USE OF ULTRAFILTRATION TO RECYCLE CLEANING SOLUTIONS USED IN NORTH AMERICAN RAILROAD AD MAINTENANCE AND REPAIR FACILITIES

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Summary
Ultrafiltration technology can be used to substantially reduce the consumption of parts cleaning chemicals and the cost of waste water treatment and discharge from railroad shops. Waste water treatment is the second largest environmental expenditure for North American railroads, and discharge from large parts washing machines is the primary contributor to waste water pollution load at major shops. The Association of American Railroads (AAR) has evaluated the practical application of ultrafiltration technology as a way to reduce the volume of this discharge. This filtration process uses a cross flow membrane filter to separate dirt and oil from the cleaning solution thereby substantially extending the useful life of the cleaning solutions. The productivity of the parts washer is also increased because of the reduced time required for general maintenance and replenishing the parts cleaning solution. In addition to these benefits, the burden on the waste water treatment plant is reduced because the volume of waste water and mass of cleaners and oils reaching the plant are diminished. Taken together, the savings from these factors will justify investment in ultrafiltration equipment at many railroad facilities. AAR and the Illinois Waste Management Research Center (WMRC) conducted laboratory testing of different types of filters for performance and compatibility with the major cleaning chemicals used in North American railroad shops. In addition, we conducted a test of a prototype ultrafiltration unit in a railroad shop that was quite promising; the filtration test unit achieved a significant reduction in the discharge of dirty cleaning solution and saved approximately $2,000 in cleaner cost in only two months of operation.

Key Words: waste water discharge, recycling, pollution prevention

INTRODUCTION

The operation and maintenance of waste water treatment plants is a major environmental expense for North American railroads. It is estimated that over $US 40 million is spent annually on waste water treatment and related permits (Friedman 1996). Most of the treatment is to separate oil and grease from the water before it is discharged. However, treatment is made more difficult when these dirty cleaning solutions are discharged to the treatment plant. The dirty cleaning solutions contain a high concentration of oil and dirt, but they also contain large amounts of useful cleaning chemicals that inhibit the separation of oil and water, and make operation of the waste-water treatment plants more costly. If these useful chemicals could be separated from the oil and dirt, and returned to the parts cleaning machine, the cost of replenishing these chemicals and the cost of waste treatment would be reduced.

Ultrafiltration is a technology that enables this type of separation to be effectively and economically accomplished (Paul 1981). It has been successfully used in other industrial cleaning situations (Karrs and McMonagle 1993, Schwering et al 1993), but the harsh operating environment of the railroad shop has generally prevented it from being successfully applied in North American railroad facilities. Preliminary testing by the Burlington Northern and Santa Fe Railway (BNSF) in conjunction with the Illinois Waste Management Research Center (WMRC) indicated that ultrafiltration might be successfully employed for recycling the cleaning solutions used in railroads' large parts washers, if proper design and operating procedures were developed.

Based on the information learned in the preliminary BNSF/WMRC testing, the AAR constructed and operated a prototype ultrafiltration unit to test the performance characteristics and compatibility of ultrafiltration membranes with the cleaners commonly used by North American railroads (Rajagopalan in prep.). The goal of the AAR research was to determine the general design features necessary for broad, successful application of ultrafiltration technology in North American railroad shops and to evaluate the economics of this application. Preliminary test results indicate that application of the technology is feasible, and that there is a large potential for cost savings from ultrafiltration. The anticipated savings are the result of three primary factors.

- Reduced consumption of cleaner solutions.
- Increased productivity of the parts washing machine by decreasing the time for cleaning and refilling the parts washer.
- Reducing the load on the shop waste water treatment plant.

For the high usage parts washers typically found in many large shops, the estimated return on investment for an ultrafiltration unit is between one and two years. This will vary depending on the cost of the cleaner and the production load on the particular parts washer under consideration.

LOCOMOTIVE PARTS WASHING

Most of the large North American railroads operate one or more major shops in which they conduct extensive overhauls and rebuilding of locomotives. At these facilities, locomotives are taken apart and components of all types are removed, disassembled, repaired and reassembled for reuse in remanufactured locomotives. A critical step for many of these parts is the removal of the oil, grease and dirt that has accumulated while in service. Railroads operate large washing machines, that rely on high temperature and water pressure, along with chemical cleaning agents to cleanse these parts prior to repair and rebuilding. These parts washers typically have large reservoir tanks that hold the cleaning and rinse solutions. These solutions are reused until they become sufficiently fouled with oil and dirt that they no longer satisfactorily clean the parts. At this stage the dirty solution is discharged to the facility's waste water handling and treatment system, and a fresh solution of water and cleaning compound is prepared. The machine will often be cleaned at this stage as well. The operation of these parts washers is a major activity in locomotive rebuilding facilities, and railroads expend a large amount of money operating them. A substantial contributor to this cost are the cleaning compounds used in these washers.

ULTRAFILTRATION OF PARTS WASHER CLEANING SOLUTION

The basic concept of ultrafiltration is that instead of discharging the dirty cleaning solution to the waste water system, the chemical compounds and water in the cleaning solution pass through a filter and are recycled back to the parts washer (Figure 1). Meanwhile, the oil and dirt particles which are too large to pass through the filter, accumulate in a concentrated solution called the retentate.

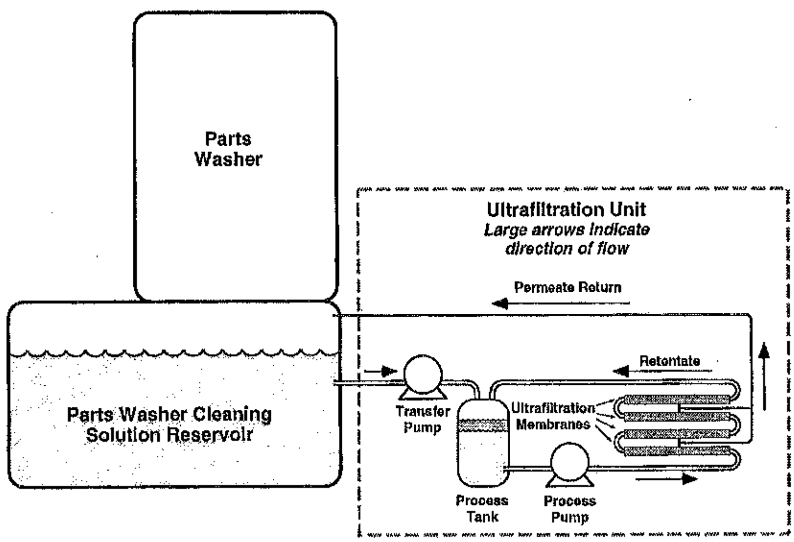

Figure 1. Schematic diagram of ultrafiltration unit connected to a parts washer for use recycling the cleaning solution.

The AAR constructed a prototype ultrafiltration unit and conducted tests with a parts washer that cleaned traction motor parts at the BNSF locomotive shop in West Burlington, Iowa. The transfer pump periodically pumps dirty cleaner solution from the parts washer reservoir into the process tank. A second pump, the process pump, continuously circulates the mixture through the membrane tubes and back to the process tank. The permeate, containing the water and cleaning chemicals, is returned to the parts washer, while the oil and dirt are concentrated in the process tank. Eventually, the increasing concentration of dirt and oil in the retentate will coat the membranes and reduce the permeate flow through them. The membranes are then cleaned by circulating a special solution through the system to remove the built up deposits. During the membrane cleaning operation, the concentrated sludge in the process tank is transferred into a drum for separate disposal. After the membrane cleaning and sludge removal operation, the normal filtration operation of the unit resumes. This cycle of, filtration - membrane cleaning - filtration, etc. continues until the cleaner solution in the parts washer is no longer capable of satisfactorily cleaning the parts. At this time, the cleaner solution in the parts washer may be replaced. Sometimes the useful life of the cleaning solution can be further extended by replenishing it with appropriate chemicals.

TEST RESULTS OF ULTRAFILTRATION UNIT

The test of the AAR ultrafiltration unit showed that it was highly effective at keeping the concentration of oil and grease, and suspended solids in the parts washer reservoirs at acceptably low levels over an extended period of operation. Figure 2 compares these levels with and without ultrafiltration. The levels of both contaminants rapidly rise when ultrafiltration is not used, whereas they decline or remain stable at low levels when ultrafiltration is used. After about 16 days of operation without ultrafiltration, the high concentration of dirt and oil caused the parts washer operator to follow his usual practice and discharge the cleaning solution. By contrast, during the 50 day period when the test ultrafiltration unit was in operation, discharge of the cleaning solution was never required.

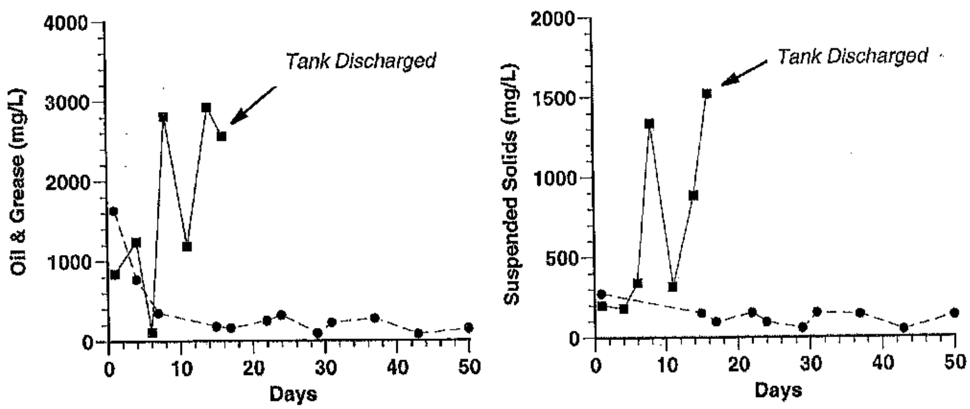

Figure 2. Levels of Oil & Grease and Suspended Solids in a parts cleaning machine when ultrafiltration was not used (squares and solid lines) compared to when ultrafiltration was used (circles and dashed lines). After 16 days of operation without ultrafiltration, the high concentration of contaminants caused the operator to discharge the dirty cleaning solution.

For each parts washer, the economic feasibility of membrane filtration will be determined by the cost and concentration of the cleaner, the volume of the cleaning solution, and the frequency of its replacement if ultrafiltration is not used. Table 1 summarizes the cost and savings values from the initial AAR test at the BNSF locomotive shop (these calculations do not include the estimated reduction in waste water treatment plant operation that would accrue). The variation in estimated monthly savings is due to the price differences among the commonly used parts cleaning chemicals.

Table 1: Pay Back Calculations

Capital Invested	$25,762
Monthly Savings	$1,557 - $2,701
Monthly Costs	$536
Net Savings per Month	$1,021 - $2,165
Payback Period	12 - 25 months

EFFECT OF TEMPERATURE AND ALKALINITY

Railroad parts washers typically operate with cleaning solutions at temperatures of 80 degrees Celsius, or higher, and at a pH between 10 and 12. The currently available polymer membranes can withstand either these high temperatures or the high pH of the solutions, but not both at the same time. Ultrafiltration membranes are costly, so to avoid their disintegration and preserve the favorable economics of ultrafiltration, we had to reduce the temperature of the solution to which they were exposed to approximately 55 degrees Celsius. We accomplished this by equipping the test unit with a cooling radiator in the processing tank. Cold water circulates through the radiator whenever the temperature is above 52 degrees Celsius. Should the cooling system malfunction or be insufficient, a thermostat stops the process pump if the retentate temperature reaches 55 degrees Celsius.

MEMBRANE FOULING

All membrane filters will eventually foul and require cleaning. However, the degree of fouling and the ease of cleaning a membrane can vary significantly due to interactions between the compounds in the dirty solution and the membrane material. The membrane filters selected for this initial test performed quite well. The tubular construction design of the filters resists fouling by the oil and particulates, and the matter that did accumulate on the inner surface of the membrane could be removed with minimal cleaning effort. However, this will not always be the case. Chemical compatibility between the cleaner, the facility's water, the dirt and oil in the cleaning solution, and the membrane material are critical to the performance of the system (Rajagopalan, in prep.). Each potential application of membrane filtration should be tested for interactions between the cleaner and the membrane to determine filter performance.

Chemical interactions affecting filter performance can occur for a variety of reasons. For example, during the testing a white precipitate formed on the inside of the membranes, cutting off the permeate flow. Due to the hardness of the water at the shop, calcium salts were becoming concentrated in the wash solution due to water evaporation. A small water softener unit was added to treat only the makeup water, and this successfully prevented the buildup of salts in the cleaner.

SURVEY OF RAILROAD ALKALINE CLEANER USE

Due to the potential interaction between cleaners and membranes, we also conducted laboratory testing to evaluate the compatibility of the major cleaners used by railroads with some common membrane materials. Major North American railroads were surveyed regarding alkaline cleaner brands, consumption, and price. Responses were received for 17 facilities from eight railroads. Of 21 brand-name cleaners in use at the reporting facilities, four are powders and 17 are liquids. Approximately \$US 1.5 million was spent for these cleaners in 1994 by the reporting facilities. Six cleaners accounted for 80 percent of cleaner consumption from a total of 680,000 litres of liquid concentrate and 170,000 kg of powder. Based on information about their ingredients and the uniqueness in their composition, the four cleaning products listed in Table 2 were selected for filter compatibility testing.

Table 2: Cleaners selected for filter compatibility testing

Company Name	Cleaning Product
Chemical Methods	CM809
Madison Chemical	#14
Calgon	AK6215
Calgon	Roundhouse

MEMBRANE AND CLEANER COMPATIBILITY TESTING

Laboratory tests were conducted on small test samples of four polymer membranes, and on one ceramic membrane, that were selected for their resistance to high pH and temperature conditions. All the combinations of cleaners and membranes showed some interaction based on a reduction in the rate of permeate passage, or flux rate. This is attributed to the physical process of the cleaner molecules occupying passageways in the membrane. Next, the membranes were tested against three samples of used cleaner solutions obtained from railroad shops. These dirty solutions produced a larger decrease in the flux rate of all the membranes. Membrane surfaces can get fouled by particulate matter and by coating the interior passageways with other chemicals. Particles in the solution can also form a layer on the inside of the membrane filter surface. The layer acts as a secondary filter with a smaller pore size and this becomes the controlling factor in flux rate. As the layer builds the flux rate decreases and some cleaner compounds can be stripped from the permeate. At this point in an actual application, the concentrated retentate in the filtration unit would be removed, and the filters would be cleaned to restore efficiency to the unit. The membrane cleaning process may be as simple as flushing the filters with warm soft water and fresh cleaner. More extensive fouling may require the use of citric acid or other chemicals to remove the buildup layer. The method and frequency for cleaning the filters must also be evaluated prior to designing or selecting a membrane filtration unit.

The membrane and cleaner compatibility testing showed that a filter pore size of 0.1 μm was appropriate for most railroad cleaner applications. The results also indicated that the flux range for each filtration membrane was affected by the particular cleaner but that a flux rate of 15 - 30 litres/m^2/hour was typical. We also investigated the effect on flux rate of pressures ranging from 138,000 to 414,000 Pa. Flux rate was generally independent of pressure; however, at pressures below about 207,000 Pa there was less buildup of secondary particulate matter on the inside of the membranes.

CONCLUSIONS

The AAR's research and testing of ultrafiltration technology indicates that it can be successfully used to recycle railroad shop cleaning solutions, thereby reducing pollution and saving money at the same time. The research has also provided insight regarding how well different membrane materials and filter designs can be used in railroad cleaning applications. The test results will help railroads evaluate potential applications of membrane filtration with specific parts washers. The testing procedure will also provide information on how to evaluate manufacturers' performance claims for their filters and filtration units.

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