests, the performance of the 1992 process is superior to that of the 1988 process. Virtually no rejects occur after the 1992 cleaning sequence. The same was not true for the 1988 cleaning sequence, which occasionally did have cleaned parts rejected and returned for recleaning before assembly.

Cost Comparisons Between Coil Cleaning Sequences

Figure 10 summarizes costs for the two cleaning sequences. Labor costs are estimated to be similar, but the capital costs associated with half-time use of the original ultrasonic apparatus exceed those of full-time use of the modified newer unit. $6,000 of the capital costs represent modifications to the off-the-shelf unit.

Prorated, Nondepreciated Capital Costs, No Price Index Adjustment

1988			1992		
		Footprint* **(ftxft)**			**Footprint** **(ftxft)**
Ultrasonic CFC bath	$100,000	24x7	Ultrasonic petroleum distillate bath	$26,000	6x4
			Centrifugal dry (including a safety modification)	10,000	2.5x2.5
Total	$100,000		Total	$36,000	

Prorated, Operating Labor Costs - 1992 Dollars

Ultrasonic CFC bath	0.5 man year/shift ($38,000)	Ultrasonic petroleum distillate bath Centrifugal dry	0.5 man year/shift ($38,000)

*Footprint: the dimensions of the floor space occupied by the equipment.

Figure 10. Comparisons of coil cleaning costs.

PART D, VITON B O-RING

Bosch's fully assembled fuel injector has five O-rings, all of which are purchased. The only Bosch processing of the O-rings is cleaning before assembly. Just one O-ring is in a sensitive location, and only this O-ring is audited for cleanliness.

1988 Cleaning Sequence for O-Rings

The 1988 cleaning sequence for the O-rings (Figure 11) was identical to the 1988 cleaning sequence for the coils, Part C (Figure 9). These parts shared the same cleaning equipment in 1988, splitting the use of the ultrasonic apparatus between them. CFC-113 was the solvent used during ultrasonic cleaning of both parts.

1992 Cleaning Sequence for O-Rings

Early concern over ultrasonic CFC cleaning of O-rings arose because of suspected part degradation caused by the ultrasonic action. This fear of damage directed Bosch's replacement selection away from ultrasonics and high-pressure sprays and toward the lower intensity mechanical actions of the turbo washer. The cleaning sequence labeled 1992 in Figure 11, depicts a three-step wash operation consisting of a turbo wash (140 °F), a turbo rinse (60 °F), and a centrifugal drying step. In practice, the 1992 cleaning sequence has been found to work better without any detergent or cleaning agent in the wash solution. The wash step and the rinse step are, in effect, a rinse-rinse sequence. Both use the same cleaning solution (deionized water) although carried out in sequence in separate units at different temperatures.

These turbo washers are small, 15 gallon units dedicated to O-ring cleaning. The centrifugal drying step is done in a spin dryer. These low cost units easily maintain an adequate throughput.

1988	1992
□ Warehouse ↓ ■ Immersion ultrasonic cleaning CFC ↓ □ Assembly	□ Warehouse ↓ ■ Turbo wash deionized water (140 °F; 2 min) ↓ O Turbo rinse deionized water (60 °F; 2 min) ↓ O Centrifuge dry (room temperature; 1 min) □ Assembly Qty/day: 42,000 each of 5 types of O-rings (210,000 total) O-rings/basket: 1500

□ = Noncleaning
■ = Wash
O = Dry

Figure 11. Cleaning sequences for Part D, Viton B O-rings.

Performance Comparisons Between O-Ring Cleaning Sequences

The primary measure of cleaning effectiveness comes from the visual inspection audits. Plastic or metal fibers are the most common cause of lot rejection. By this measure, the 1992 cleaning sequence outperforms the 1988 cleaning sequence. Lot rejection runs about 1% now compared with 1988 lot rejections of approximately 5%. The obvious improvement caused by the 1992 process led to only 10 days elapsing between the initial production trial and full production acceptance.

Extraction tests yield nondiscriminating poor results for both cleaning sequences. Neither cleaning sequence performs well by this test. This observation supports the suspicion of part damage by ultrasonics. Indeed, prolonged exposure to ultrasonic agitation in the petroleum distillate results in O-ring disintegration and disappearance. The O-ring evidently is eroded away. Even the five minute exposure to ultrasonic petroleum distillate produces eroded Viton B particles in addition to foreign particles extracted off the surface. The extraction test is therefore of dubious value as a measure of cleaning sequence efficiency for these Viton O-rings.

Cost Comparisons Between O-Ring Cleaning Sequences

Costs of the 1988 O-ring cleaning sequence are identical to those of the induction coil. The 1992 cleaning sequence, on the other hand, is carried out in small units that reduce capital costs significantly (Figure 12). Even these modest capital costs could be reduced by eliminating the rinse step that is a repeat of the wash step.

Labor costs are estimated to be the same for the two cleaning sequences.

Prorated, Nondepreciated Capital Costs, No Price Index Adjustment

1988		Footprint* (ftxft)	1992		Footprint (ftxft)
Ultrasonic CFC bath	$100,000	24x7	Turbo wash		2x3
			Turbo rinse	$11,000	2x3
			Centrifuge		1x1
Total	$100,000		Total	$11,000	

Prorated, Operating Labor Costs - 1992 Dollars

Ultrasonic CFC bath	0.5 man year/shift ($38,000)	Turbo wash Turbo rinse Centrifuge	0.5 man year/shift ($38,000)

*Footprint: the dimensions of the floor space occupied by the equipment.

Figure 12. Comparisons of O-ring cleaning costs.

SECTION 5

SUMMARY

The examples reviewed in Section 4 show that Bosch, Charleston has succeeded in every instance in replacing a CFC-113 or TCE cleaning sequence with a sequence based on a nonchlorinated solvent. Furthermore, these replacement sequences have all cleaned as well as or better than the chlorinated sequence and have done so with reduced capital costs and the same or reduced labor costs.

Costs of replacement solvents and operating power were not broken down by part cleaning sequence. For the entire Charleston site, however, the 1988 costs, based on the CFC/TCE cleaning sequences of that year, greatly exceed those of the 1993 cleaning sequences (Table 1). The primary reason for the dramatic reduction in nonlabor operating costs over this 5-year period has been the elimination of CFC solvent losses, as plotted in Figure 1. Although the price per pound of CFC-113 has more than tripled over that period, Bosch's CFC costs have been eliminated. Cost reductions in the future will not be as impressive now that all CFCs have been replaced. The dominant nonlabor operating cost factor in Table 1 is now electric power, but even this cost has been cut in half because of the new cleaning sequences.

Comparative costs between 1988 and 1993 cleaning sequences (Table 1) do not include the engineering and other labor expended in developing and carrying out the replacement strategies and tactics. These costs are substantial and continue to be incurred today as Bosch continues to upgrade and improve its parts cleaning operations. Many 1992 cleaning sequences described in this report will differ from the sequences actually in use in the future. Some have already changed. Clearly, Bosch is convinced that the time and resources already spent in converting from chlorinated solvents have been a good investment. This activity will continue until all TCE and hydrocarbon solvents have been replaced.

None of the aqueous cleaning systems employed or designed by Bosch, Charleston, have been "closed loop" in the sense of having zero discharge. However, the replacement washers typically recirculate the wash solution through filters (ultrafiltration is planned on some units) which has lengthened bath replacement times to one to two weeks. The need for bath changes between scheduled periods of preventive maintenance is determined by the particle count in the bath. Parts with less critical cleanliness requirements may not require as frequent replacement of the bath solution.

Complete regeneration of the wash solution in the Charleston plant is a future project. Bosch GMBH has several sites in Germany that have been operating with a closed-loop aqueous system since 1989. During 1994, Bosch, Charleston plans to set up some closed-loop systems based on vacuum drying and distillation.

SECTION 6

POSTSCRIPT REFLECTIONS

While carrying out Bosch's plan for eliminating chlorinated solvents, the replacement team contacted many equipment vendors in the United States. Support for the team's efforts was not always uniform, with many promises made and then disregarded by the vendors. More surprising and troubling was the lack of basic product information. For example, power densities of ultrasonic cleaners and energy distribution in the bath were generally not known. Worse yet, methods for measuring this characteristic seemed not to exist.

Chemical suppliers, on the other hand, were able to provide detailed information regarding product composition and residues. However, particle concentration in many delivered chemicals seemed unnecessarily high.

The conclusion is that successful replacement of chlorinated cleaning solvents is unlikely to be a simple, routine task. Outside suppliers will not provide all needed answers. The right answer for a given site will ultimately have to be made by that site, and the quality of the replacement selection will reflect the time and effort invested in making the selection. The encouraging message of the Bosch experience is that a determined program, with total support from management, more than justifies itself both economically and environmentally.

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16. ABSTRACT The report documents actions taken by Robert Bosch Corp., Charleston, SC, in replacing the cleaning solvents 1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113) and trichloroethylene (TCE) with aqueous solutions. Bosch has succeeded in eliminating all their CFC-113 use and so far has eliminated two-thirds of their TCE use. Their goal is to be completely free of chlorinated cleaning solvents by the end of 1995. These cleaning changes have not only responded to the environmental goals of the Montreal Protocol and EPA's 33/50 program but have also resulted in improved cleaning at dramatically reduced costs. An early key decision was to replace their aging, large central degreasing stations with several small cleaning units, each designed and dedicated for cleaning just one part at one step in the product assembly process. This strategy demanded reassessment of each cleaning step and identification of apparatus and chemistry for optimizing each aqueous replacement. The report summarizes the actions taken to achieve aqueous cleaning of four typical components, previously cleaned with chlorinated solvents. The report provides quantitative comparisons of cleaning performance and costs of the old chlorinated (1988) and the new aqueous (1992) cleaning methods. For each component, the new method matched or exceeded the old method at similar or lower costs.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Prevention	13B
Solvents	Stationary Sources	11K
Cleaning	Chlorinated Solvents	13H
Degreasing	Aqueous Cleaning	

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