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Oil Waste Reduction and Recycling Pilot Test

Tim Lindsey
Tony Montemurro
University of Illinois

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ILLINOIS DEPARTMENT OF NATURAL RESOURCES

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Oily Waste Reduction and Recycling Pilot Test

by

Timothy C. Lindsey
Hazardous Waste Research and Information Center
One East Hazelwood Drive
Champaign, IL 61820

and

Tony Montemurro
Outboard Marine Corporation
200 Sea-Horse Drive
Waukegan, IL 60085

Prepared for

Hazardous Waste Research and Information Center
One East Hazelwood Drive
Champaign, Illinois 61820

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ABSTRACT

Triad Engineering under the direction of the Illinois Hazardous Waste Research and Information Center (HWRIC) conducted a study comparing ultrafiltration and vapor recompression recovery technologies on the water soluble die lubricant (die lube) waste produced at the OMC Waukegan facility. Water soluble die lube waste disposal represents an annual disposal expense of approximately $123,000.

A side-by-side comparison of ultrafiltration technology and vapor recompression technology was conducted for a period of 25 days. This period of time was considered adequate to evaluate both technologies' ability to perform under normal production conditions. The permeate quality from the ultrafiltration system was generally somewhat poorer than the condensate from the vapor recompression system. However, field trials utilizing both permeate and condensate from the systems indicated they could be used in the water soluble die lube make up process. Biological growth and sulfide odors would be a problem with both systems.

The capital costs and operation and maintenance costs of the ultrafiltration system are slightly lower than the vapor recompression system for this application. A single sample was also collected and evaluated using atmospheric evaporation. The capital costs and operating costs for an atmospheric evaporation system are higher than either the ultrafiltration or the vapor recompression system, primarily due to the addition of a condenser system to recover distillate.

The payback period for the ultrafiltration system would be 1.19 years with an annual savings after payback of $90,275 per year. The payback period for the vapor recompression system would be 1.48 years with an annual savings after payback of $77,900 per year. The estimated payback period for the atmospheric evaporator system would be 1.51 years with an annual savings after payback of $56,200 per year.

1.0 BACKGROUND

Outboard Marine Corporation, identified four major categories of hazardous waste sources within the OMC manufacturing facility in Waukegan, Illinois. These sources included metal cleaning or treatment wastes, die cast oily wastes, solvents/fuel, and other miscellaneous sources. Of these four sources, the die casting operation was identified as the single largest contributor of waste material which required special handling and disposal as specified under federal regulations for special industrial or hazardous wastes.

The die casting operation generates wastes which include:

- Die lube water and sludge from sumps around die casting machines
- Oil sludge and hydraulic oils used within the hydraulic components
- Water soluble coolants
- Water soluble die lubricants

Water soluble die lubes are a mixture of 1 part concentrated die lubricant and 100 parts water. The concentrated die lubricant is 64% petroleum hydrocarbons, 26% oxidized polyethylene, 5% carbon and 5% silicone dioxide. The mixture is sprayed on the die casting machine die to allow a clean release between the die and the aluminum cast part.

Die lube is held in a large reservoir and supplied to each machine by means of a distribution system. Repeated use causes the die lube to break down, reducing its effectiveness as a release agent. Breakdown is both thermal and biological.

Other die casting materials which become a part of the die lube waste are water soluble coolants (40% organic) die lube additives (14% organic, 10% inorganic), phosphate ester hydraulic oils, and pigment grease (7% sulfonic acid, 1% sulfuric acid, 92% graphite/petroleum grease).

Approximately 4,000,000 pounds of die cast waste are generated per year, which represents approximately 47 percent of the total waste produced at the Waukegan facility. This waste is Toxicity Characteristic Leachate Procedure (TCLP) hazardous for D028, D029, and D040 constituents. Disposal costs for die cast waste amounted to $300,000 per year. The water soluble die lubricants accounted for 73 percent of the total volume (approximately 290,000 gallons), and 41 percent of the die cast waste disposal cost ($123,000 per year). Based on the large disposal cost and volume associated with the water soluble die lubricant waste, this stream was targeted as an ideal candidate for waste minimization.

Ultrafiltration and evaporation were identified as potential techniques to separate the spent soluble die lubricant material from the makeup water. Ultrafiltration is a low pressure (10 to 150 psi) membrane process which separates suspended solids and high molecular weight dissolved solids (such as oily emulsions) from liquid.

Evaporation allows separation of multi-component mixtures due to differences in vapor pressure. Lower boiling point components (including water) can be separated from high boiling point compounds such as die lubricants. Both ultrafiltration and evaporation can produce waste volume reductions exceeding 90 percent for many dilute wastewaters while producing a reusable water phase.

In order to assess the effectiveness of these processes, OMC conducted a pilot scale feasibility study under the Reduction and Recycling Techniques (RRT) matching fund program offered by the Hazardous Waste Research and Information Center (HWRIC). A pilot vacuum evaporation unit was supplied by the HWRIC, and OMC obtained a pilot ultrafiltration unit from Koch-Abcor through its agent, Arbortech, Inc. These pilot units were installed and operated by Triad over a six-week period from late October to December 1992. Data obtained from the pilot study was used to determine process feasibility along with capital and operating costs of similar full scale equipment.

2.0 MATERIALS AND METHODS

2.1 Ultrafiltration Equipment

A Koch Membrane System Model 4F-4VA was installed in the OMC Waukegan Die Casting Facility. The Model UF-4VA includes four 5-foot Abcor tubular membranes, each with 1.1 square feet of membrane area. Based on bench scale screening studies, HFP-276 hollow core membranes were selected due to their history of producing good quality permeate from oily wastes at a high flux rate. The Model UF-4VA also includes a 50-gallon process/cleaning tank, centrifugal recirculation pump, permeate flowmeter, pressure gauges, high temperature and low pressure shut-off switches, control panel, pipe, valves, and interconnecting wiring. A schematic of the UF system is shown in Figure 1.

Waste in the process tank is pumped through the ultrafilter at a high rate. A small amount of flow is forced through the membranes due to the pressure gradient. The filtered flow is referred to as the permeate. The bulk of the circulated liquid (along with the rejected material) flows back to the process tank as concentrate. The process tank was set up with a float switch which opened a feed valve to allow fresh feed (spent water soluble die lubricant) into the tank as the liquid level dropped due to the loss of permeate. A 500-gallon permeate storage tank was obtained to allow continuous collection of permeate during the week.

The system was set for an operating pressure of 30 to 32 psig across the membranes, with an outlet pressure of 10 to 11 psig. The membranes were cleaned weekly (usually on Monday), utilizing the manufacturer's recommended cleaning procedure. A 0.1 percent alkaline soap solution was made up with warm water in the process tank after removal of the concentrated process waste. The cleaning solution was circulated for three to four hours, with the permeate directed into the process tank. After cleaning, the ultrafilter was rinsed with cold tap water and drained. The waste concentrate was then pumped back into the process tank for further treatment.

2.2 Single Effect Mechanical Vapor Recompression Evaporator

A LICON Model C-5 single effect mechanical vapor recompression evaporator was installed adjacent to the ultrafilter. This evaporator utilizes electric heat to boil wastewater at a reduced temperature and pressure. The vapor passes through a mist eliminator and is cooled in the condenser. A vacuum is maintained by a venturi eductor which also draws the vapor through the mist eliminator. Cooling water is used on the cold side of the condenser, and is discharged after absorbing the latent heat of the vapor.

Heat to the evaporator is generated by three electric heaters. Water is used as the heat transfer medium, and is heated to 160° to 180°F and pumped through the Bayonet Augmented Tube (BAT) at a flow rate of 10 to 15 gpm, and then returned to the heating elements.

Cooling water (plant water) flows through the overhead condenser BAT heat exchanger. A 3/8-inch branch provides cooling water to the distillate cooler. Cooling water flow is controlled by setting a throttling valve in reference to flow indicator. Make-up water is controlled by separate valves and referencing a second flow indicator.

The distillate is recycled by a high pressure pump which operates the jet eductor at a pressure of 35 to 40 psig. The eductor exhausts any non-condensable gases along with condensate to the distillate tank. When the distillate level reaches the top float switch in the distillate tank, a solenoid valve opens and allows high quality distillate to flow to a 55-gallon holding tank. When the tank is pumped down, a lower float switch is tripped, closing the solenoid valve. Should the distillate quality be poor (as indicated by a high conductivity alarm), the distillate is directed to the feed holding tank for re-processing until the high conductivity condition is cleared. A high conductivity set point of 100 micromhos was selected.

The concentrate is recycled by a CPVC centrifugal pump which extracts concentrate from the separator and evaporator shells. The mixture of the recycled concentrate and the concentrate tank feed is vacuum transported back to the evaporator shell at a rate of 0.3 to 0.6 gpm, or about three times the evaporation rate. This high recirculation rate assures complete wetting of the tubes for good heat transfer. The recycle flow rate is controlled by a throttling valve. The difference in temperature between the vapor and the concentrate recycle indicates the boiling point elevation (BPE).

2.3 Atmospheric Evaporator Bench Study

A two-gallon sample of soluble die lubricant waste was shipped to Samsco, Inc. (a manufacturer of boiling-type evaporators) for their Evaporative Boil Assessment. This technology is called an atmospheric evaporative concentrator. Water is evaporated from the system by distillation at 212 degrees F. The waste sample is concentrated by evaporation at the boiling point under atmospheric conditions. The boiling sample is observed for tendencies such as foaming, solids precipitation, or scaling which would be problematic at full scale. Changes in pH are measured, and the final boiling temperature is noted, as is the ultimate volume reduction.

The Samsco evaporator can be used with or without a vapor condenser, depending on the requirements regarding volatile organic emissions or the desire to capture the water vapor for reuse. Because this study focused on the reuse of recovered water, this technology was evaluated with the vapor condenser option.

3.0 RESULTS AND DISCUSSION

3.1 Raw Waste Characteristics

The raw soluble die lube waste was analyzed following each fill of the pilot system feed holding tank, located in the die lube make-up area (See Table 2 and Figure 5). The waste die lube had a fairly high organic content, as reflected in the total organic carbon (TOC) content of 1970 mg/l (average). The chemical oxygen demand (COD) was also quite high (3390 mg/l) due to the oxygen demand of the die lube organic compounds. The total solids (TS) concentration was measured at 2000 mg/l, which is slightly higher than the TOC concentration. This would indicate that a substantial portion of the solids in the waste die lube are organic in nature. The total dissolved portion of the solids (TDS) averaged 1025 mg/l. All parameters except TDS showed large variations during this study.

The oil and grease (I.R. Method) ranged from 80 mg/l to 3000 mg/l (average of 870 mg/l). A strong sulfide odor was noticeable in the raw wastewater which may be an indication of biological reduction of sulfates in the dilution water. A sulfide concentration of 5 to 21 mg/l was measured (Table 2). Sulfides may also be produced from the sulfonates and sulfates in the pigmented grease compounds.

3.2 Ultrafiltration Test Results

The pilot ultrafilter test results from October 30 through December 3 are summarized in Table 2. The test results represent 25 days of operation, with a total run time of approximately 360 hours. During this test period, the process tank contents were supplemented with raw waste as the tank level dropped, and the concentrated waste was never discarded. A total waste volume of 3,110 gallons was processed which is equivalent to a 62:1 concentration factor in a 50-gallon process tank.

Figure 2 shows the variation in hydraulic flux rate through the 4.4 ft^2 module. The average flux rate was nearly 50 gpd/ft^2 at ambient temperature. No significant loss in flux was noted during the study provided adequate cleaning and maintenance were provided. While the flux rate did drop to 30 gpd/ft^2 at times, the alkaline-detergent cleaning procedure was effective at restoring the membrane permeability by the removal of the fouling material. At the end of the study the membrane tubes were removed and visually inspected. The membrane surfaces were quite clean and there was no evidence of fouling or scaling. It is interesting to note that the initial bench scale membrane evaluation produced a flux rate of nearly 40 gpd/ft^2 at ambient temperature and a pressure of 18 psig. The measured flux rate tended to increase throughout the study.

The permeate quality is plotted versus days of operation in Figures 3 to 6. The permeate was free of suspended solids, but was somewhat colored and had a sulfide odor. The sulfide concentration of the permeate was slightly lower than the raw waste, and ranged from 2 to 4 mg/l. Figure 3 shows that oil and grease (I.R. Method) was quite low in the permeate, but fairly high COD and TOC residuals were present as evidenced by Figures 4 and 6. Since ultrafiltration is not effective for low molecular weight dissolved compounds, these organics (along with dissolved inorganics) will pass through the membrane. The membrane will generally reject all chemical compounds in the molecular weigh range of 50,000 or higher. For example, sulfide (molecular weight 38), generally passes through the membrane whereas oil and grease are rejected.

The composition of the ultrafiltration concentrate is provided in Table 2 (UFCONC). As would be expected, there is an increase in COD and oil and grease in the concentrate as the study progressed. The TOC appeared to remain fairly constant, but this may have been due to analytical difficulties caused by the presence of high levels of tar-like greases. In general, COD or oil and grease are better parameters for monitoring the quality of the concentrate. It would appear that an oil and grease concentration of 2 to 3 percent is readily achievable in the process tank. A final batch concentration step could be performed to further reduce the final disposal volume and to increase the organic content for enhanced fuel value as a waste oil source.

3.3 Pilot Evaporator Results

The pilot evaporator test results are summarized in Table 2. The test results represent approximately 20 days of operation, with a total run time of 156 hours. During this test period, the feed tank was automatically filled with raw waste as condensate was produced, and the concentrated feed was never discarded. A total waste volume of 275 gallons was processed, which is equivalent to a 40:1 concentration factor in a 7-gallon feed tank.

An overall processing rate of 1.8 gal/hr was achieved during the study. The processing rate appeared to be fairly uniform during the course of the study, with no decline noted as would occur should there be fouling of the heat transfer media (bayonet augmented tubes). The waste boiled without excessive foaming, and general operation was trouble-free, though the overhead condenser temperature had to be maintained above 118° to 120°F or the boiling wastes would rise up the vapor tube and cause a high-level alarm shut-down.

The distillate quality is plotted versus days of operation in Figures 3 to 6. The distillate was slightly gray in color, with negligible odor, though the sulfide concentration was equivalent to that in the permeate. Sulfides, light fraction oils and phenols will codistill with the water vapor.

While the distillate generally had lower levels of COD, TOC, and TDS than the permeate, the oil and grease concentration often exceeded that of the permeate (Figure 3). This may be explained by the loss of volatile material which is recovered in the distillate. While the TDS of the distillate was generally quite low, the organic carbon content (TOC) actually exceeded the TDS. This apparent anomaly can be explained by the loss of volatile organics during the 104°C TDS drying step, thereby yielding a misleadingly low TDS value. Based on the COD and TOC, the distillate quality is good, but still contains a significant organic content. The evaporator concentrate composition is shown in Table 2 (EVCONC).

In general, the evaporator concentrate has a greater TOC, COD, and oil and grease content than the ultrafilter concentrate, due to the better separation of contaminants in the evaporator. The COD:TOC ratio is more consistent (approximately 2:1) than in the ultrafilter concentrate. The heating of the concentrate may have produced a waste more conducive to TOC analysis. Oil and grease sampling was somewhat difficult due to the poor mixing conditions in the feed tank, but a waste concentration of at least 3 percent oil and grease is achievable.

At the end of the study, the evaporator heating elements were removed and inspected. The three heating tubes were severely fouled with a 1/8-inch thick layer of hard material, with an overlying layer of brown, tar-like paste which completely occluded the space between the tubes in some areas. The foulant was very difficult to remove by physical means such as scraping. No attempt was made to solvent clean the tubes.

3.4 Bench Scale Atmospheric Evaporator Test Results

The bench scale atmospheric evaporator tests conducted by Samsco were successful. A volume reduction of almost 99 percent was achieved (final volume of 13 ml with 1000 ml original sample size). Foaming was not problematic, and the pH increased slightly from 6.7 to 7.6 during the test so that no alkaline pH adjustment was necessary. A final boiling point elevation (BPE) of 5°(F) was noted. This 5° (F) BPE was also noted in the pilot evaporator tests.

The final concentrate had a viscosity that appeared similar to water. The only negative characteristic was the increase in chloride concentration from 98 ppm to 9800 ppm. Due to the chloride content, titanium is recommended as the materials of construction. These construction materials increased the capital cost of equipment significantly.

3.5 Capital and Operating Costs

The capital and operating costs for the three options (ultrafiltration, mechanical vapor recompression evaporation, or atmospheric evaporation) are shown in Tables 3 to 5 and Figure 8. The design basis for options is as follows:

Treated Volume = 290,000 gal/yr
Daily Volume = 1,500 gal
Weekly Volume = 7,500 gal
Operating Days = 5 days/wk, 24 hr/day
Percent Downtime Allowance = 20%
Cooling Water Temperature (Max.) = 78°F Max Rise = 70°F
Natural Gas Cost = $2.7/million BTU
Cooling Water Cost = $4/1,000 gal
Hauling Cost of Concentrate = $0.5/gal
Operator Compensation and Benefits = $35,000/yr

While a single-stage vacuum evaporator from Licon was tested, a multi-stage vapor recompression unit is costed to reduce operating costs and to eliminate the cost of cooling water. A Samsco atmospheric evaporator with vapor recovery was costed. It should be noted that two condensers for the Model 600, add $46,000 to the capital cost and add about $17,400/year to the operating cost.

Finally, all three options assume that the tanks used in OMC's batch treatment system could be reused in each option. The ultrafiltration unit had the lowest capital and operating cost profile. Capital costs for the vapor recompression (VR) unit and the atmospheric evaporator (AE) were approximately the same although the VR unit O&M costs reflect the lower energy input required for the VR system.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Product Reuse

Samples of the permeate and condensate were collected during the field trials and provided to OMC for evaluation in water soluble die lubricant (die lube) makeup tests. OMC personnel noted a slight discoloration and odor from the reuse water in both the permeate and the distillate. However, all die casting operations utilizing either the permeate or the concentrate proceeded normally and the die cast parts were acceptable in appearance. It was noted that the die lube made from permeate caused a dull, silver-like cast to the part.

As a result of this evaluation, OMC determined that both the permeate and concentrate from the ultrafiltration process and the vapor recompression process would be acceptable for reuse within the facility. It is apparent from the sulfide odor that biological activity would be a problem for both permeate and condensate storage and reuse. For this reason, it is recommended that these materials be stored in aerated tanks until they would be made available for reuse.

4.2 System Comparison

Both the vapor recompression and ultrafiltration systems produced acceptable, quality effluent which could be reused within the facility. The quality of effluent produced by the vapor recompression system was superior in terms of COD, TDS, and TOC pollutants. However, the permeate from the ultrafiltration system was superior in terms of lower total oil and grease concentrations.

Attempts to analyze the performance of the UF and VR technologies using a mass balance approach were not successful. Using the average raw feed (RAW-AV) and permeate (PEAM-AV) or distillate (DISTILL-AV) values reported in Table 2 and the UFCONC-11 or EVCONC-11 data, it should have been possible to calculate a mass balance. Concentrate samples from the UF and VR systems taken on December 3, 1992 (day 25), should represent the net accumulation of chemicals during the study. A mass balance was calculated for oil and grease, TDS, TS, COD and conductivity. The mass in the concentrate plus the mass in the distillate or permeate rarely accounted for more than half the mass in the raw waste.

The differences may be attributable to the difficulty with obtaining representative samples of the UF or VR concentrate. Since the raw waste and permeate or concentrate were more homogeneous, average concentrations from these waste streams were used to approximate how the wastes are partitioned.

Figures 9 and 10 are schematic depictions of UF and VR mass balance analyses. The average raw, permeate and distillate analytical results were used to calculate pounds of oil and grease, organic carbon, and dissolved solids generated by each technology. Concentrate volumes were previously reported as concentration factors recorded during the study. The concentration factor for UF is 62:1. The concentration factor for VR is 40:1. The pounds of waste reported for the concentrate were calculated by subtracting the permeate from the raw waste.

Figures 9 and 10 illustrate the relative partitioning efficiency of these technologies. A waste volume of 1000 gallons was selected for comparison purposes. Although the concentration factors are significantly different, both UF and VR are very efficient in concentrating the waste (16 gallons/l000 gallons for UF, 25 gallons/1000 gallons for VR). Both technologies were effective in removing oils and grease from the water (99.2% for UF versus 98.4% for VR). The membrane technology partitioned 17% of the organic carbon and 84% of the dissolved solids to the permeate phase. Distillation partitioned 9.7% of the organic carbon and only 2.7% of the dissolved solids to the distillate. The lower partitioning efficiencies for ultrafiltration are a reflection of the membranes' inability to reject low molecular weight chemicals.

No mass balance analysis was attempted for the atmospheric evaporator because the data represents a single, two-gallon sample trial run. That limited sampling event was not considered adequate to allow a detailed partitioning evaluation.

The ultrafiltration system membranes were unaffected by contaminants in the water soluble die lube wastewater. They maintained a consistently high flux rate over the period of the study and responded well to cleaning procedures. The vapor recompression system developed a tar-like coating around the heating tubes. This coating was difficult to remove and would represent an operation and maintenance problem during long-term operation.

The ultrafiltration system had the lowest capital installed cost at $146,500. Based on operation and maintenance estimates, it also had the lowest total O&M

costs of $32,725 per year. The ultrafiltration system would demonstrate a payback period of 1.19 years and an annual savings after payback of $90,275.

The vapor recompression evaporator had an estimated capital cost of $182,500 with an annual operating and maintenance cost of $45,100 per year. A major portion of this O&M cost was due to the estimated time required to clean fouling from the tubes. The system payback would be approximately 1.48 years with an annual savings after payback of $77,900.

The atmospheric evaporating system was evaluated on a single-point basis, and therefore, was not subjected to the same level of investigation as the ultrafiltration and vapor recompression technologies. The estimated capital cost for the atmospheric evaporator system was $185,200. The primary expense associated with this system would be the use of titanium coils to prevent fouling and the additional cost of the condenser coils to recover water vapor. This system was estimated to be the most costly to operate and maintain at an annual cost of $66,800 per year. The payback period of approximately the same as for the vapor recompression system at 1.51 years with an annual savings after payback of $56,200.

This study and the conclusions drawn from the data are site specific and should not be interpreted as an endorsement or rejection of any of the technologies evaluated. Similar testing should be conducted on-site prior to determining the applicability of these systems to other facilities.

TABLES

TABLE 1: 1992 PROJECT EVENTS

Week No. 1 (10/19 to 10/23)

- Raw waste tank filled 10/20
- Evaporator and ultrafilter started up 10/22
- Evaporator shut down for weekend, ultrafilter placed on "recycle"for weekend

Week No. 2 (10/26 to 10/30)

- Raw waste tank filled 10/28
- Samples collected 10/30
- Evaporator mechanical shut-down problem (due to pressure switch inadvertent shut down) corrected
- Evaporator shut down for weekend, UF placed on "recycle"

Week No. 3 (11/2 to 11/6)

- Raw waste tank filled 11/6
- Samples collected 11/3 and 11/6
- Evaporator shut down for weekend, UF continuously processing

Week No. 4 (11/9 to 11/13)

- Raw waste tank filled 11/10
- Samples collected 11/11 and 11/13
- Evaporator shut down for weekend, UF continuously processing

Week No. 5 (11/17 to 11/20)

- Raw waste tank filled 11/18
- Samples collected 11/18 and 11/20

Week No. 6 (11/23 to 11/25)

- Short week due to holiday
- Samples collected 11/25
- Both units shut down over holiday

Week No. 7 (11/30 to 12/3)

- Raw waste tank filled 12/2
- Samples collected 12/1, 12/2, 12/3
- Both units shut down 12/4, final examination of membranes and heating elements performed on 12/7

TABLE 2: ANALYTICAL RESULTS

Sample ID	Date(1992)	Day	O&G (ppm)	TS (ppm)	TOC (ppm)	COD (ppm)	TDS (ppm)	S (ppm)	COND umho
Raw–1	10–30	6	140	1,800	320	1,600	1,100	18	1,000
UFCONC–1	10–30	6	3,100	11,000	360	5,600	2,200	–	1,200
EVCONC–1	10–30	6	4,100	5,100	760	7,900	3,800	–	260
PERM–1	10–30	6	39	–	180	810	980	1.6	700
DISTILL–1	10–30	6	94	–	86	270	<4	.81	80
PERM–2	11–3	8	2	–	–	–	–	–	–
RAW–3	11–6	11	1,700	1,700	280	2,500	1,000	21	1,200
UFCONC–3	11–6	11	5,000	89,000	280	50,000	32,000	–	5,600
EVCONC–3	11–6	11	130	8,200	1,200	4,600	6,800	–	1,000
PERM–3	11–6	11	1.2	–	170	1,400	1,000	4.7	1,000
DISTILL–3	11–6	11	9.2	–	55	260	20	3.5	160
UFCONC–4	11–11	14	18,000	–	–	–	–	–	–
EVCONC–4	11–11	14	220	–	–	–	–	–	–
PERM–4	11–11	14	0.88	–	–	–	–	–	–
DISTILL–4	11–11	14	2.2	–	–	–	–	–	–
RAW–5	11–13	16	120	1,500	260	4,402	1,100	5.2	1,200
UFCONC–5	11–13	16	1,200	85,000	360	16,000	7,300	–	1,100
EVCONC–5	11–13	16	2,400	12,000	1,500	14,000	8,000	–	6,300
PERM–5	11–13	16	<0.5	–	130	550	890	3.8	5,100
DISTILL–5	11–13	16	4.3	–	49	91	28	3.1	140
RAW–6	11–18	18	400	3,500	860	6,400	1,100	–	1,100
UFCONC–6	11–18	18	6,700	79,000	570	38,000	11,000	–	1,200
EVCONC–6	11–18	18	9,900	47,000	1,600	9,700	7,800	–	6,300
PERM–6	11–18	18	1.2	–	140	680	940	–	1,200
DISTILL–6	11–18	18	2.8	–	55	230	24	–	120
RAW–7	11–20	20	80	1,500	830	1,300	1,200	–	1,000
UFCONC–7	11–20	20	1,500	25,000	3,300	21,000	5,400	–	1,100
EVCONC–7	11–20	20	11,000	23,000	3,900	26,000	9,200	–	7,600
PERM–7	11–20	20	0.91	–	310	650	780	–	1,100
DISTILL–7	11–20	20	4.0	–	–	–	–	–	–
RAW–8	11–25	21	360	1,900	4,300	3,000	980	–	1,100
UFCONC–8	11–25	21	3,200	58,000	3,000	15,000	8,900	–	920
EVCONC–8	11–25	21	6,600	25,000	15,000	29,000	9,900	–	9,300
PERM–8	11–25	21	2.0	–	1,200	430	810	–	1,200
DISTILL–8	11–25	21	4.4	–	82	430	16	–	150
RAW–9	12–01	23	240	1,800	4,000	3,300	930	–	1,200
UFCONC–9	12–01	23	7,000	20,000	2,600	20,000	8,000	–	1,000
EVCONC–9	12–01	23	6,800	20,000	18,000	38,000	7,900	–	8,700
PERM–9	12–01	23	1.7	–	1,700	670	730	–	1,200
DISTILL–9	12–01	23	1.6	–	1,100	600	100	–	290

TABLE 2: ANALYTICAL RESULTS

Sample ID	Date(1992)	Day	O&G (ppm)	TS (ppm)	TOC (ppm)	COD (ppm)	TDS (ppm)	S (ppm)	COND umho
RAW−10	12−02	24	1,800	2,700	3,300	6,100	880	−	1,200
UFCONC−10	12−02	24	3,300	60,000	23,000	62,000	4,900	−	1,200
EVCONC−10	12−02	24	8,200	27,000	16,000	34,000	10,000	−	8,400
PERM−10	12−02	24	14	−	1,200	610	820	−	1,200
DISTILL−10	12−02	24	7.5	−	560	370	<4.0	−	150
RAW−11	12−03	25	3,000	1,600	3,600	3,100	940	−	1,200
UFCONC−11	12−03	25	23,000	74,000	2,300	17,000	2,900	−	1,200
EVCONC−11	12−03	25	34,000	49,000	17,000	30,000	10,000	−	8,700
PERM−11	12−03	25	16	−	1,300	270	910	−	1,200
DISTILL−11	12−03	25	15	−	540	320	28	−	150

AVERAGE CONCENTRATIONS

Sample ID	O&G (ppm)	TS (ppm)	TOC (ppm)	COD (ppm)	TDS (ppm)	S (ppm)	COND umho
RAW−AV	871	2,000	1,542	3,522	1,026	15	−
PERM−AV	7.7	−	633	674	873	3.4	−
DISTILL−AV	14.5	−	355	403	28	2.5	−

TABLE 3: UF CAPITAL AND OPERATING COST SUMMARY

Capital Costs

Design Flux = 35 gpd/ft^2

Area = Normal 42 ft^2

Select Unit = UF-70

Cost (No Process Tank) =		$36,000
Assume:	Installation =	$24,500
	Mechanical =	34,000
	Electrical =	15,900
	Design Eng. =	16,000
	Constr. Mngt. =	10,100
	Contingency (10%) =	10,000
	TOTAL	$146,500

Annual Operation and Maintenance Costs

Membrane Replacement, Chemicals, Electricity	$725/year
Operators (4 hours/day)	17,500/year
Waste Disposal Costs (29,000 gpy)	14,500/year
TOTAL O&M	$32,725/year

System Payback

Payback Period ($146,500 ÷ $123,000/yr) =	1.19 years
Annual Savings After Payback =	$90,275/year

TABLE 4: MECHANICAL RECOMPRESSION EVAPORATOR CAPITAL AND OPERATION COST SUMMARY

Capital Costs

Licon Model C-75 = $125,000 (1800 gpd)

Assume:	Installation =	$10,000
	Mechanical =	8,200
	Design Eng. =	15,000
	Constr. Mngt. =	10,000
	Contingency (10%) =	14,000
	TOTAL	$182,500

Annual Operating and Maintenance Costs

Steam, Cooling Water, Electricity	$4,350/year
Operators (6 hours/day)	26,250/year
Waste Disposal (29,000 gpy)	14,500/year
TOTAL	$45,100/year

System Payback

Payback Period ($182,500 ÷ $123,000/yr) =	1.48 years
Annual Savings After Payback =	$77,900/year

TABLE 5: ATMOSPHERIC EVAPORATOR CAPITAL OPERATING AND COST SUMMARY

Capital Costs

Capital Costs $126,500 for (2) Model 600

Assume:	Installation =	$18,200
	Design Eng. =	11,000
	Constr. Mngt. =	12,500
	Contingency (10%) =	17,000
	TOTAL	$185,200

Annual Operating and Maintenance Costs

Energy, Cooling Water	$34,800/year
Operators (4 hours/day)	17,500/year
Waste Disposal (29,000 gpy)	14,500/year
TOTAL	$66,800/year

System Payback

Payback Period ($185,200 ÷ $123,000/yr) =	1.51 years
Annual Savings After Payback =	$56,200/year

FIGURES

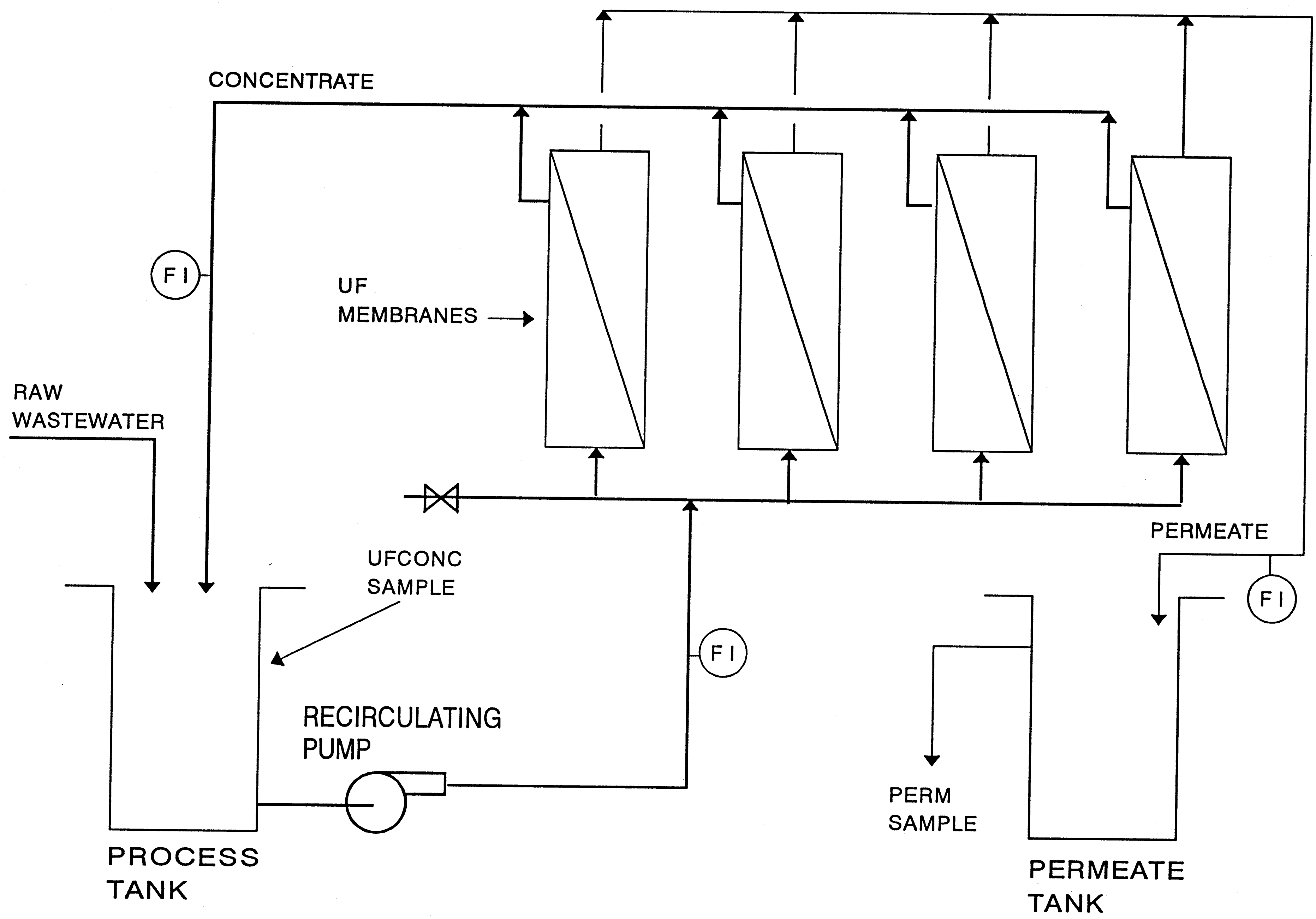


FIGURE 1: ULTRAFILTRATION SCHEMATIC

FIGURE 2: ULTRAFILTER FLUX VERSUS DAYS OF OPERATION

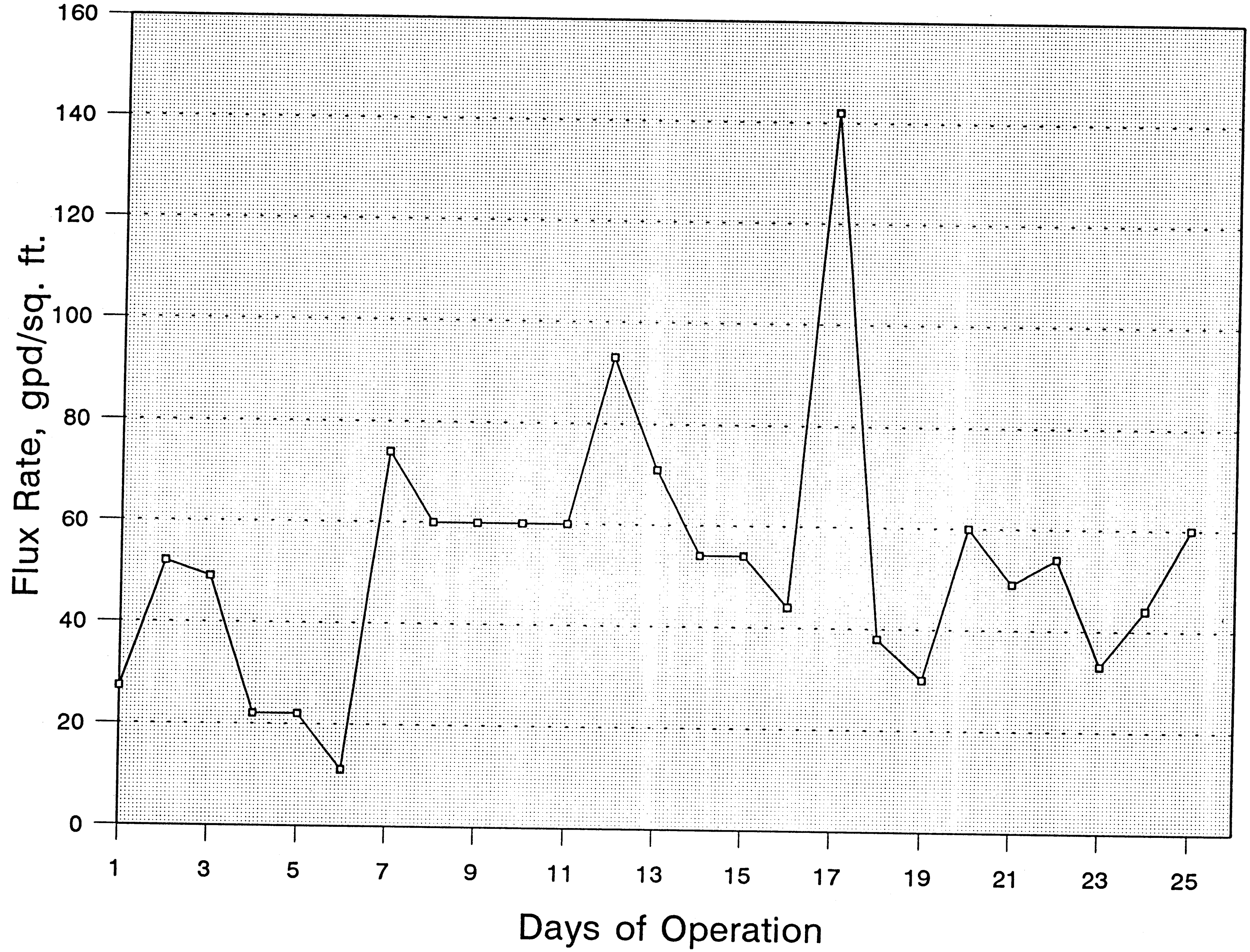


FIGURE 3: PERMEATE/DISTILLATE OIL AND GREASE VERSUS DAYS OF OPERATION

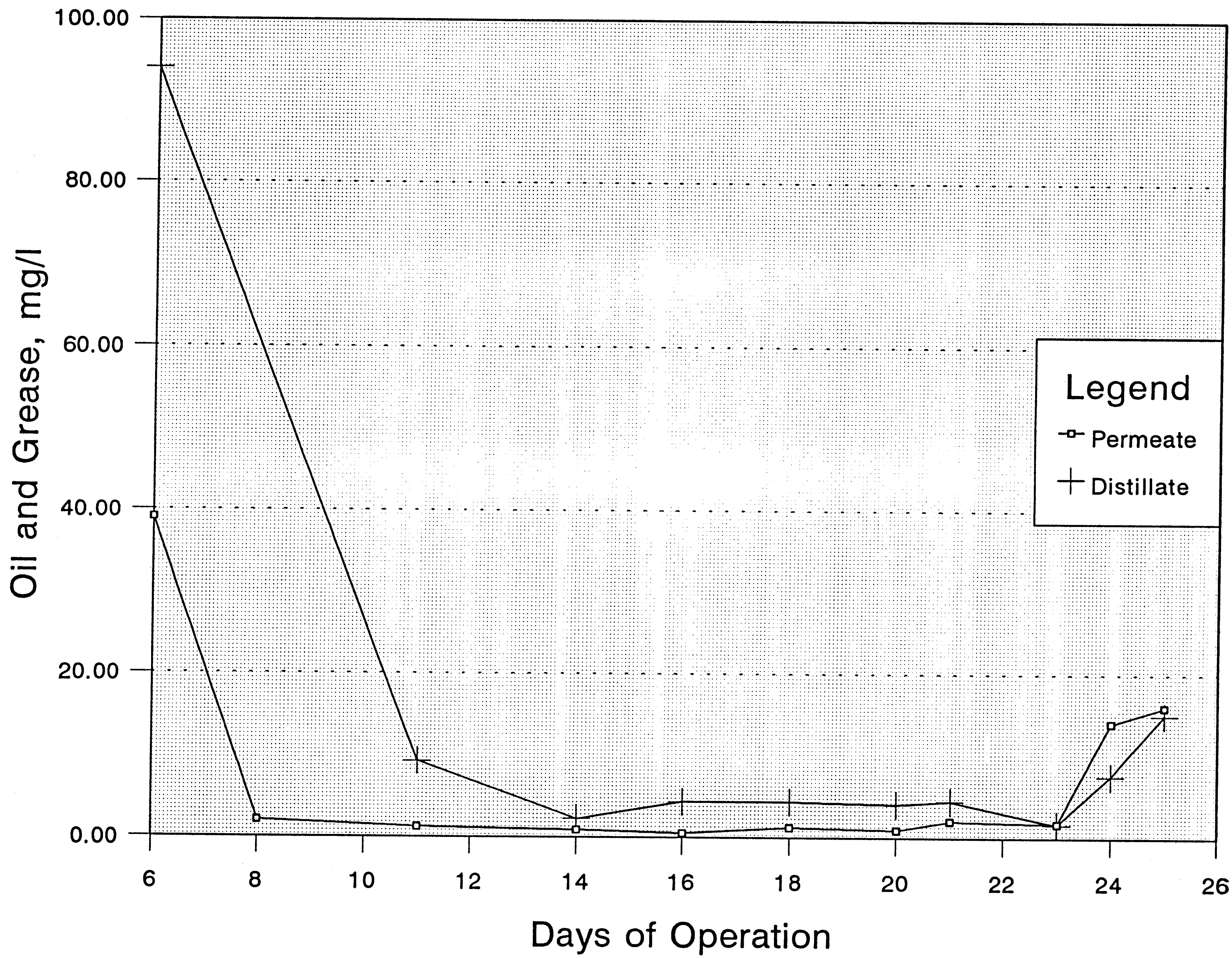


FIGURE 4: PERMEATE/DISTILLATE COD VERSUS DAYS OF OPERATION

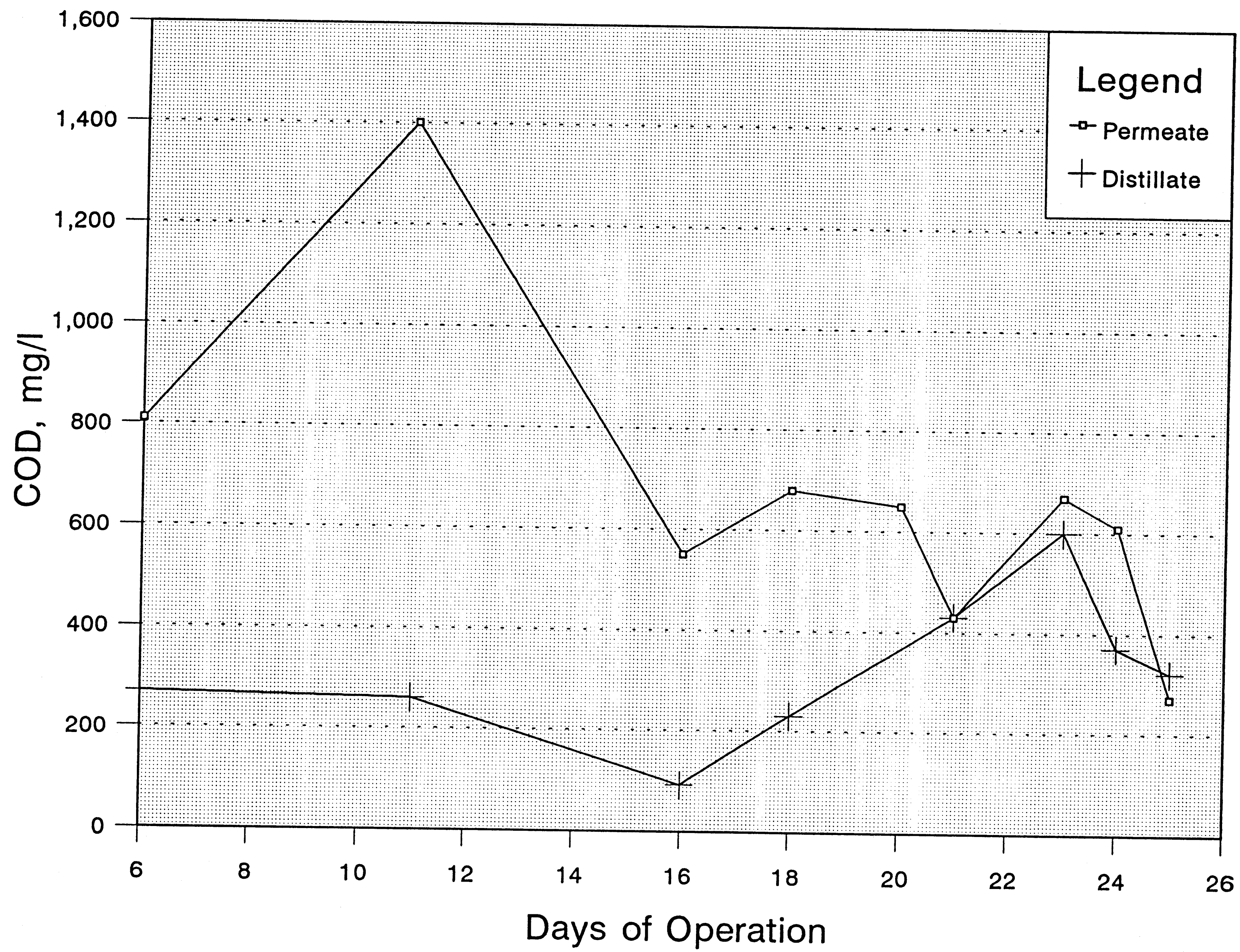


FIGURE 5: PERMEATE/DISTILLATE TDS VERSUS DAYS OF OPERATION

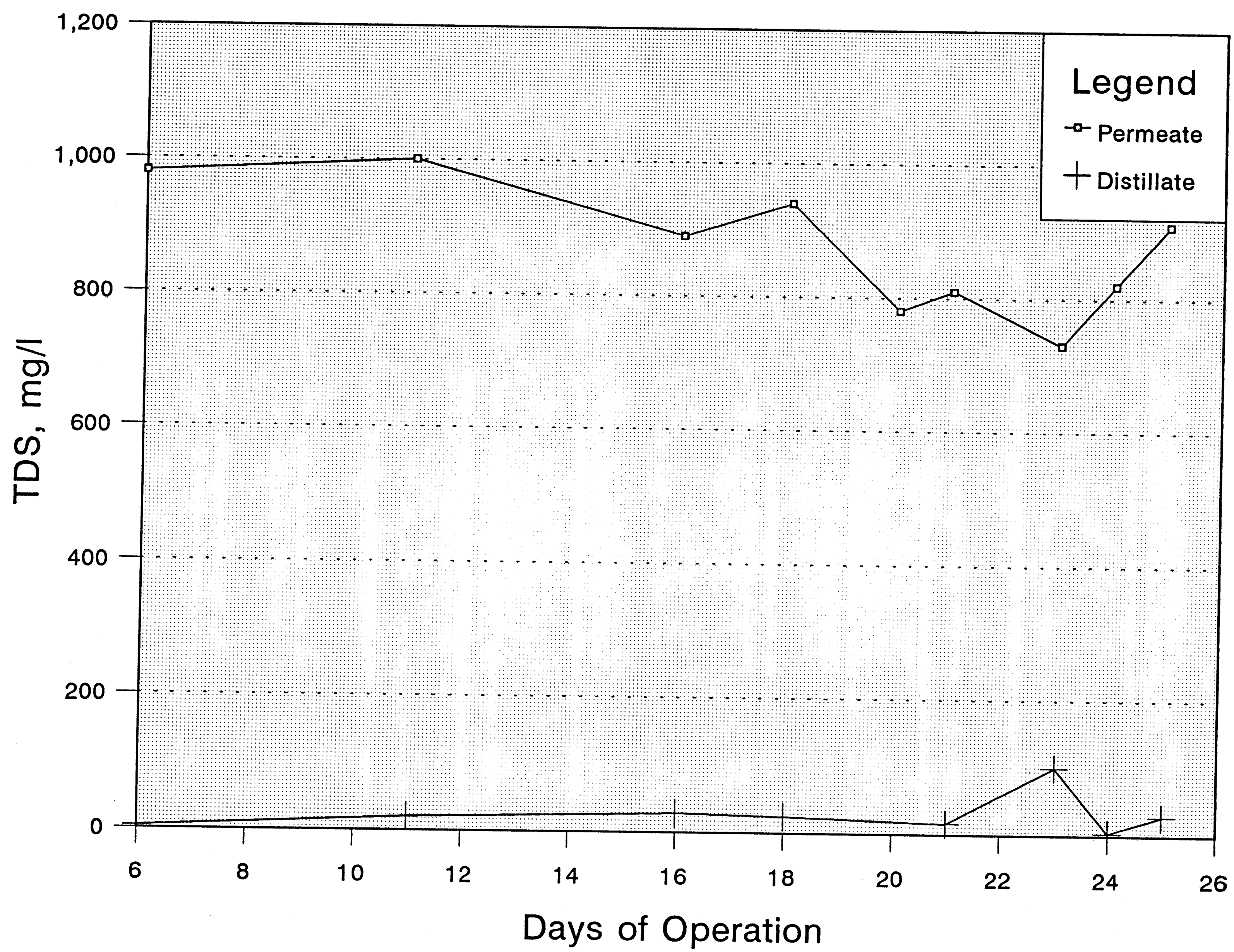


FIGURE 6: PERMEATE/DISTILLATE TOC VERSUS DAYS OF OPERATION

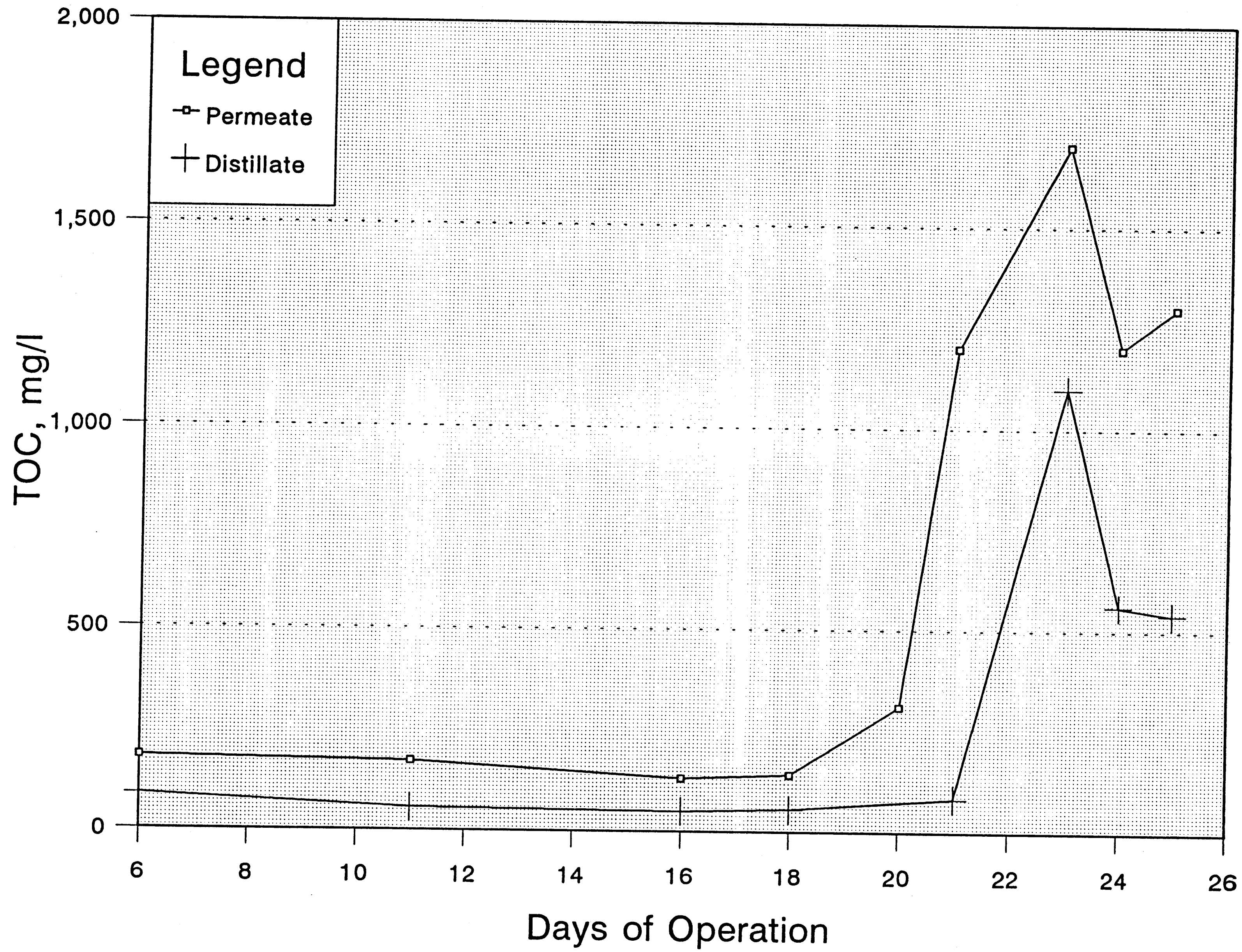


FIGURE 7: RAW FEED WATER QUALITY VERSUS DAYS OF OPERATION

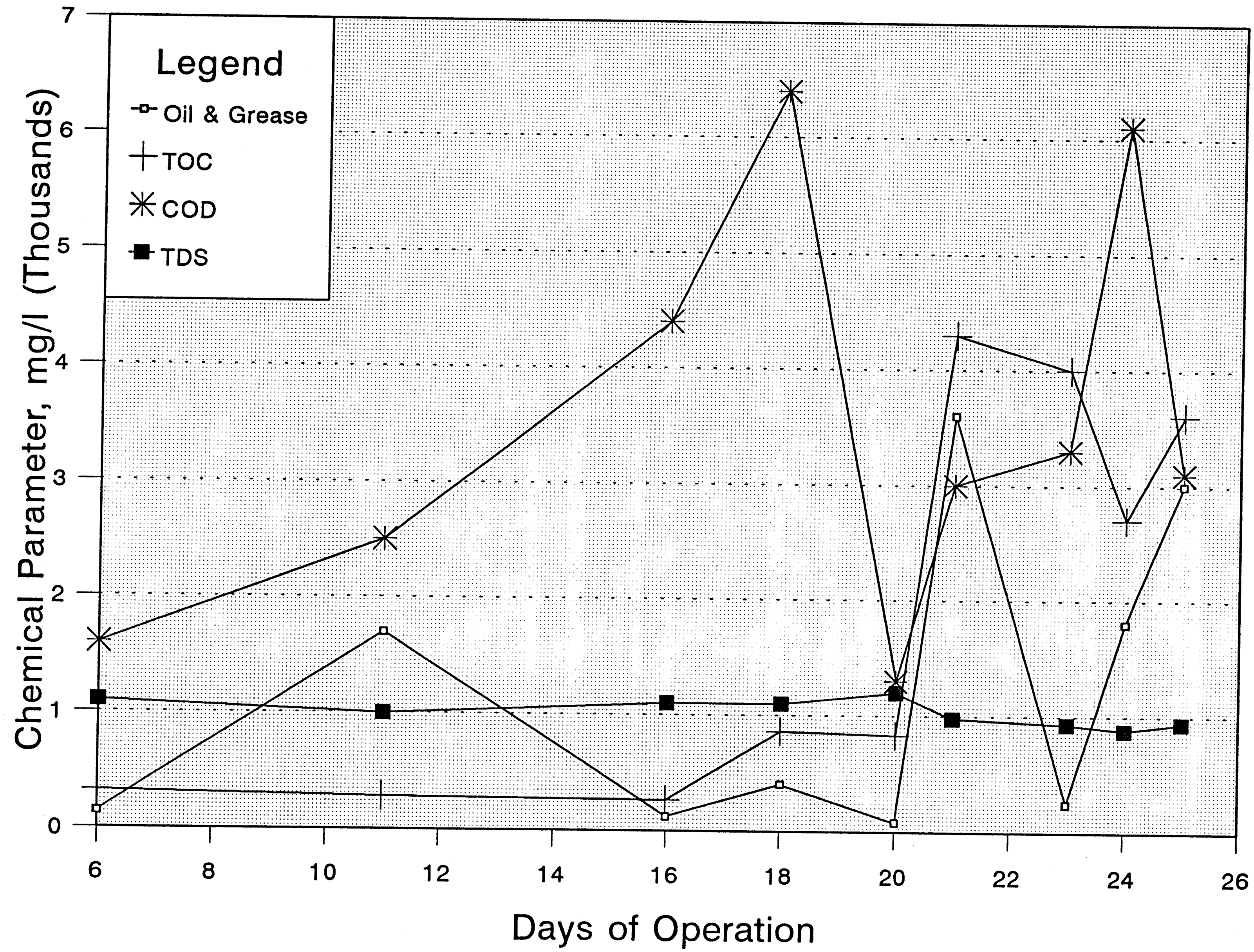
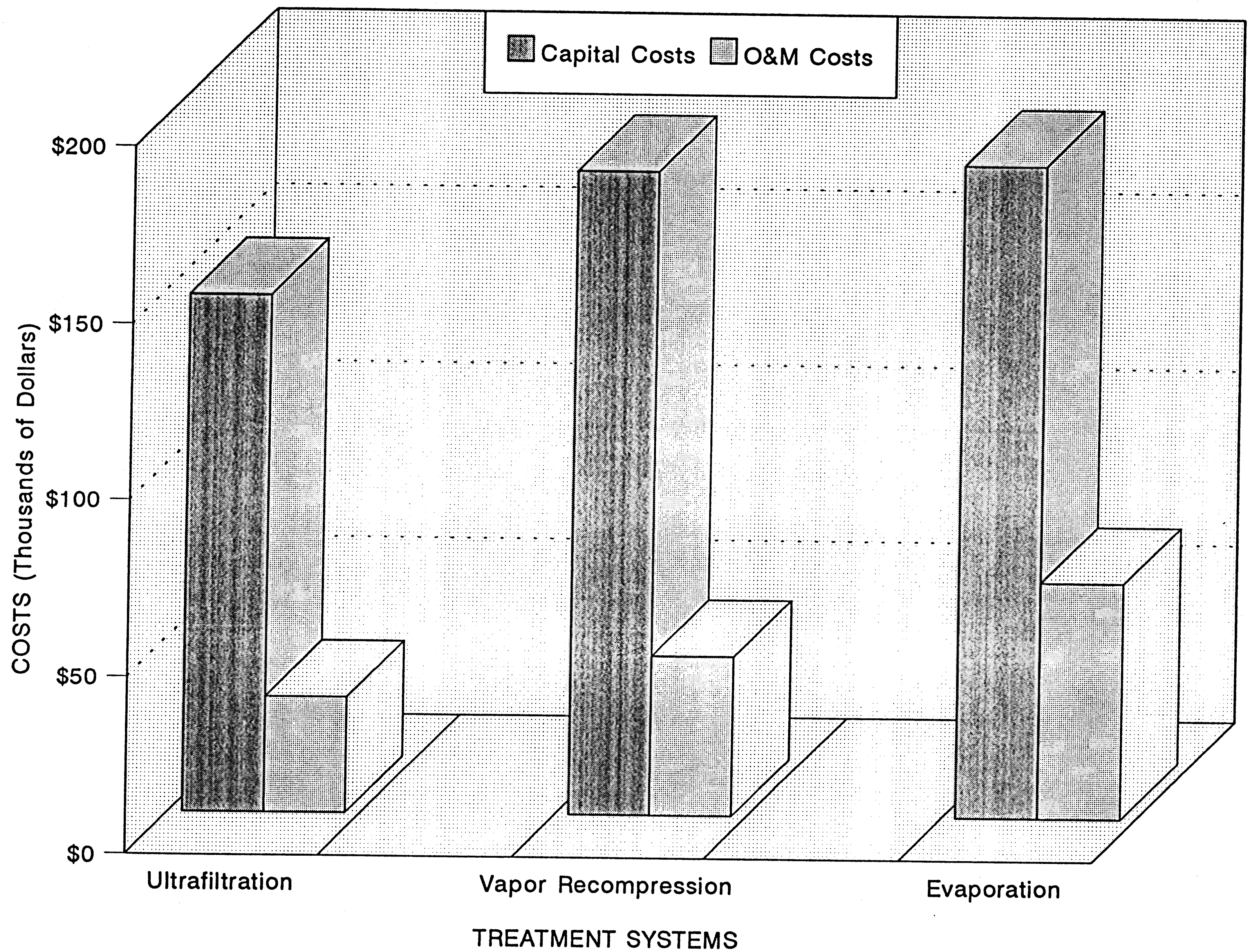


FIGURE 8: A COMPARISON OF CAPITAL AND OPERATING COSTS



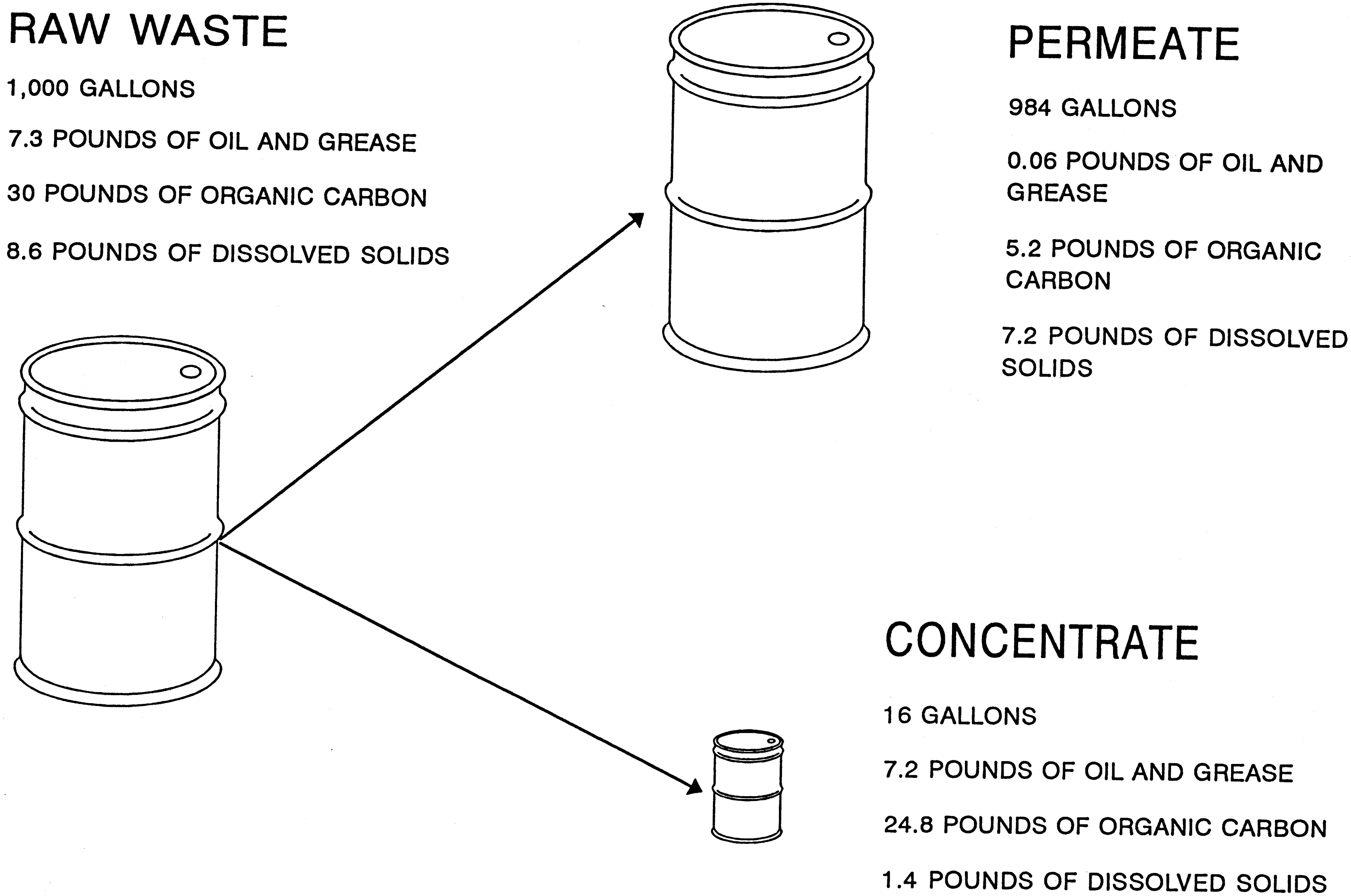


FIGURE 9: ULTRAFILTRATION MASS BALANCE

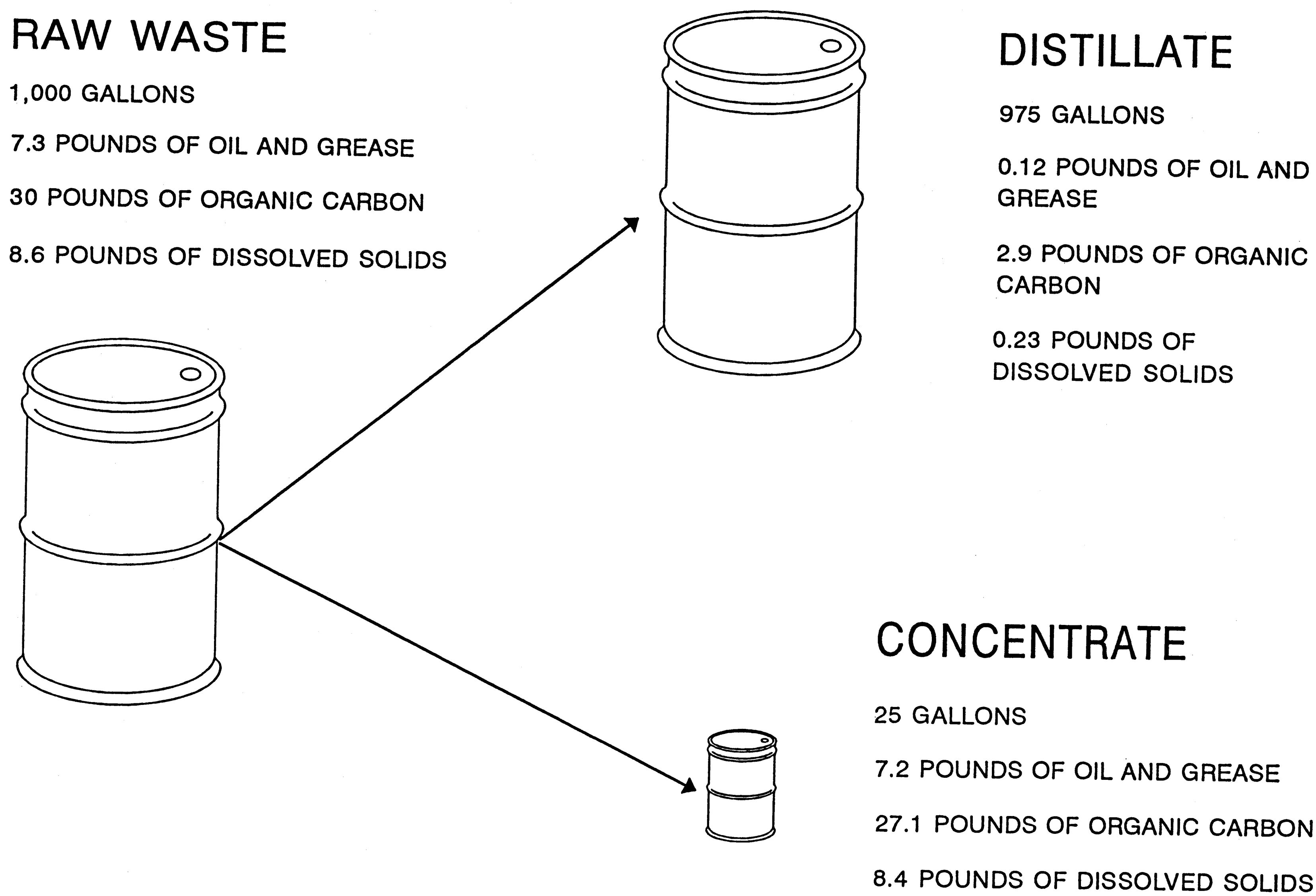


FIGURE 10: VAPOR RECOMPRESSION MASS BALANCE