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THE APPLICATION OF MEMBRANE TECHNOLOGY AS AN ELEMENT OF BUSINESS COMPETITIVE ADVANTAGE

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ABSTRACT

Three case studies are presented from the metal working and finishing industry where the application of flow through membrane technology was implemented as a cost-saving and waste reduction element within the manufacturing process. These systems were installed as integral elements of the manufacturing process, different than an end-of-process treatment scheme. The project approach in each case study was: establishing a baseline of operating conditions; a preliminary economic analysis of the application; generation of meaningful business economic criteria; preliminary pilot testing to confirm technical feasibility; schematic design and conceptual layout, design and approval; installation; start-up and shake-out; full scale operation; testing; and auditing of cost savings and production improvements. The three case studies were implemented in the metal working and finishing industries where cleaning, degreasing and phosphating is widely used in the manufacture of metal products to precondition metal surfaces. Typically, distinct phases are involved: alkaline- or acid-based aqueous cleaning and degreasing, metal phosphate treatment, and ultra-pure rinse or sealer. Counter-flow or continuous rinses are also employed, depending on the application. The aqueous cleaning solutions are re-circulated and dumped to a pretreatment facility or hauled away when spent. This involves a significant cost burden to the facility in terms of waste requiring treatment, replacement chemistry for bath dumps, associated purchased water costs, sewer discharge costs, permitting costs, and labor costs. In addition, the manufacturing process itself produces significant opportunities for deviation from target product quality. This occurs as a result of the buildup of contaminants in each of the metal preparation stages. Quite often this inherent lack of control on the bath quality will manifest itself in the form of poor paint quality, rejected parts, and production downtime. All of these costs are measurable and, more importantly, avoidable.

KEYWORDS

wastewater, metal working and finishing, membrane filtration, aqueous cleaning, parts washing

INTRODUCTION

Membrane technology historically has been used in the water treatment industry to generate desalinated water in areas where raw water supplies dictated this requirement. Recently, membrane technology has been applied as a surface water treatment element, particularly where micro filtration provides a feasible alternative to conventional filtration schemes. The application of membrane technology in the industrial arena has been predominately to produce ultra-pure water for manufacturing processes and, in some cases, the pretreatment of oily wastewater streams prior to discharge to a Publicly Owned Treatment Works (POTW) or to a receiving water under a National Pollution Discharge Elimination System (NPDES) permit.

This paper focuses on three case studies in the metal working and finishing industry where the application of membrane technology was used as an element within the manufacturing process itself, not as an end-of-pipe treatment. These case studies will illustrate how documented operating cost savings can be realized along with a commensurate reduction in the volume of pollution generated. In each case study presented, the authors predicted and later verified, using audited cost accounting techniques, that the installed membrane systems gave an operating competitive advantage to the manufacturing businesses.

The paper will discuss:

1. Pressure-driven flow through membrane technology.
2. The metal working and finishing industry and how membrane technology can be used to manage aqueous cleaning solutions.
3. The authors' project approach to implementing a successful membrane technology project, along with a brief discussion of previously published work on the subject.
4. Three specific case studies where a competitive advantage was realized in the metal working and finishing industry by implementing a membrane technology strategy to manage aqueous cleaning solutions as part of the manufacturing process.

PRESSURE-DRIVEN MEMBRANE TECHNOLOGY

A wide range of different separation processes can be used to remove unwanted contaminants from a solution or to reclaim a specific component in an aqueous solution. Figure 1 (*Separation Processes*) identifies some of the different types of separation processes and the useful separation ranges of the various processes. Membrane filtration technology is a separation process often used in industry to remove contaminants such as solids, metals and oil grease from aqueous solutions. Membrane filters commonly used fall into two categories: depth filters, such as cartridges, and cross-flow filters, such as ultra-filtration (UF) or reverse osmosis (RO) filtration. With depth filters, the solution being filtered flows through the media, causing particles to collect on the surface. As the depth of the particles increases, the pressure across the filter increases until the filtration rate decreases or stops completely.

Cross-flow filters use a high velocity flow path across the medium. This tangential flow scrubs the filter surface clean of solids which means the solution being filtered sees a relatively clean filter surface. The membrane filtration technology that will be discussed in this paper is a cross-flow pressure-driven technique for separating submicron particles from large dissolved molecules through a porous membrane. It is actually the filtration of suspended, dispersed, or emulsified solute from a solution. It works by producing two separate streams: concentrate and permeate. The permeate stream contains only the components in the feed solution small enough to pass through the membrane. The concentrate contains everything that is rejected by the membrane (emulsified oil and dirt). Figure 2 (*Cross-Flow Membrane Filtration Concept*) illustrates the cross-flow membrane filtration concept. Membrane filters are made from a variety of materials and the application will determine the pore size and the material of construction.

WASTEWATER MANAGEMENT IN THE METAL WORKING/FINISHING INDUSTRY

The metal working and finishing industry produces products such as metal furniture, automotive parts, machinery, fixtures, appliances, and hardware. Unfinished products made of aluminum, iron, steel, copper, brass and other metals are processed through a series of metal working and finishing operations before they become a finished product. The metal working operations include metal forming, metal removal, and metal fusing. The finishing operations include cleaning, surface preparation, and surface finishing. Figure 3 (*Metal Working and Finishing Process Flow Diagram*) is a general metal working and finishing industry process flow diagram. The figure identifies the metal working and finishing operations that the unfinished metal product is processed through before becoming a finished product. In addition, it lists the specific types of processes that correspond to each metal working and finishing operation.

In the metal working operations, lubricants (cutting fluids) are often used to facilitate the machining process. As the metal part is machined or processed it becomes contaminated with metal fines and cutting fluids. These contaminants, if left on the part, can later result in a defective part or hinder finish quality. Therefore, each part is typically cleaned and processed through some type of surface cleaning or pre-conditioning process prior to being coated or finished. The purpose of surface treatment is to condition or prepare the surface so that the coating applied later forms a better bond with the metal surface. Historically, chlorinated solvents were used to clean metal parts, but concerns over environmental and health effects associated with using chlorinated solvents significantly reduced their use. The metal working and finishing industry now primarily uses mechanical action and chemical reactions to clean and precondition the surface of metal parts prior to them being coated or further processed. The chemical reaction often involves the dissolution of the contamination and metal into an aqueous cleaning media.

The constituents of the aqueous solutions/cleaners typically include:

- Alkaline/acidic salts—Alkaline salts such as sodium or potassium hydroxide neutralize acidic soils/contaminants. Acids such as sodium, iron, or potassium phosphates in their different forms exhibit some detergency, especially in the case of mineral oil and also promote efficient cleaning by binding ions that cause hardness.
- Sequestering or chelating agents—Chelating agents are a class of chemicals that are especially incorporated into the aqueous cleaning solution to bind problem-solving ions such as calcium or iron, which tend to form deposits on cleaned parts.

- Wetting/emulsifying agents (surfactants)—Surfactants help remove oil from dirty parts and stabilize the removed oil, preventing it from redepositing on the cleaned part.
- Co-solvents—Co-solvents can perform several functions, such as lowering the surface tension of the cleaner, promoting solubility of surfactants, and stabilizing oil emulsions.

The cleaning/chemical solution used, the physical or mechanical cleaning processes (immersion washers, spray washers, vibratory finisher, heat), and how the cleaning process is controlled determines the final cleaning quality. To illustrate: one such cleaning system is an aqueous degreasing and iron phosphate process which is widely used in the manufacture of metal products to clean and precondition metal surfaces. Typically, three distinct stages are involved: 1) alkaline-based cleaning and degreasing, 2) iron phosphate treatment, and 3) application of an ultra-pure rinse or sealer.

Each stage or bath is typically re-circulated so that the chemical solution is reused. Oil skimmers or bag filters are sometimes used to remove free oils and particulates. Rinses are employed in between each phase, either counter-flow or continuous depending on the specific application. Under normal conditions, the chemical solution/cleaner picks up contaminants such as oil and grease (O&G), metals and particulates and the chemical solution begins to show signs of aging and degradation, as follows:

- oil and grease, if held in the emulsified form, will consume the surfactants to a point where emulsification action is compromised;
- the alkaline salts will become neutralized;
- the alkalinity of the bath will decrease; and
- the metal-loading can increase to the extent where it will overcome the sequestering agents' capacity to keep the metals in solution.

These limitations can be dealt with by adding the correct quantity of the depleted component, but, as the contamination continues to build, the chemical cleaning solution will no longer prevent redeposits of the contaminants on the cleaned part and the bath must be disposed of and replaced.

Replacing the bath involves a significant cost burden to the facility in terms of waste requiring treatment, replacement chemistry for bath dumps, associated purchased water costs, sewer discharge costs, permitting costs, and labor costs. In addition, as the bath becomes contaminated, the manufacturing process itself produces significant opportunities for deviation from target product quality as result of the build-up of contaminants in each of the metal preparation stages (alkaline cleaner, phosphate, sealer, and rinses). Quite often this inherent lack of control on the bath quality will manifest itself in the form of poor paint quality, rejected parts, and manufacturing downtime.

Depending on the specific application, a management strategy using membrane technology can be used to reclaim the chemical solutions used in the industrial cleaning/surface preconditioning process and can result in definable costs savings and manufacturing process improvements. Figure 4 (*Cleaner Bath Management*) graphically illustrates how using a membrane system to continuously remove the oil and solids from a cleaning bath can improve the overall quality of the bath. The graph compares a membrane filtration strategy used on an aqueous cleaning bath to a strategy centered around regular dumping of the cleaning bath. With membrane technology, the level of contaminants in the bath is dependant upon the size of the membrane system.

Membrane filtration systems can vary significantly based on the desired operating conditions at the facility (degree of automation verses manual operation and bath sequencing). The systems can be designed to generate a high degree of flexibility, recognizing that once a significant change is made to a manufacturing process, subsequent adjustments are required to reduce any production perturbations. Capital costs for different systems can, therefore, vary, but a favorable net present value (NPV) can be achieved depending on the system installed.

KEY ELEMENTS IN IMPLEMENTING A SUCCESSFUL MEMBRANE TECHNOLOGY STRATEGY

Membrane filtration has long been used in special applications in industrial settings, but widespread acceptance has been hindered by the perception that the systems have short membrane life and high operating costs. Recent breakthroughs in materials and configurations, along with manufacturers' guarantees for membrane life, have significantly improved the economics. In addition, as manufacturers move toward quality systems and certifications, the importance of understanding a process and implementing process controls makes membrane technology even more attractive. Numerous articles have been published on using membrane filtration as a means to reclaim cleaner chemistry in an industrial setting. The articles identified the following key factors as critical to membrane filtration operation:

1. Make sure it is the right application for membrane technology.
2. Understand the variability of the solutions that will be processed and make sure the system is robust enough to handle the variability.

3. Understand the properties of the bath chemistry.
4. Chose an appropriate membrane material that is compatible with the chemistry and contaminants.
5. Properly precondition the solution before processing it through the membrane system and use the correct filter size.
6. Implement effective membrane cleaning procedures.
7. Understand and replace the active components in the chemistry that are being depleted in the bath.

The goal of this paper is to show how applying membrane technology in the metal working and finishing industry can provide a business with a competitive advantage. The authors agree that, from a process perspective, the factors identified above are key; however, the project approach and how it is implemented adds significantly to whether the project will be successful and ultimately provide the industry with a competitive advantage.

To implement a successful project, the authors recommend a three-phase approach:

1. Initial Phase: process audit and justification
2. Pilot Phase: pilot study and pre-design
3. Installation and Start-up Phase: final design, installation and start-up

The initial phase and pilot phase have defined objectives and deliverables which are used to justify the final purchase and instillation of a membrane system. In the three case studies which will be discussed later in this paper, the phased project approach allowed the manufacturer time to understand the risks associated with the project while limiting the financial liability until sufficient data was collected to justify the entire project. In addition, it provided the manufacturing people with a level of confidence that, if implemented, the membrane system would not negatively affect the manufacturing operations or product quality.

Initial Phase—The objective of the initial phase is to collect baseline operating data on the process so that the first three key factors identified previously can be addressed. To achieve this, a project team is created consisting of manufacturing personal, the provider of the process chemistry, and the membrane filtration design firm. This team audits the existing process to establish a baseline of operating conditions and to determine cleaning quality. Experience has shown that projects often fail or do not achieve the anticipated result because a process change is unknowingly made while implementing the project, resulting in a change to the baseline operating conditions.

In addition, during the initial phase the operating costs are identified and quantified. This data is used to estimate the potential project savings and determine other benefits that may be realized should a membrane technology strategy be implemented. The potential benefits that are looked at and quantified are:

1. **Operational savings**, such as reduced chemistry costs, reduced disposal costs, reduced purchased water costs, reduced labor costs, and reduced sewer costs.
2. **Regulatory relief**, such as reduced permitting cost, reduced wastewater monitoring costs, and reduced hazardous waste reporting requirements.
3. **Production enhancements,** such as better cleaning quality, less scrap or defective parts, improved process control, and reduced down time.
4. **Environmental and social benefits**, such as no wastewater violations, future regulatory relief, reduced liability, and the importance of being a good corporate citizen.

After the data on the process is collected and understood, the project team confirms that membrane technology is the appropriate technology, that the project will "pay for itself" and that it can be justified over other possible management strategies. If all three receive a positive response, it is time to proceed with the second phase of the project, the pilot study.

Pilot Phase—The objective of the pilot phase is to verify that a membrane system is compatible with the process chemistry, confirm design data, and give the operators who will ultimately run the system some hands-on experience. After completion of the pilot test, the following is determined:

- The design permeate flux rate and flow rate demands.
- The appropriate membrane material that is compatible with the chemistry and contaminants.
- The size of the membrane filtration system and any other equipment needed.
- The effective membrane cleaning procedures and recommended frequency.
- What, if any, components in the chemistry are being depleted from the bath.

The testing is accomplished on-site by routing the wastewater through a pilot-scale membrane filtration unit. Samples of the feed solution, the permeate, and the concentrate are collected and analyzed to confirm process chemistry and whether the permeate can be reused in the process. The pilot testing also provides actual operating data to refine utility and supply usage reductions. After confirming that the treated wastewater can be reused and establishing size requirements and flux rates, a treatment system plan and specifications are developed to include:

- wastewater tank types and sizes;
- transfer pump and pipe sizes;
- skimmer/membrane type and surface area requirements;
- high level, low level, pressure sensors, and controls;
- effluent flow meter; and
- overall equipment layout.

The final design incorporates the membrane system into the existing manufacturing operation, addresses space constraints (floor space is typically very valuable in a manufacturing facility), and augments the membrane strategy with other best management practices.

Installation and Start-up Phase—Proceed with the final design, construction, and installation of the membrane system; provide start-up and operating assistance; and train and provide written operating and maintenance procedures.

MEMBRANE FILTRATION CASE STUDIES

Three different metal working and finishing manufacturers are used as case studies to illustrate how membrane technology, along with other management techniques, can be implemented in the metal working and finishing industry to reduce chemical purchasing costs, reduce operational costs, and improve product quality.

Case Study #1—Furniture Manufacturer

Case Study #2—Air Conditioning and Heat Exchange Equipment Manufacturer

Case Study #3—Job Shop Machined Parts Manufacturer

In each case study, the project approach was similar, with consideration taken for site-specific conditions. The project approach followed the three-phase approach discussed previously and entailed completing a preliminary economic analysis of the application, including projected construction and installation costs; the generation of meaningful business economic criteria, such as definition of anticipated net present value and payback and return on investment; preliminary pilot testing to confirm technical feasibility; development of a schematic design and conceptual layout; confirmation pilot testing, if needed; design and approval; installation; start-up and shake-out; full scale operation; testing; and auditing of cost savings and production improvements.

The advantages conferred to these facilities included the following, documented results:

- approximately 75% recovery of process chemistry
- approximately 95% reduction in waste volume generated
- reduction in purchased water costs
- reduction in product rejection rate
- reduction in process downtown
- reduction in process bath variability and contaminant loadings

In some cases, the following advantages were also conferred:

- elimination of wastewater discharge, thereby reducing permitting costs
- reduction in labor
- positive public relations resulting from pollution prevention efforts
- elimination of permit violations

Case Study # 1: Furniture Manufacturer

The furniture manufacturer produces cafeteria-type tables which are made from aluminum frames. The aluminum frames are made from purchased aluminum pieces that are cut, stamped, bent, and welded together at the manufacturing facility prior to being processed through a three-stage aqueous spray washing process and then painted. The first stage of the aqueous washing process is an iron phosphate cleaner spray wash, the second stage is a spray rinse which uses purchased city water, and the third stage is a spray application of a rust inhibitor/sealer. The solutions in each stage are sprayed on the parts and then collected in a tank and re-circulated.

Prior to the installation of the membrane filtration system, the phosphate cleaner bath was shipped off site for disposal each month. The second-stage rinse wastewater was overflowed and discharged to the sewer without any pretreatment, while the third-stage wash was collected and disposed of off-site each month.

Annual operating costs were $78,480 per year for wastewater management, $36,000 per year for cleaner chemistry, and $2,583 per year for purchased water. During the initial phase of the project, the project team estimated that the operating cost could be reduced to $2,800 per year for wastewater management, $9,000 per year for cleaner chemistry, and $574 per year for purchased water with a successfully implemented membrane strategy. As a result, the company decided to pursue a membrane filtration approach for the parts washing system to reduce the annual operating costs and to eliminate a need for additional pretreatment (the local wastewater discharge limits were being lowered and would require pretreatment of the rinse water prior to discharge to the sewer).

Figure 5 (*Case Study #1: Furniture Manufacturer*) is an isometric drawing of the three-stage cleaning process after the membrane system was installed. The membrane filtration system was designed to remove the solids and O&G from the first-stage phosphate cleaner tank and essentially regenerate the phosphate cleaner for reuse. The first-stage cleaner tank is processed on a somewhat continuous basis. Doing this extends the life of the cleaning solution indefinitely (eliminating regular batch dumps) and substantially reduces the build-up of O&G and solids in the tank; therefore, less is "dragged out" into the next stage.

Since significantly fewer solids and O&G are dragged into the second-stage rinse, the tank remains cleaner and the need to continuously overflow the tank is eliminated. The second-stage tank is also processed through the UF unit at some frequency to remove any O&G or solids that have built up. The third-stage RO water sealer tank is also processed through the UF at some frequency to remove O&G and solids and is no longer dumped monthly.

In addition to processing each tank through the UF system, wastewater minimization techniques were integrated into the strategy. The first-stage phosphate cleaner tank requires frequent additions of "make- up" water because of evaporative losses and drag out. The wastewater management system was designed so that any loss of water in the first-stage phosphate cleaner tank is made up using water from the second-stage rinse tank. Clean water is then used to replenish the second-stage rinse tank. The benefits of this are:

- the second-stage rinse tank stays cleaner;
- the phosphoric acid concentration in the second-stage rinse tank stays at an acceptable level; and
- the cleaner chemistry dragged out into the second-stage rinse tank is sent back to the cleaner tank.

Results and Benefits of the Membrane System

The total project cost was $45,000 and the company spends approximately $4,000 a year operating the membrane filtration system. The annual operating costs are now $700 per year for wastewater management, $11,887 per year for cleaner chemistry, and $431 per year for purchased water. This corresponds to a 89% reduction in operating costs. The total annual cost avoidance is $104,000. Table 1 (*Financial Summary, Case Study #1: Furniture Manufacturer*) is a financial summary of the project. The investment produced future cash flows with a present value of $5.80 for every $1.00 invested. Other project benefits included:

- product quality improvement due to more consistent cleaning of parts;
- wastewater permit not required because plant no longer discharges wastewater;
- level of O&G and solids in phosphate cleaning tank reduced;
- facility now manages and controls their chemical usage; and an
- annual waste reduction of 783,000 gallons

Case Study #2: Air Conditioning and Heat Exchange Equipment Manufacturer

This facility manufactures industrial refrigeration, air conditioning and heat exchange equipment. Manufacturing operation at the facility includes machining, plate fabrication, metal finishing, solvent coating, assembly, and product testing. As part of the finishing process, metal components are processed through a five-stage immersion washing process prior to being coated. The five stages or tanks in the process are an acid wash followed by a water rinse, a caustic wash followed by a water rinse, and a rust inhibitor. The parts are immersed into the tanks. Prior to the installation of the membrane filtration system, each tank became contaminated and was periodically dumped and disposed of off-site at a cost of $108,000 per year. In addition, the company was spending $60,000 per year on cleaner chemistry and $331 per year on purchased water.

After completing the initial stage of the project, the project team projected that the operating costs could be reduced to $5,400 per year for wastewater management, $15,000 per year for cleaner chemistry, and $83 per year for purchased water with successful implementation of a membrane strategy.

Figure 6 (*Case Study #2: Air Conditioning and Heat Exchange Equipment Manufacturer*) is an isometric drawing of the five-stage cleaning process after the membrane system was installed. The membrane filtration system was designed to remove the solids and O&G from the first-stage acid cleaner, the second-stage water rinse, and the third-stage caustic cleaner. The first-stage acid cleaner tank is processed on a somewhat continuous basis. Doing this extends the life of the cleaning solution indefinitely (eliminating regular batch dumps) and substantially reduces the build-up of O&G and solids in the tank; therefore, less is "dragged out" into the next stage.

Since significantly fewer solids and O&G is dragged into the later stages, they remain cleaner and the need to frequently dispose of them is eliminated. The second-stage rinse tank and the third-stage caustic cleaner tank are also processed through the UF unit at some frequency to remove any O&G or solids that have built up.

In addition to processing each tank through the UF system, wastewater minimization techniques were integrated into the strategy. The first-stage acid cleaner tank requires frequent additions of make- up water because of evaporative losses and drag out. The process was changed so that any loss of water in the first-stage acid cleaner tank is made up using water from the second-stage rinse tank. Clean water is then used to replenish the second-stage rinse tank. The benefits of this are:

- the second-stage rinse tank stays cleaner;
- the acid concentration in the second-stage rinse tank stays at an acceptable level; and
- the cleaner chemistry dragged out into the second-stage rinse tank is sent back to the cleaner tank.

Results and Benefits of the Membrane System

The total project cost was $50,000 and the company spends approximately $15,000 a year operating the membrane filtration system. The annual operating costs are now $21,600 per year for waste disposal, $24,000 per year for cleaner chemistry, and $166 per year for purchased water. This corresponds to a 73% reduction in operating costs. The total annual cost avoidance is $122,500. Table 2 (*Financial Summary, Case Study #2: Air Conditioning and Heat Exchange Equipment Manufacturer*) is a financial summary of the project. The investment produced future cash flows with a present value of $5.63 for every $1.00 invested. Other project benefits included:

- product quality improvement due to more consistent cleaning of parts;

- reduced liability because waste no longer being disposed of off site;
- reduced hazardous material handling; and the
- facility now manages and controls their chemical usage.

Case Study #3: Job Shop Machined Parts Manufacturer

A job shop machining operation manufactures precision Swiss-style machined products for various industries by utilizing two main types of machining equipment (screw machines and CNC lathes), along with various secondary machining operations. The materials machined include all types of steels, copper, brass, aluminum, titanium, and some plastics. The majority of the machining equipment uses petroleum-based cutting oils for lubrication and cooling.

Historically, the company used oil dry as a means for keeping the machine shop floor free of oil. After completion of a large expansion that doubled the size of their manufacturing operation, a decision was made to eliminate the use of oil dry and began to use an aqueous-based cleaner and floor scrubber to keep the facility clean. Initially, the wastewater from the floor cleaning operations was discharged to the local POTW.

When the local POTW proposed new wastewater discharge limits, management realized the company would not be able to consistently meet the new limits and began to ship the floor cleaning wastewater off-site. Annual disposal costs to ship floor cleaning wastewater off-site was $26,091 per year. The company was also spending $15,570 per year on cleaner chemistry. After looking into several different wastewater management alternatives, a decision was made to pursue a strategy that would use a membrane filtration system to recycle the floor cleaning wastewater. The expected benefits were waste disposal costs reduced to $762 per year; a zero-discharge system, eliminating the wastewater permit and the risk of a violation; and cleaner chemistry purchases reduced to $3,770 per year.

Figure 7 (*Case Study #3: Job Shop Machined Parts Manufacturer*) is an isometric drawing of the membrane filtration installation. After cleaning the machine shop floor, the contaminated cleaning solution is processed through the membrane system where the O&G and solids are removed and the permeate or reclaimed cleaning solution is held until the next floor cleaning. Prior to cleaning the floor the next time, some new cleaning solution is added to the reclaimed cleaner to make up for any losses that may have occurred and the floor scrubbing operation is repeated.

Results and Benefits of the Membrane System

The total project cost was $30,000 and the company spends approximately $4,000 a year operating the membrane filtration system. Waste disposal costs were reduced to $530 per year and cleaner chemistry purchases are now $3,000 per year. This corresponds to a 92% reduction in operating costs. The total annual cost savings is $38,500. Table 3 (*Financial Summary, Case Study #3: Job Shop Machined Parts Manufacturer*) is a financial summary of the project. This investment produced future cash flows with a present value of $3.25 for every $1.00 invested.

Other project benefits included:

- reduced liability because waste is no longer being disposed of off-site,
- reduced hazardous material handling, the
- facility now manages and controls the cleaner usage, and
- no wastewater permit is needed.

SUMMARY & CONCLUSIONS

Membrane technology has long been used in special applications in industrial settings, but widespread acceptance has been hindered by the perception that the systems have short membrane life and high operating costs. Recent breakthroughs in membrane materials and configurations have significantly improved the economics of membrane systems. Combining the improved economics, the potential environmental benefits, and the added process control benefits, manufacturers in the metal working and finishing industry have begun to successfully integrate membrane filtration strategies into the aqueous cleaning process.

The project approach used in the three case studies presented in this paper limited each company's financial liability and risk until sufficient data was collected to assure them that the key elements to successfully implement a membrane strategy were addressed:

1. Make sure it is the right application for membrane technology.
2. Understand the variability of the solutions that will be processed and make sure the system is robust enough to handle the variability.
3. Understand the properties of the bath chemistry.

4. Chose an appropriate membrane material that is compatible with the chemistry and contaminants.
5. Properly precondition the solution before processing it through the membrane system and use the correct filter size.
6. Implement effective membrane cleaning procedures.
7. Understand and replace the active components in the chemistry that are being depleted in the bath.

The final results from these case studies on aqueous cleaning processes proved that 1) **operational savings**, such as reduced chemistry costs, reduced disposal costs, reduced purchased water costs, reduced labor costs, and reduced sewer costs; 2) **regulatory relief**, such as reduced permitting costs, reduced wastewater monitoring costs, and reduced hazardous waste reporting requirements; 3) **production enhancements**, such as better cleaning quality, less scrap or defective parts, improved process control, and reduced down time; and 4) **environmental benefits**, such as no wastewater violations, future regulatory relief, and reduced liability, can all be achieved by successfully implementing a membrane filtration strategy. In each case study presented, the authors predicted and later verified, using audited cost accounting techniques, that the installed membrane systems have given an operating competitive advantage to their respective businesses.

References Section follows

BIBLIOGRAPHY

Bilgo, James, Kaszubowski, Kenneth. "Development of a Treatment Scheme for Spent Cleaning Solutions Using Statistical Process Control Concepts," *45th Purdue Industrial Waste Conference Proceedings*, May 1990.

Bodzęk, Michal and Konieczyn, Krystyna. "The Use of Ultrafiltration Membranes Made of Various Polymers in the Treatment of Oil Emulsion Wastewater," *Waste Management*, 1992, Vol 12 pp. 75-84.

Byers, Bill. "Zero Discharge: A Systematic Approach to Water Reuse," *Chemical Engineering*, July 1995, pp. 96-100.

Callahan Michael, Jensen Tom, Meltzer, Michael. *Metal-Bearing Waste Streams - Minimizing, Recycling, and Treatment*, Noyes Data Corporation, 1990.

Cappos, Steve. "Membrane Minimize Liquid Discharge," *Chemical Engineering*, July 1995, pp. 102-104.

Chang, Chong E., Huh, Ki H. "Predict Concentration of Partition in Ultrafiltration," *Chemical Engineering*, June 1998, pp. 145-146.

DeSilva, Francis. "Tips for Process Water," *Chemical Engineering*, August 1996, pp. 72-82.

Gaines, W.A. "When Water Quality is Job One," *Consulting Specifying Engineer*, June 1998, pp. 34-46.

Huang, Yi-chu, Batchelor, Bill, Koseoglu, Sefa S. Texas Engineering Experiment Station, Texas A&M University System, "Surfactant-Enhanced Ultrafiltration of Heavy Metals from Waste Streams with Pilot Scale System," *Hazardous Waste & Hazardous Materials*, Vol. 11, Number 3, 1994, pp. 385-395.

Humphrey, Jimmy L., Keller, George E. II. *Separation Process Technology*, McGraw-Hill, Copyright 1997.

Kim B.R., Lalis E.M., Florkey, D.L., Swatsenberg S.L., Luciw L., Bailey C.H., Gaines W.A., Phillips J.H., Kosokowsky G.P. "Evaluation of Commercial Ultrafiltration Systems for Treating of Automotive Oily Waste Waters," *Water Environmental Research*, Nov./Dec. 1998, pp.1280-1289.

Lindsey, Timothy C., Ocker, Alisa G., Miller, Gary D. "Recovery of an Aqueous Iron

Phoshating/Degreasing Bath by Ultrafiltration," *Air & Waste*, Vol 44 May 1994, pp. 697-701.

Lindsey T., Rajagopalan N., Sparks J. "Recycling of Aqueous Cleaning Solution with Membrane Filtration: Issues and Practice," *Metal Finishing*, March 1999, pp. 39-51.

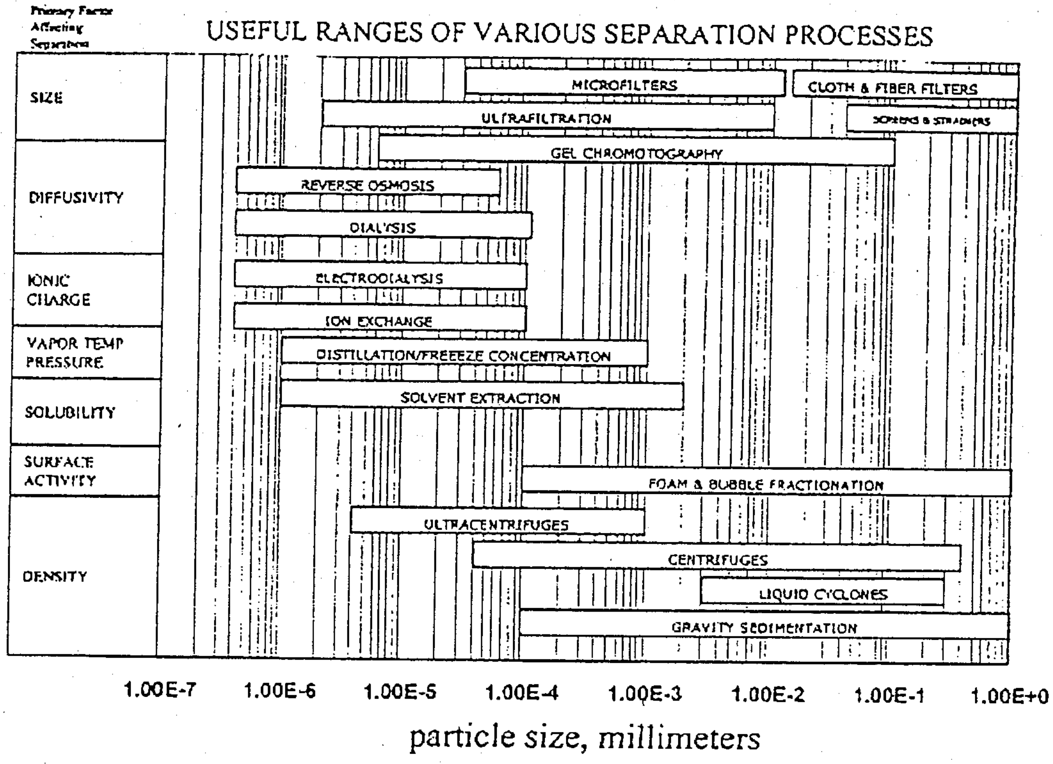
Mueller, F. "Good Cleaning Practices Part 2: High Tech Methods," *Plating and Surface Finishing*, Sept. 1998, pp. 66-67.

Ralchigo, Philip. "Filtration Basics," *Industrial Wastewater*, January/February 1997, pp. 35-40.

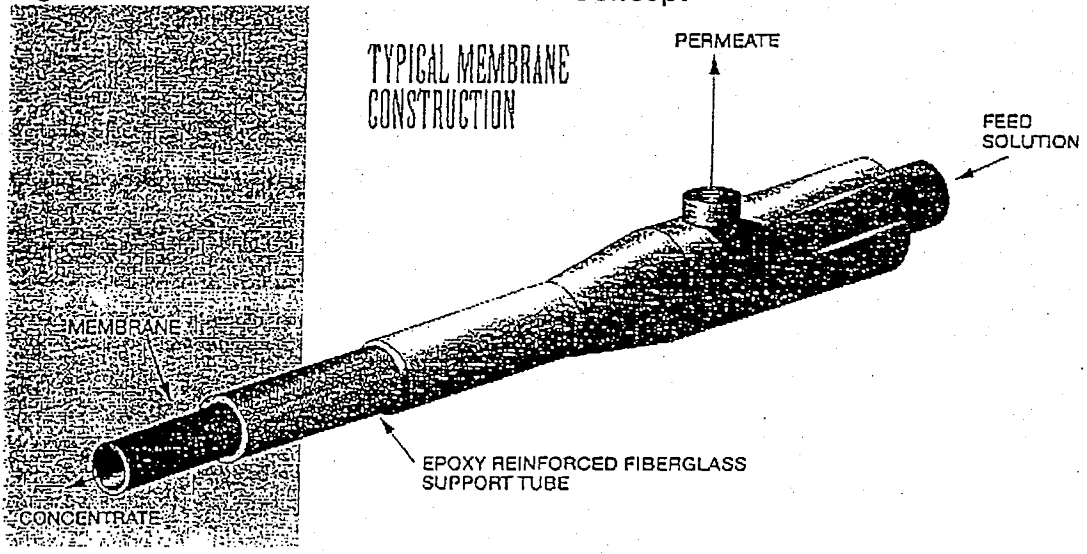
Wendell, Paul J. *Corporate Controller's Manual - Second Edition*, 1989, pp. D10-20 - D10-22.

Wright, Andrew G. "Microfiltration Runs Wide Open," *ERN*, Sept. 21, 1998, pp. 34-38.

igure 1. Separation Processes



igure 2. Cross-Flow Membrane Filtration Concept



gure 3. Metal Working and Finishing Process Flow Diagram

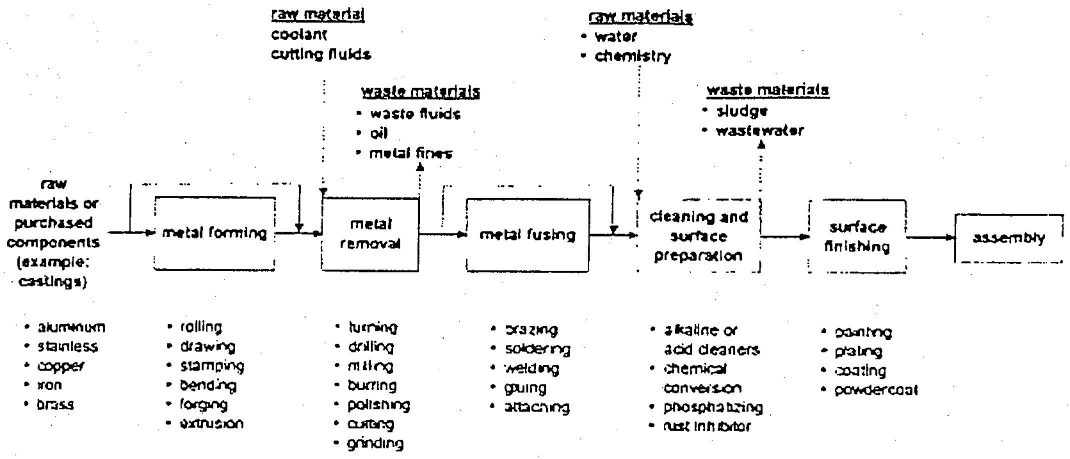
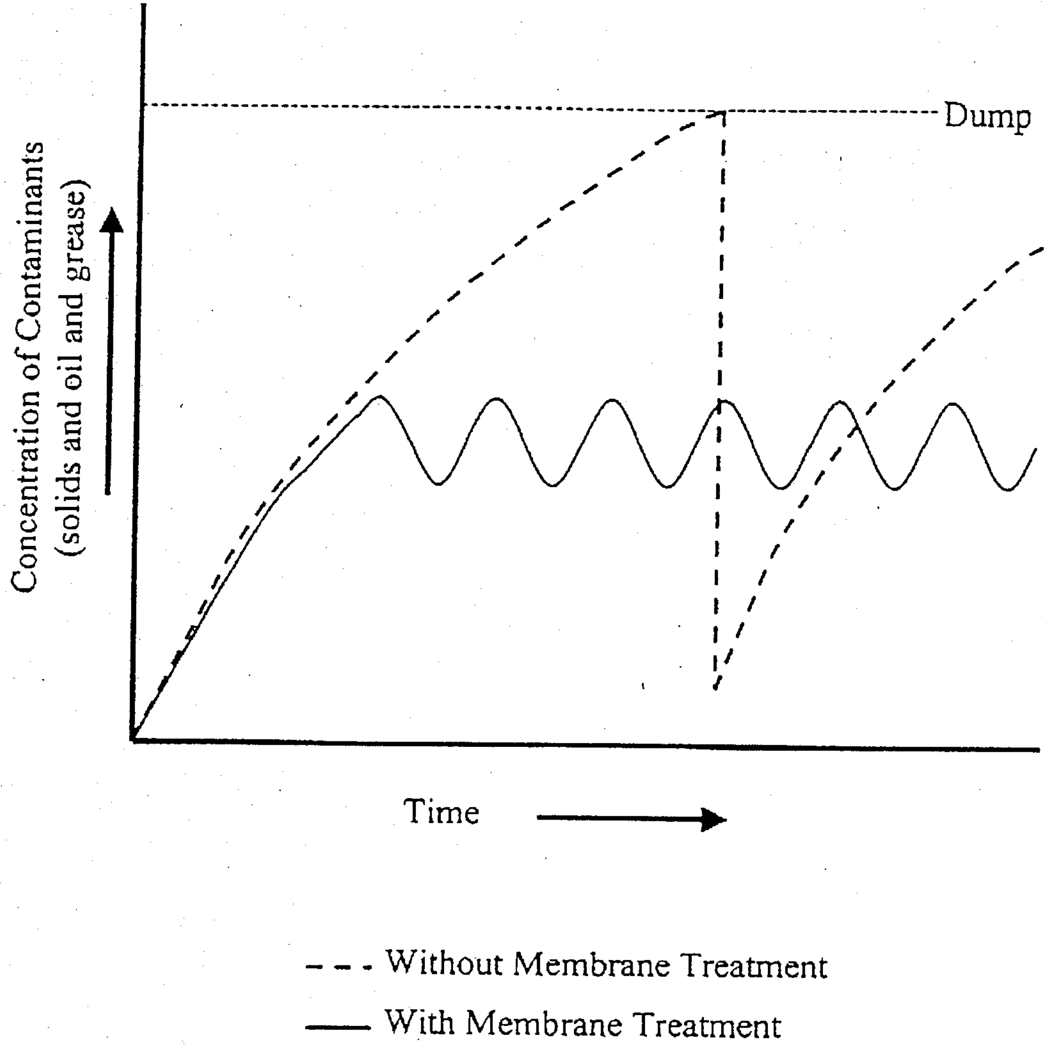
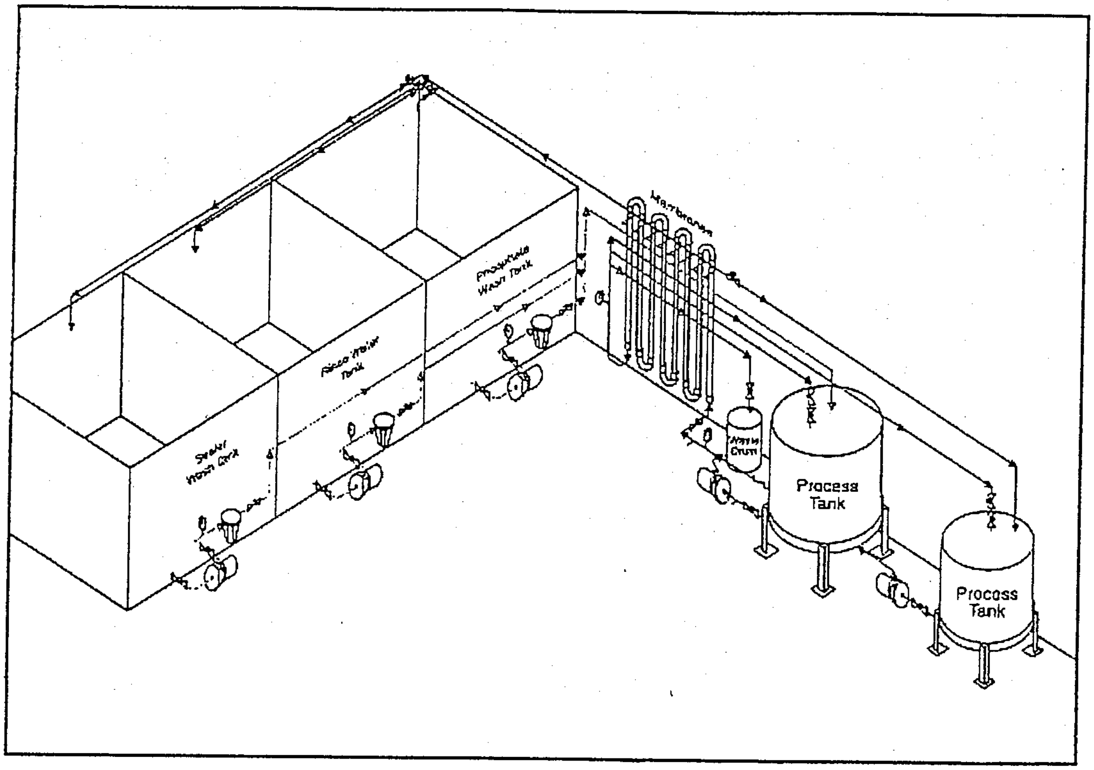


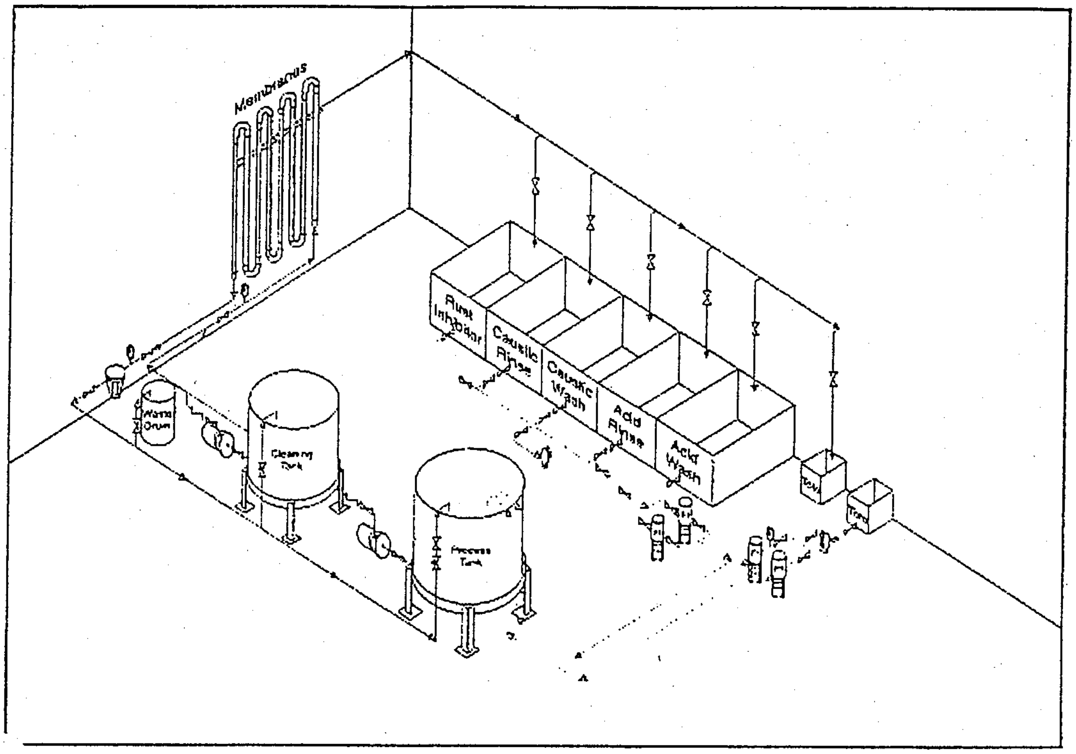
Figure 4. Cleaner Bath Management



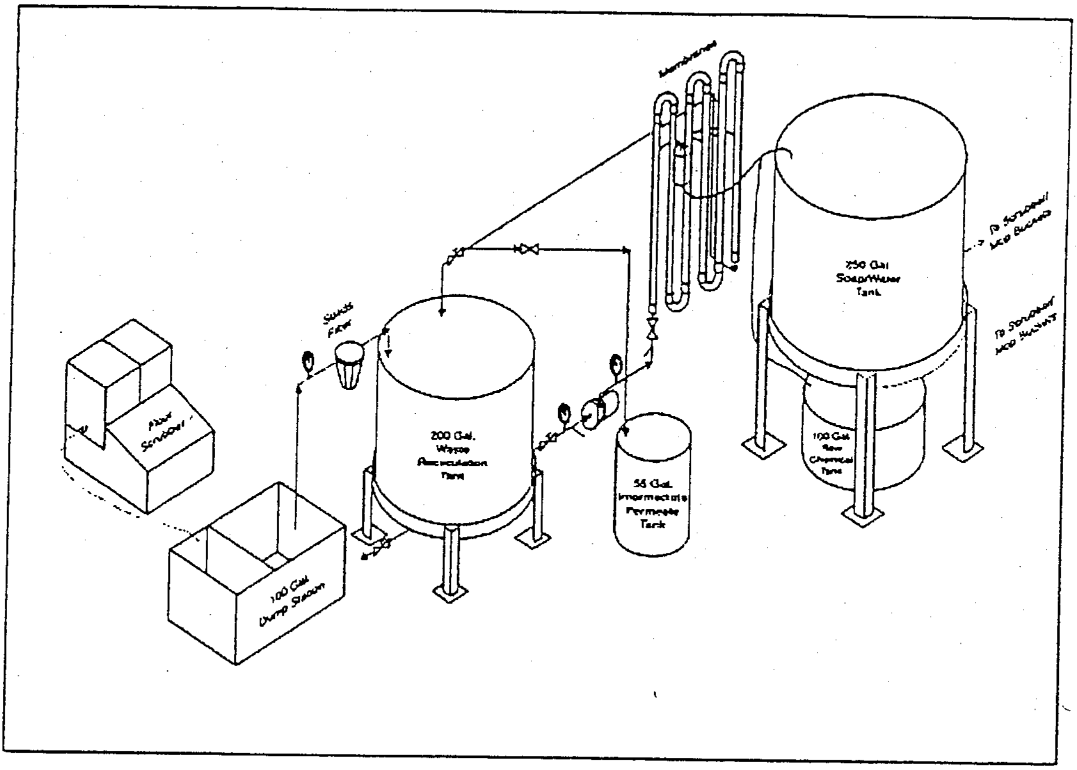
gure 5. Case Study #1: Furniture Manufacturer



.gure 6. Case Study #2: Air Conditioning and Heat Exchange Equipment Manufacturer



.gure 7. Case Study #3: Job Shop Machined Parts Manufacturer



ble 1. Financial Summary Case Study #1: Furniture Manufacturer

Annual Cash Flow: Years 1-5	
Cost Avoidance per Year	$ 104,000
System Operating Cost per Year	(4,000)
Federal Income Tax on Net Cost Savings per Year (34%)	(34,000)
Depreciation (7 Years Straight Line)	6,429
Net Cash Flow per Year	$ 72,429

Net Present Value Calculation

Year	Cash Flow	Present Value Factor @ 12%	Present Value
0	(45,000)	1.0000	$ (45,000)
1	72,429	0.8929	64,672
2	72,429	0.7972	57,740
3	72,429	0.7118	51,555
4	72,429	0.6355	46,029
5	72,429	0.5674	41,096
Present Value of Cash Inflows			$ 261,092
Net Present Value @ 12%			$ 216,092

The $45,000 investment in the project produced cash inflows of $72,429 per year or $362,145 for five years. When adjusted for the time value of money, in this case a present value factor of 12 percent was used, the cash inflows have a discounted value of $261,092. The net value of the company is increased by $216,092 over five years ($261,092 minus $45,000).

The present value index (or profitability index) is the Present Value of Cash Inflows divided by Capital Invested ($261,092 / $45,000 = 5.80).

The discounted payback period is the time that it takes this investment to recoup the capital invested from increased discounted cash flows. Initial Investment divided by Annual Discounted Cash Inflow ($45,000 / $64,672 = .70 years)

able 2. Financial Summary Case Study #2: Air Conditioning and Heat Exchange Equipment Manufacturer

Annual Cash Flow: Years 1-5			
Cost Avoidance per Year			$ 122,500
System Operating Cost per Year			(15,000)
Federal Income Tax on Net Cost Savings per Year (34%)			(36,550)
Depreciation (7 Years Straight Line)			7,143
Net Cash Flow per Year			$ 78,093
Net Present Value Calculation			
Year	Cash Flow	Present Value Factor @ 12%	Present Value
0	(50,000)	1.0000	$ (50,000)
1	78,093	0.8929	69,729
2	78,093	0.7972	62,256
3	78,093	0.7118	55,587
4	78,093	0.6355	49,628
5	78,093	0.5674	44,310
Present Value of Cash Inflows			$ 281,510
Net Present Value @ 12%			$ 231,510

The $50,000 investment in the project produced cash inflows of $78,093 per year or $390,465 for five years. When adjusted for the time value of money, in this case a present value factor of 12 percent was used, the cash inflows have a discounted value of $281,510. The net value of the company is increased by $231,510 over five years ($281,510 minus $50,000).

The present value index (or profitability index) is the Present Value of Cash Inflows divided by Capital Invested ($281,510 / $50,000 = 5.63).

The discounted payback period is the time that it takes this investment to recoup the capital invested from increased discounted cash flows. Initial Investment divided by Annual Discounted Cash Inflow ($50,000 / $69,729 = .72 years) ble 3. Financial Summary Case Study #3: Job Shop Machined Parts Manufacturer

Annual Cash Flow: Years 1-5	
Cost Avoidance per Year	$ 38,500
System Operating Cost per Year	(4,000)
Federal Income Tax on Net Cost Savings per Year (34%)	(11,730)
Depreciation (7 Years Straight Line)	4,286
Net Cash Flow per Year	$ 27,056

Net Present Value Calculation

Year	Cash Flow	Present Value Factor @ 12%	Present Value
0	(30,000)	1.0000	$ (30,000)
1	27,056	0.8929	24,158
2	27,056	0.7972	21,569
3	27,056	0.7118	19,258
4	27,056	0.6355	17,194
5	27,056	0.5674	15,352
Present Value of Cash Inflows			$ 97,531
Net Present Value @ 12%			$ 67,531

The $30,000 investment in the project produced cash inflows of $27,056 per year or $135,280 for five years. When adjusted for the time value of money, in this case a present value factor of 12 percent was used, the cash inflows have a discounted value of $97,531. The net value of the company is increased by $67,531 over five years ($97,531 minus $30,000).

The present value index (or profitability index) is the Present Value of Cash Inflows divided by Capital Invested ($97,531 / $30,000 = 3.25).

The discounted payback period is the time that it takes this investment to recoup the capital invested from increased discounted cash flows. Initial Investment divided by Annual Discounted Cash Inflow ($30,000 / $27,056 = 1.11 years)