Costs of Cleaning

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Introduction

In an increasingly technologically complex and economically competitive environment, we look beyond traditional cost considerations to look at the impact of cleaning process changes on manufacturing. It is no longer sufficient to choose the cleaning agent and cleaning equipment solely on the basis of performance, capital and consumable costs, and regulatory acceptability. Just as all processes have potential environmental baggage, all new processes have potentially onerous hidden costs. The costs we fail to consider can result in process failure in cleaning operations ranging from metal stamping to microelectronics.

Differential costs between the original and adopted process are often extrapolated from one application to another. It is very useful to look at process conversion costs for individual applications. However, despite the convictions of regulatory agencies or of equipment and chemical suppliers, the cost conversions that are important in one application are not necessarily applicable to your application. It is critical to determine those factors which are important in the anticipated application and to look at all available options. Previously (Kanegsberg and LeBlanc, 1999), we indicated that findings of cost studies appeared linked to the orientation of those groups performing the study. In addition, even sophisticated companies found unanticipated costs associated with process conversion.

A Starting Point

One approach might be to use existing studies as a starting point, and then consider your own company requirements. As a starting point (Table 1), we will use the process conversion costs for one West Coast manufacturer were estimated, as indicated below, as an indication that conversion from an existing in-line cleaning system using 1,1,1-trichloroethane to an aqueous cleaning system resulted in a cost savings of over $50,000 (Ref. "The Alternative," Winter, 2001).

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Table 1: Starting Point
Annual Cleaning Costs, Solvent to Aqueous Conversion
(Costs rounded to three significant figures)

Cost Factor	TCA	Aqueous
capital	NA	$28,600
Training/start-up	NA	$1,540
Labor	$93,200	$93,200
Maintenance	$8,740	$3,450
Electricity	NA	$6,000
Gas	$3,000	NA
Cleaning agent	$95,000	$9,360
Consumables	NA	$6,860
Regulatory	$1,240	NA
Disposal	$600	$390
Total	$202,000	$149,000

The study is impressive in that an environmentally-preferred process for removal of adherent soils in a high-volume application has been successfully implemented. However, in terms of determining your process costs, your company may need to consider a number of additional factors. The adage “the devil is in the details” hold true of all remodeling jobs, including process renovation. What follows are some additional details that you may wish to consider or that may inspire additional considerations which are important to your process.

Total Footprint Costs

Floor space is not an issue for everyone, but floor space is not free.

In the above study, which does not consider the real-estate factor, because the process was indicated to be very high volume, the presumption is that the two pieces of equipment had essentially identical footprints. Certainly, if a large, in-line solvent cleaning system is replaced with an in-line aqueous system, the footprints of the two systems may be similar. Many aqueous parts washers, manual spray cabinets and cabinet washers are fairly compact and comparable in size to a small vapor degreaser., However, in many other situations, the author has observed that, particularly where extensive rinsing and drying are required, a vapor degreaser the size of a medium to large office desk may have to be replaced with a 3 foot by 30 foot in-line cleaner, plus associated systems for deionization, filtration, and recovery of the cleaning agent.

As an indication or floor space costs, some estimates have been provided for the Los Angeles area. The figures are obtained from a Los Angeles mortgage banking firm involved in industrial loans. The assumptions are:

- The manufacturing firm is a tenant rather than an owner
- The building is 20,000 square feet with approximately 10 to 15% office space
- The areas have a B+ location
- The rent is on a triple net lease basis

Manufacturing firms typically lease their location. A 20,000 square foot facility would be typical for a small manufacturer. A B+ location is not the most expensive, prime location. It would be typical of an area acceptable for manufacturing which is not of prime quality but not dilapidated. A triple net lease basis means that the tenant pays taxes, insurance, building maintenance, and utilities. Real estate costs vary (location, location, location). Some recent monthly rental rates per square foot are indicated in Table 2: To the triple net lease must be added all of the taxes and maintenance costs to obtain the gross lease. These costs can vary considerably. The local mortgage banking firm estimates a range from $0.30 to $0.60 per square foot per month, in part depending on whether or not the facility is protected from tax rate increases.

Table 2: Commercial Rental Rates in Los Angeles Area

Location	Triple Net Lease Cost/ square foot/month	Gross Lease Costs including taxes, upkeep/ square foot/ month
Valencia	$0.40 to $0.50	$0.70 - $1.10
City of Commerce	$0.45 to $0.60	$0.75 - $1.20
Ontario	$0.35 to $0.40	$0.65 – $1.00
Torrence	$0.50 to $0.60	$0.80 - $1.20
Los Angeles, Center City	$0.50 to $0.60	$0.80 - $1.20
Riverside	$0.45	$0.75 - $1.05

Rental costs per year for the Los Angeles area could then range from $7.80 to $14.40 per square foot.

In order to estimate impact of floor space costs, a number of cleaning equipment scenarios are outlined. In these scenarios, conveyorized aqueous washers are emphasized to allow reasonable throughput. The results are summarized below (Table 3).

Floor space A: Large conveyorized aqueous washer
In the example above, the size of the aqueous cleaning system is not provided. For the purposes of comparative analysis, we can make some assumptions. An aqueous cleaning system with rinse stations and a drying station can easily be 25 feet long by 4 feet wide. However, the effective dimensions must include space to load and unload product as well as space to walk around the equipment. Whereas with many solvent-based systems, one side of the equipment can be placed very close to the wall, with most larger conveyorized or batch aqueous systems, it is necessary to have access to the equipment from all sides. If we allow for approximately 5 feet of racking and load/unload areas at each end and 3 feet on each side of the long dimensions for traffic and access to the equipment, the foot print of the cleaning equipment plus work area could increase to 35 feet by 9 feet. (315 square feet). These dimensions will vary depending on the process involved. Particularly if drying is an issue, the product may have to be more carefully fixtured. In addition to load/unload activities, areas to allow the product to cool before proceeding to the next step may be required. Based on the areas in Los Angeles listed above, the annual floor space cost could range from: $2450 to $4540

Floor space B, Moderate Size Single-Chamber Batch Aqueous System
For smaller-scale processes in a limited space, it is sometimes possible to use an aqueous system where washing, rinsing, and drying all take place in a single chamber. One design has a 26 x 26 x 26 inch chamber. The external dimensions are 66 l x 36 d x 66 h. (5.5 ft x 3 ft). (Call, 2001). Adding a total of 2.5 feet clearance on the sides of the equipment, and one foot behind the equipment for access along with 3 feet in front to open the door plus 3 feet for parts loading, total floor space is approximately:
8 ft x 9 ft = 72 sq ft. Floor space costs become $562 to $1040.

Floor space C, Elevator Vapor Degreaser, compared with
Floor space D 3-belt aqueous washer

In another high-volume application, a 15 x 9 foot solvent vapor degreaser was replaced with a 3-belt aqueous washer with a footprint of 70 feet x 12 feet. The overall floor space dimensions in this example were not provided. However, assuming fairly generous parts-handling spaces, a reasonable floor space estimate would be:
Solvent system: 23 x 12 feet = 276 square feet; $2150 - $3970
Aqueous system: 80 feet x 18 feet = 1440 square feet; $11,200 - $20,700

You might keep in mind that auxiliary filtration and deionizing systems can add 100 or more square feet to the required floor space. A typical boiler can be 12 x 12 feet; however, boilers are typically required for all types of heated systems.

Floor space E, Small, NESHAP Compliant Open-top Vapor degreaser
Sometimes, the older solvent system being replaced may have been equivalent in size to the newer aqueous system. However, in critical cleaning applications, the author has often observed that the initial system was a small, desk-top size liquid/vapor phase open top degreaser.

A small vapor degreaser with sufficient environmental controls to meet the National Emissions Standards for Halogenated Solvents (NESHAP) would tend to have a much smaller footprint than the aqueous system needed to replace it. This information was provided by a major manufacturer of both solvent and aqueous cleaning systems. A 4' by 2' cleaning system with back-mounted pipes would be adequate to handle many medium-volume cleaning applications. To the overall dimensions of 7' 2" x 4' 8" must be added sufficient space for a ladder, walking space, and an auxiliary chiller which can be located under the steps. Allowing an approximate floor space of 13' by 8' including the work space, this would be a 104 square foot system. The annual floor space cost of such a system would range from $811 to $1500.

Floor space F, Small, Airless Vacuum System, Standard Model
Sometimes it is desirable to use high-cost solvents such as hydrofluorocarbons, hydrofluoroethers, or hydrochlorofluorocarbon 225. Or, it the aggressiveness, broad solvency and rapid-drying capabilities of a chlorinated solvent which is covered by the Halogenated Solvents NESHAP may be required. In such cases, a vacuum cleaning system or airless system may be selected.

For this analysis, we will examine the smallest and largest standard models for a precision vacuum system (Okhubo, 2001). The smallest standard model is 92 inches x 59 inches x 79 inches high and has an optional regenerative recovery system of 20 inches x 63 inches x 79 inches high. This is a small system; the working tank space is 14 inches in diameter by 8 inches usable depth. In the interest of minimizing hazardous waste, we are further assuming that the user chooses the additional investment in a regenerative carbon system.

Allowing 4 inches between the recovery system and the equipment, the overall dimensions for the equipment itself would be 116 inches x 63 inches (9.7 ft x 5.3 ft). Adding just over 5 feet at the front of the system plus approximately 4.5 feet total to the width, the overall floor space estimates would be approximately 15 feet x 10 ft, or 150 sq ft. Annual floor space costs would range from $1170 to $2160.

Floor space G. Large Vacuum System, Regenerative Carbon, Standard Model
In the same product line, the largest standard model vacuum system is 95 in x 71 in x91 in h with a carbon recovery system of 20 x 63 x 79. The working tank is 26 inches in diameter x 14

inches usable depth. Using similar reasoning, the equipment floor space would be 119 x 71 inches or 10 ft x 6 ft. Adding 5 feet at the front plus 5 feet total to the width for work space would bring the floor space to 15 ft x 11 ft, or 165 sq ft. Annual floor space costs would range from $1290 to $2380. For systems F and G, floor space costs are relatively similar.

Floor space H. Compact airless system, non-regenerative carbon system
This system does not include a regenerative carbon system.
The dimensions are 4 ft cube for a system with a 12 in cubic chamber (Gillman, 2001). It is assumed that the carbon canister can be placed on roof. If the canister were located in the work area, impact on floor space would be greater. For consistency with F and G, we will assume an additional 5 ft at the front of the equipment, plus 5 ft total on the sides.
Total workspace 9 x 9 ft 81 sq ft.

Table 3: Summary, Annual Floor Space Cost Estimates, Los Angeles Area
Assume" $7.80 to $14.40/ sq ft

Cleaning System	Floor space, square feet	Annual Cost, floor space
A. Large Conveyorized aqueous washer	315	$2550 - $4540
B. Medium Single chamber batch cleaner	72	$560 - $1040
C, Elevator vapor degreaser	276	$2150 - $3970
D. 3-belt aqueous washer	1440	$11,200 - $20,700
E. NESHAP-equipped open-top vapor degreaser	104	$811 - $1500
F. Small Vacuum Solvent System, Regenerative carbon	150	$1170 - $2160
G. Large Vacuum Solvent System, Regenerative carbon.	165	$1290 - $2380
H. Small Vacuum Solvent System, remote non-regenerative carbon system	81	$630 - $1170

Floor space costs are not always considered in process selection. However, as is indicated in the above comparative analyses, the impact of selected cleaning system on floor space costs can be significant and can also be quite variable. Some additional floor space related factors could be important in your process may necessitate relocation of bench work, hand cleaning, or overhaul and rework operations.

• Organic solvents. It may be inadvisable to conduct assembly and repair activities in the vicinity of large cleaning equipment due to potential employee exposure concerns.

• Noise. Blowers, air knives, high pressure spray, and ultrasonic transducers can additively produce noise levels which are unacceptable to employees and may be officially unacceptable to your Safety Department.

• Mists, odors, heat. One typically thinks of solvents in terms of unpleasant odors. However, in the presence of high heat and vigorous cleaning action, aqueous formulations can also produce heat, mists, and odors.

• Product configuration, process flow. If large parts (for example very long tubes) must be handled or allowed to cool, additional space will be needed.

• Total available floor space, relative value of various manufacturing activities.
Often, particularly in regulatory-related analysis, it is assumed that the manufacturing facility should choose to devote unlimited amounts of space to cleaning and pollution control activities. Given that manufacturing space is not unlimited, consideration of the relative value of all manufacturing activities must be considered.

Capital Equipment and Major Recurrent Expense Costs

A: Large conveyorized aqueous washer

We do not have a complete picture of conveyorized aqueous washer. While we know that the annual capital cost is $28,600, we do not know the payback period. For the purposes of this discussion in comparison with other systems, we will assume a payback period of five years, bringing the total estimated cost to $143,000.

B, Moderate Size Single-Chamber Batch Aqueous System

The cost of a typical medium sized batch equipment with a single square chamber 26 inch on a side described for floor space B estimates is $35,800. (Call, 2001

(note: capital cost analysis for a new elevator degreaser was not performed)

D 3-belt aqueous washer

Very large three-belt aqueous system
The cost of the very large three-belt aqueous system described in floor space D is estimated at $1,000,000
$750,000, basic equipment cost
$250,000, deionized water system
(Gillman, 2001

E, Small, NESHAP Compliant Open-top Vapor degreaser

Given requirements for solvent containment as well as options for automated solvent handling, costs of a typical new NESHAP-compliant liquid/vapor solvent system can range from $21,000 to $70,000, depending on part-handling options.
For this analysis we will use for comparison purposes a range of:
Non-programmable NESHAP system, $21,000
Programmable NESHAP solvent system, $50,000

The cost breakdown is as follows:
4 foot x 2 foot NESHAP compliant degreaser, with filter and spray, $20,000 - $30,000
Coffey chain hoist $1,000
Automated, programmable hoist: $20,000 to $40,000. A $20,000 hoist provides adequate part handling capabilities for many applications. (Gillman, 2001).

F, Small, Airless Vacuum System, Standard Model
The smallest standard airless system with a regenerative carbon system would cost $167,000 (Ohkubo, 2001)
This is based on:
$114,000 basic system cost
$47,000, recovery system
$6,000 optional spray

G. Large Vacuum System, Regenerative Carbon, Standard Model
The largest standard airless system with a regenerative carbon system would cost $224,000 (Ohkubo, 2001)
This is based on
$150,000, basic system
$66,000, solvent recovery
$8,000 tumbler

H. Small, Compact airless system, non-regenerative carbon system
An alternate compact airless system is estimated as follows. In this discussion, we will assume that no ultrasonic cleaning is needed, bringing the cost to:
$71,400
$70,000 basic system cost, immersion or spray cleaning
$10,000 ultrasonics
$1,200 - $1,400 annual costs, carbon, assuming usage of two drums per year on an exchange program.
Additional variable factors:
An external still may be required depending on throughput and soil loading.

In addition, carbon usage depends on the solvent. Azeotropes and blends sometimes have to be managed and at greater costs where one of the components is flammable. The adsorption rate of carbon for some of the newer, engineered solvents such as HFC's and HFE's is not as great as for classic, chlorinated solvents.

Installation, Development Costs
Many cost analyses do not consider the full impact of installation costs.

In an analysis of solvent waste stream minimization (McChesney and Scapelliti, 2001), there is a statement that "installation costs can be a significant percentage of the capital equipment purchase price; 25% is usually a good budgetary estimate." They are referring to a distillation unit. However, 25% is probably a good, conservative overall guideline. By the way, this same analysis provides excellent tools for estimated energy costs and likely payback.

In the aqueous process conversion described above, it is not clear if the annualized capital costs of $28,500 included installation costs (which could include removal of the original system). If such costs were not included in the original analysis, an amortized installation estimate of $7120 could reasonably be added to the cost of process change.

Installation and process development costs can vary; and such costs can be very high for both aqueous or a solvent-based cleaning. In the aqueous conversion, an allusion is made to start-up issues, but the engineering effort is not outlined. If the cleaning process is new, or if the cleaning equipment and cleaning agent have not been tested together in large-scale production, it is prudent to budget for time and effort. In one critical cleaning application, a large, high-technology company purchased a contained solvent cleaning system for $156,000. Because of historical company issues with chlorinated solvents, the intent was to use the new system with a newer, very costly environmentally-preferred organic solvent blend. The solvent process is not yet in production. However, the estimate is that capital equipment, installation, and engineering costs are currently between $350,000 and $400,000. In this case, the installation and process development costs were over 150% of the original equipment costs. A large aqueous in-line system in a similar high-technology application required approximately five years to optimize. This effort included a non-quantitated level of engineering, maintenance, training, and equipment modification.

Many high technology cleaning processes are site-specific. The equipment may be custom-designed; the cleaning agent blends and sequences of cleaning agents may not have been widely used. To control installation and set-up costs (or at least to anticipate surprises), it is prudent to get as much information as possible as to where similar processes have been successful. Direct contact with a number of cleaning agent and cleaning equipment suppliers is invaluable. Ask for references using similar equipment and chemicals and then contact them (Kanegsberg, 2000).

Total Process Costs

It is profitable to analyze the impact of cleaning time on total process flow and throughput. All other things being equal, an increase in cleaning process time is considered a negative. As always, this must be analyzed in context of the total process. Sometimes the increase in cleaning time does not represent a bottleneck, or it can be compensated for by increasing cleaning capacity. If the increased process time is due to poor cleaning and the need for additional rework, this can be a problem.

Lefiell analyzed their overall manufacturing process and determined that adopting an airless cleaning system could greatly improve process time, throughput, quality; and had environmental benefits (Ray *et al*, 2000). Their original open-top degreaser using perchloroethylene required a 45-minute cleaning cycle; while the selected airless cleaning system required a one-hour cycle. However, use of an airless system allowed cleaning, parts handling, and heat treatment of large metal parts to be conducted in a single work cell. Cleaning and heat treatment can now be conducted within 20 feet of each other, with a saving of 60 per cent of travel footage. Previously, very large, bulky parts had to be transported from the separately-contained vapor degreaser. The savings in time and increased quality of the heat treatment process (in part due to more controlled parts handling) resulted in far superior process flow. The overall process time was reduced by 50%. In some cases overall production time (sheet metal to shipped product) decreased from 20 weeks to 10 weeks. In this case, a 15 minute increase in the cleaning cycle falls into the noise level as compared with a 10 week reduction in overall process time.

Cost of Excessive Cleaning

Often, particularly where there are environmental drivers, a company has found that fewer cleaning steps were required. This implies cost savings on a number of levels including chemicals, equipment, and labor.

Chawla notes that an exceedingly low failure rate may imply over-cleaning (Chawla, 2001. He provides a general cost/benefit analysis to determine optimum level of cleanliness relative to acceptable conformance. In some applications, it can be beneficial to factor in the cost of direct, in-house surface monitoring and/or periodic analytical testing as part of overall process control and cost reduction.

The costs of excessive cleaning are so process-specific that they will not be considered in this analysis. In general, however, determining how much cleaning is actually needed can save in overall costs. In one high-technology biomedical application, by improving cleaning efficiency and by determining what cleaning was actually needed, cleaning steps were cut from 18 to 6, reducing the labor costs to approximately one third.

Cleaning Agent Costs

Cleaning agent costs depend on the quantity purchased, cleaning efficiency, solvent losses, and depletion of the aqueous solutions. In the sample study above, the comparison was made between aqueous cleaning and cleaning with1,1,1-trichlorothane (TCA); the cost of TCA was $95,000. Some typical cost comparisons are provided in the following table (Table 4). This table is based on the cost of TCA approximately one year ago, to be more reflective of the time frame when the decision to change the process might have been made.

Assuming that reclaimed TCA at $4.50 per pound were acceptable for the process, the company would have used 21,100 pounds of TCA annually. If perchlorothylene (PCE) at $0.52 per pound could have been used, annual solvent costs would have been $10,900. If trichloroethylene (TCE) at $0.90 per pound, could be used, the cost would be approximately $19,000. Of course, the equipment would have to be at least consistent with NESHAP requirements, and in California, air toxics regulations require even more stringent environmental controls. A capital investment of $200,000 for containment equipment would cost $32,500 annually (assuming a 10% capital equipment loan for 10 years) and since annual savings in solvent cost would be at least $75,000 (using TCE, more if using PCE), the capital investment would have a payback of under five years.

Table 4: Solvent Cost Comparison

Solvent	Cost/pound	Quantity purchase	Source, Comments
TCA, virgin, film grade, no dioxane	8.68	1 x 55 gallon	Distributor A, not currently available
TCA, virgin, with dioxane	7.28	1 x 55 gallons	Distributor A, currently available
TCA, reclaimed	4.50	1 x 55 gallons	Distributor B, no current stock, price several months old, reported of good quality,
HCFC 141b, generic	2.50	10 x 55 gallons	Distributor A
HCFC 141b, Allied	3.70	10 x 55 gallons	Distributor A
TCE	0.77	10 x 55 gallons	Distributor A
TCE	0.90/0.75	1 x 55 gallon 10 x 55 gallons	Distributor B
MC	0.57	10 x 55 gallons	Distributor A
MC	0.70/0.57	1 x 55 gallons 10 x 55 gallons	Distributor B
PCE	0.52	10 x 55 gallons	Distributor A
PCE	0.60 - 0.65/0.50	1 x 55 gallon /10 x 55 gallons	Distributor B

Incorporating Solvent Costs

The costs of the cleaning process depends on the situation in question. The original scenario could be expanded to indicate a number of possible productive options. Assuming that new capital equipment were not required, if PCE or TCE could be used in the current NESHAP-compliant equipment, the costs of the process could be decreased to $118,000 for PCE or $126,000 for TCE. Assuming stringent environmental requirements, one might envision installation of a $200,000 airless (vacuum) cleaning system, with a chamber adequate to meet production throughput. Some reasonable assumptions for the new airless system might include:

- a five-year payback
- training and start-up no greater than that indicated for the aqueous process
- maintenance no greater than for the aqueous
- solvent usage of one-quarter that for an open-top (actual conservation is typically much greater)
- no change in regulatory costs (in some locations such costs might decrease)

In such a scenario, the costs of TCE and aqueous cleaning become essentially identical. In this case, the payback-period for the aqueous system is not known. An assumption of 5 years is made for this comparison, although an equipment cost of $143,000 for an aqueous system (or for any other system) is likely to be a bit low for a very high-volume application.

The estimate of $200,000 is based on the smallest and largest standard airless systems described in the F and G estimates (Okhubo, 2001). For this estimate, the same figures for training and start-up were considered for aqueous and airless systems; as discussed below

(Table 5), these are probably unrealistically low for most situations.

Table 5: Cost Factors, Aqueous and Classic Chlorinated Solvent Cleaning Agents

Cost Factor	**TCA**	**Aqueous, Large, conveyor-ized**	**PCE, NESHAP-type open-top**	**TCE, NESHAP-type open-top**	**TCE, Airless System**
Capital	NA	$28,600	NA	NA	$40,000
Training/start-up	NA	$1,540	NA	NA	$1,540
Labor	$93,200	$93,200	$93,200	$93,200	$93,200
Maintenance	$8,740	$3,450	$8,740	$8,740	$3,450
Electricity	NA	$6,000	NA	NA	NA
Gas	$3,000	NA	$3,000	$3,000	$3,000
Cleaning agent	$95,000	$9,360	$10,900	$19,000	$9,500
Consumables	NA	$6,860	NA	NA	NA
Regulatory	$1,240	NA	$1,240	$1,240	$1,240
Disposal	$600	$390	$600	$600	$600
Total	$202,000	$149,000	$118,000	$126,000	$148,000

For simplicity, we have considered only the classic chlorinated solvents. Such solvents are not always the optimal choice. If HCFC 225, HFE's, HFC's, or blends were appropriate, at costs ranging from approximately $12 to $20 per pound, then an airless system would become more attractive.

Where regulatory requirements of company policy precludes the use of classic chlorinated solvents, the company might also consider cleaning with low flash point solvents such as isopropyl alcohol, isopropyl alcohol/cyclohexane azeotrope, or even acetone (which has the advantage of being exempt as a volatile organic compound. These solvents are available at well under $1.00 per pound; and the capital equipment investment is, in many cases, similar to that for an airless system (Briles *et al*, 2000).

<u>Considering Multiple Factors</u>
Mr. Gillman points out that site preparation costs can vary markedly among systems, and is highly site-specific. Such factors include plumbing and electrical facilities and water preparation costs. These factors can be prohibitively high.

One should also factor in real estate costs, keeping in mind that it can be profitable to remain flexible as to the ultimate cleaning system employed. In this analysis, we will assume the high end cost of real estate, on the grounds that bread lands butter side down. That is, when you need more real estate, the costs are likely to be high.

Table 6: Real Estate, Installation Costs

A. A. Large conveyorized aqueous washer
B. B. Medium single chamber batch aqueous
D Very large 3-belt aqueous
E NESHAP equipped open-top, simple hoist
F Small vacuum solvent system with carbon regeneration
H Compact, small vacuum solvent system, carbon not regenerated

Cost Factor	A Large convey-orized aqueous wasl

Floor Space	$4540
Capital Costs, 5 year payback	$28,600
Amortized Instal-lation costs @ 25% of capital	$7120
Total	$40,260

Discussion: Factoring in Labor, Process Flow, Waste Disposal, Energy

Even considering above summary (Table 6) of real estate and installation costs, it becomes apparent that the best pathway for a particular facility will depend on site-specific assembly requirements. It would be possible to continue to construct costs analyses "proving" that a particular cleaning technique or cleaning agent is more economical. Instead, we will provide a few additional considerations and allow the reader to construct cost tables which begin to approximate his or her own production situation.

Let us assume that, based on the original example, the company was spending $93,000 yearly in labor. In the orginal TURI study (Kanegsberg and LeBlanc, 1999), it was pointed out by C. Hinkle and others that some process conversions to aqueous cleaning resulted in a significant increase in re-cleaning requirements. This is not an isolated incident. One author (B.K.) has observed signage on equipment instructing the operator to routinely clean certain assemblies two times. Very often, end-users are reluctant to indicate the proportion of product which needs to be re-cleaned.

In the original example, the system for floor space A did a great cleaning job, equivalent to or better than the original solvent system. However, let's assume that a significant proportion of product, say, 25% of product needs two cleaning cycles. In that case, labor costs could increase by $23,300, with no value added to the product. This assumes that the parts which require re-cleaning belong to a separate product line an could be readily identified. If each part needed individual inspection or if product rework were required, the labor costs could increase even more drastically; you have probably chosen the wrong system. Let's assume for now that we can identify and segregate those parts needing extra cleaning.

We could put more money into a larger system. The investment in the very large system D is appropriate where justified by product composition and volume. It is tempting for some companies to solve a cleaning problem by investing in one very large cleaning system. However, for many applications, it would probably be better to invest a bit of time and engineering effort in an investigation of efficacy of cleaning. It might be determined that 75% of product is cleaned effectively in the in-line system (A). Perhaps 25% of the product contains soil which is effectively removed by a two or even three cleaning cycles in a batch washer (the operator would, at most, need to push a "start" button several times). Assuming that the production schedule can be adjusted the increased cycle time for 25% of product, a yearly added investment of just under $10,000 in a moderate-sized cabinet washer could more than make up for the $23,300 in labor costs. One company (O'Neill et al, 2000, a and b) accomplished a total aqueous conversion. While they were largely able to use one cleaning chemistry, they did not attempt to force all cleaning into a single large cleaning system.

On the other hand, if a very large aqueous washer with yearly base costs of $270,000 were required (as in example D), the purchase of several smaller or one larger, custom contained solvent cleaner of the type E, F, or G might be justified. As discussed in another publication, (Ray _et al_, 2000), there is a points at which it is prudent to consider aqueous cleaning for some processes and solvent cleaning for others.

It should be pointed out that, even in the midst of an energy crisis while those of us on the West Coast are encouraged to dine and write by candle light (we could claim to use our solar-powered computer), a dispassionate analysis of energy costs for cleaning processes still remains a hope of the future. As with the previous report, hard figures for energy costs are difficult to obtain. In the future, it would be desirable for energy costs to be estimated in setting up any new process.

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