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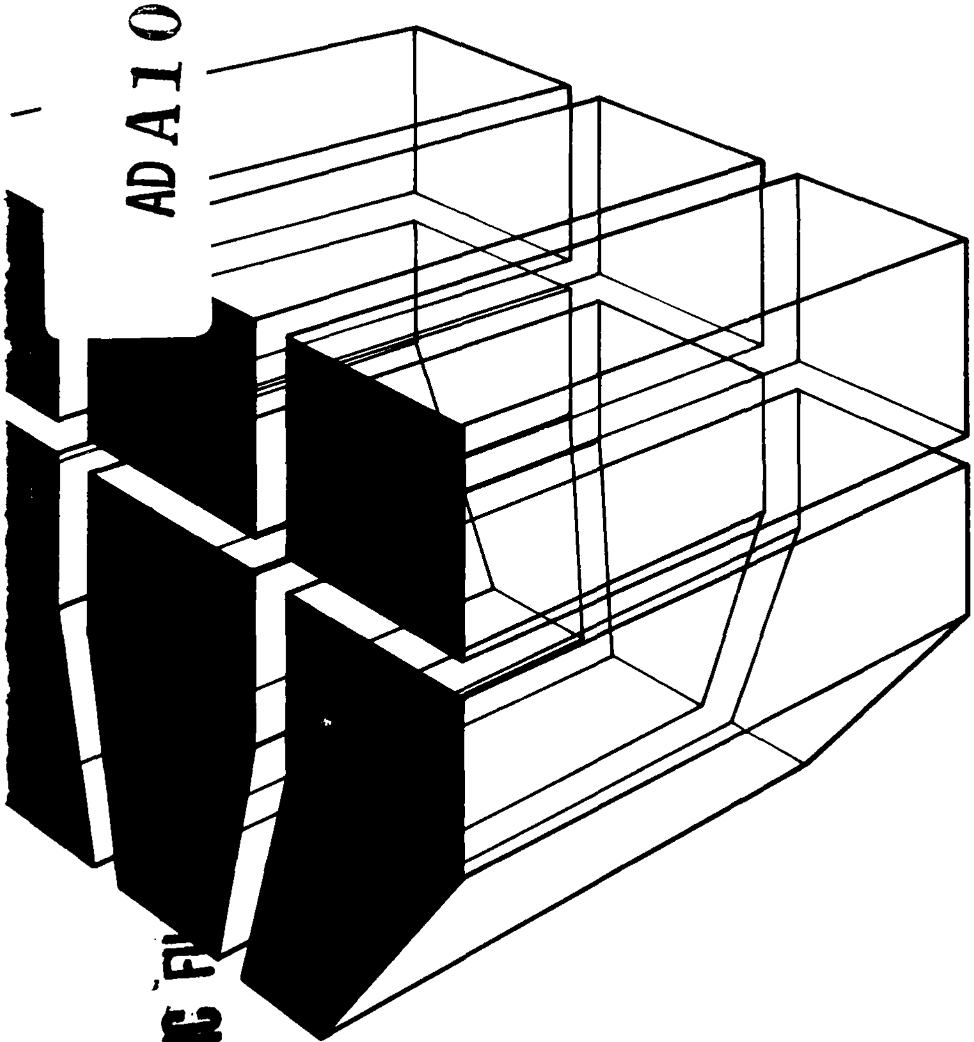
TECHNICAL REPORT N-107
August 1981
Oil Pollution Control at Military Installations

PRETREATMENT OF WASTE DISCHARGES FROM IMPROVED ARMY TACTICAL EQUIPMENT MAINTENANCE FACILITIES



by
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This report describes (1) field investigations into the use of commercial cleaning equipment for Army tactical equipment maintenance operations and (2) an evaluation of wastewater pretreatment requirements for sanitary sewer discharge. Included is an analysis of raw wastewater characteristics, an evaluation of commercial cleaning equipment performance, and the development of design criteria for wastewater pretreatment. Also described is the field verification of these criteria at a pilot test facility that used a commercially packed, gravity oil/water separator. It was determined that operation-

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ally reliable commercial cleaning equipment is available to the Army that can perform all required maintenance cleaning tasks without cleaning aids. It was also determined that wastewater pretreatment requirements could be stated in terms of total suspended solids and free oil removal to predetermined levels, if low hydraulic overflow rates and relatively long detention times are used.

FOREWORD

This report was prepared for the Directorate of Military Programs, Office of the Chief of Engineers (OCE), under Project 4A762720A896, "Environmental Quality for Construction and Operation of Military Facilities"; Task Area 02, "Pollution Abatement Systems"; Work Unit 009, "Oil Pollution Control at Military Installations." The applicable QCR is 3.01.004. The OCE Technical Monitor is Mr. Walt Medding.

The study was conducted by the Environmental Division (EN) of the U.S. Army Construction Engineering Research Laboratory (CERL). Dr. R. K. Jain is Chief of CERL-EN. Valuable contributions were made by former CERL employees Ms. C. Watson and Mr. E. Lubieniecki, and by Directorate of Facilities Engineering (DFAE) personnel and members of the 2nd Battalion/77th Armored at Fort Lewis, WA. Their cooperation in this effort is greatly appreciated.

Special appreciation is extended to Mr. Mark Massarik, former Sanitary Engineer, Fort Lewis, and Mr. David Hanke, present Sanitary Engineer, Fort Lewis, for their administrative and technical assistance.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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PRETREATMENT OF WASTE DISCHARGES FROM IMPROVED ARMY TACTICAL EQUIPMENT MAINTENANCE FACILITIES

1 INTRODUCTION

Background

Oily wastewater from Army tactical equipment maintenance operations originates principally from the improper handling and storage of new and waste oils, from equipment washing operations, and from various other maintenance activities that generate wastes that must be stored or treated. An FY77 survey of oil pollution control problems at Army installations identified the need for improved waste oil handling systems in the Table of Organization of Equipment (TOE) maintenance areas, especially those areas handling tracked equipment. This study also pointed out that heavy maintenance cleaning operations (e.g., the cleaning of engines, engine compartments, and other equipment components) performed on existing washrack facilities were inefficient and consumed large quantities of potable water. Existing high-volume, low-pressure wash hose systems also invariably required the use of solvents and industrial and domestic detergents. Under these conditions, the construction of effective wastewater treatment units at each individual washrack site did not appear to be practical or economical if a large number of sites had to be considered.[1]

Since 1975, the U.S. Army Construction Engineering Research Laboratory (CERL) has been trying to identify facility requirements for centralized vehicle washing and wastewater treatment systems and to identify improved in-motorpool maintenance facilities.[2] This latter research effort developed the concept of the tracked vehicle maintenance facility. The principal purpose of this facility was to provide a dedicated space within the hardstand area where all cleaning tasks essential to tracked vehicle maintenance operations, including oil changing, could be performed efficiently. These facilities (as designed for Fort Lewis, WA) also would handle wet maintenance requirements for all types of TOE wheeled equipment. This concept would make it possible to control wastes generated by tracked vehicle maintenance operations.

The main sanitary engineering concerns in the design of the tracked vehicle maintenance facility for military use are: (1) the selection and evaluation of commercial high-pressure, low-volume cleaning equipment capable of meeting all anticipated service conditions without the need for solvents or other cleaning aids, and (2) an analysis of wastewater treatment requirements for effluent discharge to an installation's sanitary sewer system.

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[1] Consolidated Facilities for Washing Tactical Vehicles, Engineer Technical Note (ETN) No. 77-14 (Office of the Chief of Engineers [OCE], 10 August 1977).

[2] ETN 77-14; and R. Fileccia, J. Benson, and J. Matherly, In-Hardstand Tactical Vehicle Maintenance Facilities -- Concept Design and Preliminary Recommendations for Wastewater Treatment, Interim Report N-67/ADA067985 (U.S. Army Construction Engineering Research Laboratory [CERL], March 1979).

Objective

The objective of this study is to evaluate the performance of commercial cleaning equipment under field conditions and to analyze the requirements for the treatment of the resultant wastewaters for discharge to an installation's sanitary sewer system.

Approach

This study had three phases:

1. Field tests were conducted to determine if commercial equipment could perform all the required maintenance cleaning tasks without cleaning aids. During this same period, the physical and chemical characteristics of the wastewaters were determined. Based on an analysis of these data, preliminary design criteria for wastewater treatment were developed.

2. A pilot cleaning facility which had a commercially packed, gravity oil/water separation unit was tested to validate the preliminary design criteria and to further evaluate the performance of commercial equipment.

3. The pilot cleaning facility was physically expanded to determine the hydraulic capacity of the separation unit and to confirm, if possible, estimates made of the maintenance frequency for the treatment unit. Quantitative measurements of maintenance cleaning times and potable water usage corresponding to the use of existing wash facilities were collected for comparison.

All phases of this study were conducted at the 2nd Battalion/77th Armored motorpool, Fort Lewis, WA.

Scope

The intent of this investigation was not to perform an exhaustive evaluation of all types of commercial cleaning machines or oil/water separation equipment currently on the market, but to identify those items of commercially available equipment that could potentially meet the performance criteria established for these items in the concept design of the tracked vehicle maintenance facility.

Mode of Technology Transfer

The results of this study will impact on Evaluation Criteria for Water Pollution Prevention Control and Abatement Programs, Army Technical Manual 5-814-8 (30 July 1976).

2 TRACKED VEHICLE MAINTENANCE FACILITY

Background

As presently designed, TOE maintenance facilities require that virtually all wet maintenance operations, such as oil changing and equipment cleaning, be performed on the surrounding concrete hardstand under conditions that make effective pollution control both difficult and expensive. The problem becomes especially acute when tracked vehicle maintenance operations are considered. To carry out these operations, large quantities of new and waste oils must be handled under the most primitive conditions. In addition, most maintenance cleaning tasks use high-volume, low-pressure wash hoses. Mainly as a result of these conditions, considerable quantities of waste oil are often discharged to the storm water collection system via the washrack drain. The use of existing washrack facilities for maintenance cleaning also means that soaps, detergents, and solvents such as diesel fuel are used, further complicating the wastewater treatment problem. Since the washrack facility also invariably drains a large portion of the adjacent hardstand area -- which may reach a size of 7 acres (2.8 hectares) or more -- the design of wastewater pretreatment units for effluent discharge to an installation's sanitary sewer system is generally impractical unless the existing washrack is extensively modified at the same time.

Facility Description

The concept of the tracked vehicle maintenance facility was developed to correct the conditions described above. As designed for Fort Lewis, the facility (Figure 1) essentially consists of a canopied service platform raised above the general hardstand area. This prevents stormwater intrusion from adjacent hardstand areas. The service platform is divided into two functional areas: an oil changing area and a maintenance cleaning area.

Oil Changing Area

As designed, all oil changing is done within a lighted service pit equipped with a sliding waste oil collection funnel. The funnel, which is sized to contain a quantity of oil equal to the maximum combined crankcase and transmission capacity of an M-88 tracked vehicle, discharges into a collection trough. This trough is connected by rigid 4-in. (10.2-m) piping to a 1000-gal (3790-L) underground waste oil storage tank. The funnel has a hinged two-section cover which ensures a watertight seal when the funnel is opened during cleaning operations or oil filter drainage. The waste oil inlet at the bottom of the collection funnel is protected by a reinforcing bar screen (at the funnel entrance) and a commercial-type drain plate (fitted into the bottom of the funnel at the waste drain entrance). This combination of screen and plate is designed to prevent the waste oil drainage system from being clogged by dropped tools, rags, bolts, etc.

The sliding waste oil collection funnel was designed so it has only limited movement within the service pit. This lets it act as a vehicle positioner for the M-60 tank. Vehicle position is important when servicing this vehicle type because the engine pack (engine and transmission) can only be

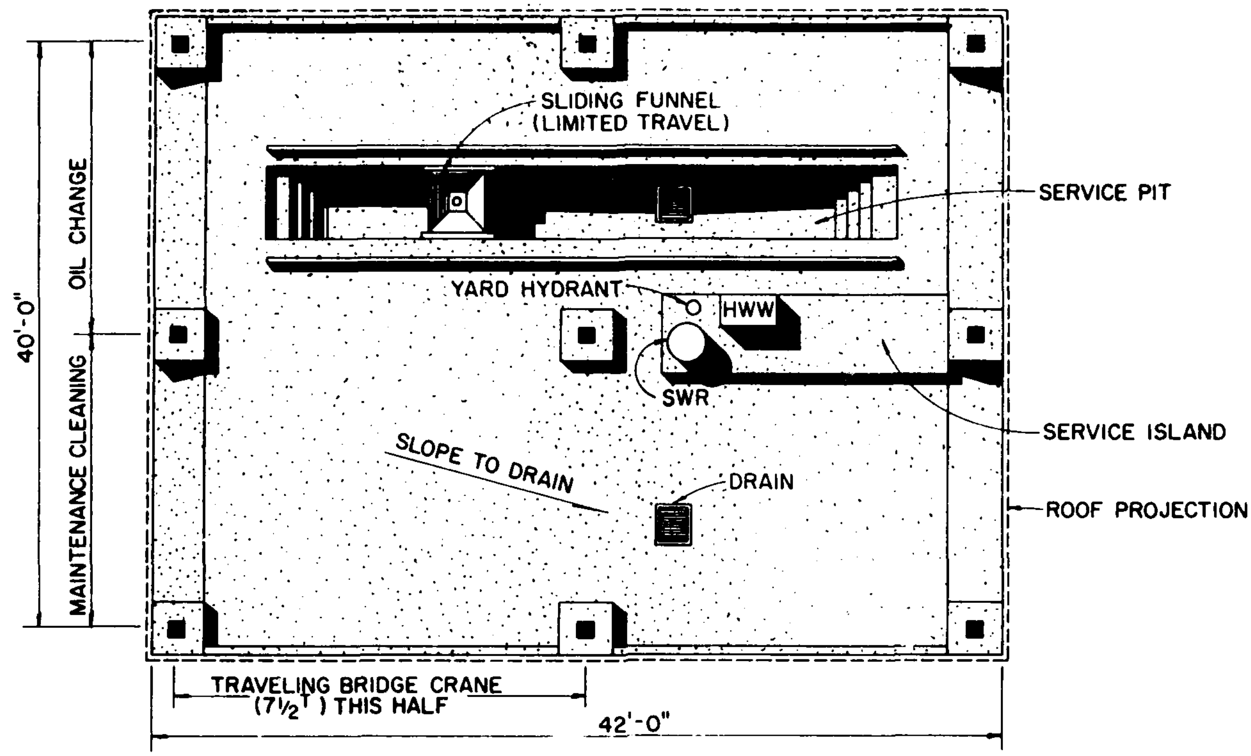

Figure 1. Tracked vehicle maintenance facility.

removed after the gun has been rotated. The vehicle must be positioned to protect the canopy columns from being damaged when the gun turret is rotated.

Maintenance Cleaning Area

Maintenance cleaning can be done either with the vehicle in position over the service pit or in the maintenance cleaning area proper. The service pit area is used mainly to clean the engine compartments and vehicle undercarriages. The main maintenance cleaning area is used for equipment inspection cleaning, and to prepare exterior vehicle surfaces before painting or before cleaning engine packs and other large components. Engine packs are moved from the service pit to the adjacent maintenance cleaning area by a 7-1/2 ton (3405 kg) capacity traveling bridge crane. Wastewater produced by the wash equipment is conveyed to the wastewater pretreatment unit by area drains located in both the main cleaning area and at the bottom of the service pit. These discharges then go into a wastewater pretreatment unit located outside the maintenance facility area. The cleaning equipment is on a service island which has a waste receptacle for used filters, worn parts, and other litter generated during vehicle servicing.

3 CRITERIA FOR EQUIPMENT SELECTION

Cleaning Equipment

Cleaning equipment needed for the proposed tactical equipment maintenance facilities was evaluated based on the following performance criteria:

1. Can efficiently clean large equipment items at low water delivery rates, preferably less than 5 gpm (19 L/min) without the use of soaps or detergents.

2. Can efficiently fine-clean vehicle exteriors.

3. Is simple to operate and as maintenance-free as possible.

4. Is of rugged construction.

5. Is operationally safe.

6. Can produce significant reductions in maintenance cleaning times.

7. Will not damage vehicle exterior surface finishes or components.

Hot water wash equipment was selected for evaluation over conventional steam cleaning equipment on the basis of safety considerations, ease of operation, versatility, and superior cleaning potential. Units manufactured by several different commercial equipment suppliers were considered; although no equipment damage was ever reported during the testing period, a thorough evaluation of this factor and its variation with cleaner operational parameters was beyond the scope of this study.

Wastewater Treatment Equipment

For the purposes of this study, criteria for the design or selection of equipment for treating wastewater discharge were:

1. The treatment process had to produce an effluent suitable for discharge to an installation's sanitary sewer system. For an installation such as Fort Lewis, where the facilities' anticipated hydraulic inputs into the sanitary sewer system were of secondary importance, effluent quality requirements were defined in terms of pH value, total suspended solids, total oil and grease, biochemical oxygen demand, and heavy metal concentrations. A complete list of effluent criteria used in this study is in Table 1.

2. The treatment process had to be operationally simple and easy to maintain.

3. The required frequency at which maintenance was to be performed was to be kept to a practical minimum.

Table 1

Effluent Quality Criteria*

Constituent	Concentration (mg/L) or Unit
Total suspended solids	300 max 200 avg
Total oil and grease	100 max 50 avg
pH	6.0-9.0
BOD_5**	400 max 300 avg

*Effluent shall not contain any visible sheen; effluent produced shall be compatible with and not interfere with an installation's domestic wastewater treatment processes.
**The 5-day biochemical oxygen demand.

4 PRELIMINARY CLEANING EQUIPMENT EVALUATION AND WASTEWATER CHARACTERIZATION

Initial Testing

For initial testing purposes, a Hotsey Model 840 hot water washer rated at 4 gpm (15.2 L/min) under an operating pressure of 1200 psi (8.27×10^6 Pa) was used.[3] The unit was powered by a 10-hp (7.46-kW) gasoline-driven water-pump motor and a kerosene-fired boiler. Burner fuel was delivered by an electric motor operating off a 110-V, 60-Hz source.

The unit was installed in one bay of a seven-bay vehicle washrack facility in the 2/77th Armored Battalion motorpool. Tests were done from 26 to 28 February 1979, when the battalion was preparing for an Inspector General visit.

The water used by each piece of equipment cleaned was measured by a 1-in. (25.4 mm) Badger cold water meter, Model Number SC-ER-C.[4] Since all vehicle wash bays drained into a common collection trough, wastewater produced by hot water washer operations was segregated from adjacent sources by enclosing three sides of the test bay with sandbags lined with sheets of polyethylene. Grab and composite samples were taken at a drainage point formed at one corner of the sandbag wall.

Test Procedures

Equipment Cleaning Tests and Wastewater Sampling

Cleaning tests were begun by positioning a vehicle or component to be cleaned completely within the prepared test bay. When the test started, an initial water meter reading and start time were recorded. All cleaning tests were done with boiler water temperatures maintained in the range of 150 to 170°F (66 to 77°C). No special cleaners or solvents were used.

Grab and composite wastewater samples were collected periodically throughout each cleaning operation for wastewater characterization and sedimentation analysis. Samples for oil and grease analyses were collected in 1-L, wide-mouth glass jars. Grab samples for other analyses were collected in 100-ml, wide-mouth plastic bottles. Composite samples were made up at the test site using a 9-L glass collection bottle. Collected samples were analyzed using the laboratory facilities at the Fort Lewis sewage treatment plant. Heavy metal and free-oil specific gravity sample analyses were done at CERL.

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[3] Hotsey Corporation, Englewood, CO.
[4] Badger Meter Manufacturing Co., Milwaukee, WI.

Analytical Procedures

All analyses were performed in accordance with Standard Methods for the Examination of Water and Wastewater, with the following exceptions:[5]

1. Total Dissolved Solids: total dissolved solids were determined with a Myron L. Company total dissolved solids meter[6]

2. Free, Emulsified, and Dissolved Oils: a test method to quantitatively differentiate between free, emulsified, and dissolved oils was devised by CERL and used on a trial basis during these analyses. This test method is given in Appendix A.

3. Sedimentation Characteristics: a sedimentation test was done to determine the settling characteristics of a wastewater suspension produced during the exterior cleaning of an M-60 tank using a method proposed by Eckenfelder.[7] To perform the test, a plexiglass column 3.5 in. (88 mm) in internal diameter and 48 in. (1219 mm) long was used. Sampling ports were provided at 6, 24, and 36 in. (152, 609, and 914 mm) below the initial fill level of the column. Testing was done by collecting about 9 L of a composite sample, making a determination of its initial suspended solids concentration, and pouring the sample into the column to a level 6 in. (152 mm) above the uppermost sampling port. Samples for total suspended solids were then periodically extracted at all three sample ports using 10-ml, broken-tipped pipettes.

4. Oil Specific Gravity: the specific gravity of skimmed oil obtained during the sampling program was determined using a glass 10-ml pycnometer.

Wastewater Characterization Tests

Wastewaters produced by several specific maintenance cleaning operations were analyzed for pH, total suspended solids, volatile suspended solids, total oil and grease, settleable solids, chemical oxygen demand, and 5-day biochemical oxygen demand (BOD_5). Total and dissolved heavy metal concentrations (cadmium, chromium, nickel, lead, zinc, and iron) produced by cleaning the engine compartment of an M-60 tank were determined on a composited wastewater sample.

Initial Test Results

Initial results showed that all maintenance cleaning tasks could be done by commercial equipment without soaps or detergents. Water usage data and cleaning times for the various items of equipment processed during the test period are given in Table 2. The cleaning unit itself, however, malfunctioned several times over the evaluation period and had to be repaired by Directorate

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[5] Standard Methods for the Examination of Water and Wastewater, 14th Edition (American Public Health Association, American Water Works Association Water Pollution Control Federation, 1975).

[6] Myron L. Company, Carlsbad, CA.

[7] W. W. Eckenfelder and D. L. Ford, Water Pollution Control-Experimental Procedures for Process Design (Pemberton Press, 1970), pp 62-65.

of Facilities Engineering (DFAE) personnel. In general, it was concluded that the unit under evaluation was unreliable for military use.

Table 2

Initial Cleaning Test Data

Vehicle/ Equipment	Item(s) Cleaned	Number of Observations	Cleaning Times (minutes) Max	Min	Avg	Water Use, gal (L) Max	Min	Avg
	Vehicle exterior	1	62			178(673)		
M-60 tank	Engine compartment	1	30			72(272)		
	Engine pack	3	67	25	42	81(306)	42(158)	65(246)
M-88 medium retriever	Vehicle exterior	1	22			71(268)		
Jeep	Vehicle exterior engine interior	5	20	5	14	69(227)	37(140)	49(185)
5-ton truck	Vehicle exterior	1	22			80(302)		
Truck, van & tractor	Vehicle exterior	2	31	25	28	90(340)	56(211)	73(276)

*1 gal = 3.785 L

Wastewater Characteristics

Table 3 summarizes the data collected on the physical and chemical analyses of the wastewater generated during the several maintenance cleaning operations investigated during the initial test period.

Several observations relative to this analysis are:

1. The extremely high grease and oil concentrations found during the engine pack cleaning operation were caused by oil spilling directly onto the cleaning area when oil filters were removed from the engine pack.

2. Although most of the oil appeared to be readily separable, the data showed that at least one operation (engine compartment cleaning) produced a wastewater with a significant emulsified oil content. It is believed that these emulsions are mechanically stabilized by fine particulate matter in the wastestream.

3. Values obtained for biochemical oxygen demand are characteristic of a weak domestic sewage.

4. The ratio of chemical oxygen demand to biochemical oxygen demand indicates that there is a considerable quantity of refractory organics, including oils, in the wastestreams.

5. Heavy metal concentrations in the wastewaters are acceptable for discharge to the sanitary sewer system.

6. The pH value and concentrations of dissolved inorganic materials, measured in terms of total dissolved solids, are within acceptable limits for effluent discharge to the sanitary sewer system.

7. As expected, concentrations of total oil and grease and total suspended solids varied considerably with the type of equipment components cleaned.

Table 3

Data Summary of Wastewater Characteristics

Activity	Constituent or Condition	Sample Type	Concentration (mg/L) or Unit
Engine pack cleaning (including filter removal)	Total grease & oil	Grab	17061
		Grab	18855
		Avg	17958
	pH	Grab	7.6
		Grab	8.0
		Grab	7.5
		Composite	7.5
	Total suspended solids	Composite	2260
	Settleable solids	Composite	6.2 (ml/L)
	% Volatile solids	Composite	27
	Total dissolved solids	Composite	135
	COD	Composite	1020
	Temperature		17.5°C
Exterior cleaning (M-60 tank)	Total grease & oil	Grab	412
		Grab	1022
		Avg	717
	pH	Grab	7.7
		Grab	7.7
	Total suspended solids	Grab	5900
		Grab	2975
		Avg	4438

Table 3 (Cont'd)

Activity	Constituent or Condition	Sample Type	Concentration (mg/L) or Unit
	Total grease & oil	Grab	3448
		Grab	664
		Avg	2056
	pH	Grab	7.3
Exterior cleaning (M-60 tank)	Total suspended solids	Grab	2375
	Settleable solids	Grab	7.0 (ml/L)
	COD	Grab	2250
	BOD	Grab	250
	Total dissolved solids	Grab	160
	Total grease & oil	Grab	664
Engine compartment cleaning (M-60 tank)	pH	Composite	7.5
	Total suspended solids	Composite	957
	Settleable Solids	Composite	0.25 (ml/L)
	COD	Composite	1800
	BOD	Composite	192
	Total dissolved solids	Composite	160
Engine compartment cleaning (M-60 tank -- special run)	Total grease & oil	Grab	553
	Emulsified oil	Grab	557
	Dissolved oil	Grab	11

Heavy Metals

Sample	Cd	Cr	Ni	Pb	Zn	Fe	Basis
Total heavy metals	0.86	0.08	0.11	0.05	1.2	7.2	mg/L
Dissolved Heavy Metals	0.017	0.012	0.02	0.005	<0.005	2.5	mg/L
EPA-proposed Pretreatment standards For metal plating Industrial category (Max/30-day avg)	1.0/0.5	4.2/1.6	3.6/1.8	0.8/0.4	3.4/1.5	--	mg/L

Sedimentation Test

The results of the sedimentation test conducted on a composite wastewater sample of 3680 mg/L initial total suspended solids concentration are given in Table 4 and Figures 2, 3, and 4, respectively. These data indicate that a sedimentation basin under ideal conditions would need an overflow rate of less than 100 gpd/sq ft (4080 L/day/m^2) and a detention time in excess of 8 hours to meet the average total suspended solids effluent criteria of 200 mg/L (95 percent removal) under the test initial suspended solids loading.

Table 4

Sedimentation Column Data*

Height ft (m)	Time (min)	Total suspended solids (mg/L)	% Total suspended solids Removal
	15	1830	50
	30	1110	70
0.5 (0.2)	60	1020	72
	120	680	82
	240	420	89
	15	1960	47
	30	1570	57
2.0 (0.6)	60	1250	66
	120	1120	70
	240	760	79
	15	2330	37
	30	2060	44
3.0 (0.9)	60	1520	59
	120	1300	65
	240	1170	68

*Initial Total suspended solids = 3680 mg/L

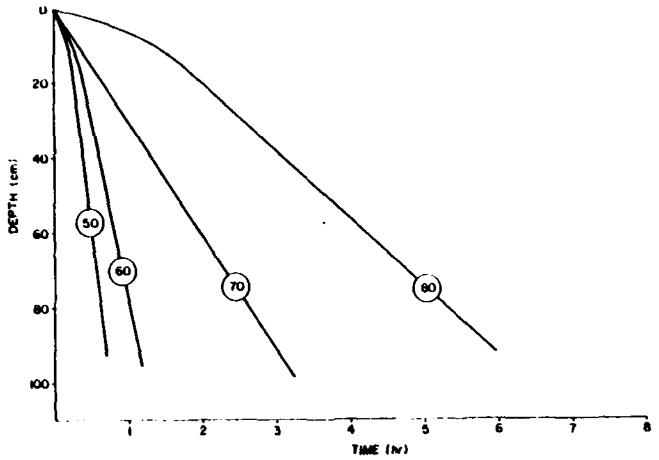

Figure 2. Percent total suspended solids removal with column depth and settling time.

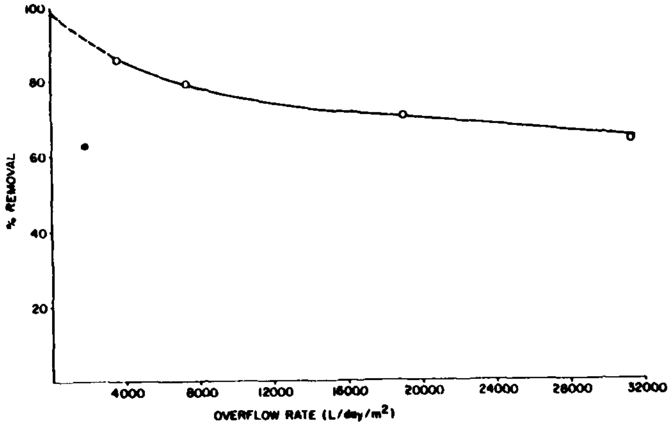

Figure 3. Percent suspended solids removal -- overflow rate analysis.

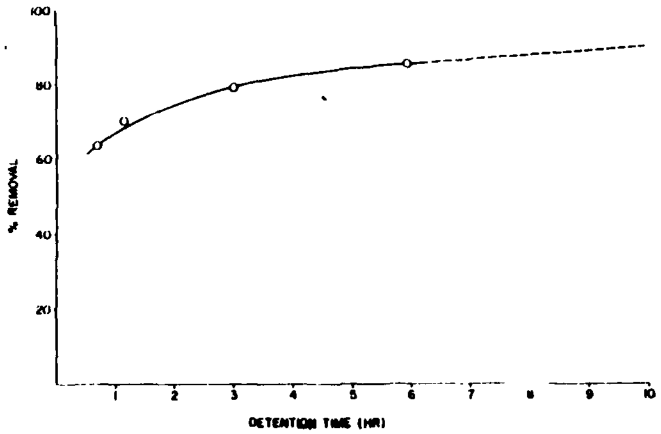

Figure 4. Percent suspended solids removal -- detention time analysis.

5 PHASE 2 INVESTIGATION

During Phase 2 of this study, commercially available hot water washing equipment was evaluated further to determine (1) the water usage and cleaning times required for various types of tactical equipment, and (2) the performance of a commercially available oil/water separator in the pretreatment of wastewater generated during tactical equipment cleaning operations.

Wastewater Treatment Unit Description

A packed gravity oil/water separator designed and manufactured by ERC/Lancy Inc., St. Paul, MN was selected for field evaluation. The unit consists of a rectangular steel basin separated into two distinct areas: a presettling area for the separation of readily separable solids and free oils, and an area housing a corrugated plate interceptor (CPI) package for the removal of fine solids and dispersed oils. Separated oils are contained on the surface of the basin to a depth established by the elevation of an adjustable skimmed oil weir. Discharges over the weir are conveyed by pipe to an external skimmed oil holding tank. Specific details and a schematic diagram of the unit are in Table 5 and Figure 5, respectively.

Table 5

Details of Pilot Oil/Water Separator

Type	Packed gravity
Model	600.25 BPR w/presettling chamber
Manufacturer	ERC/Lancy Inc., St. Paul, MN
CPI pack	1/4 full unit
Effective surface area (horizontal projection)	125 sq ft (11.6 m^2)
Plate spacing	3/4 in. (19.1 mm)
Rated capacity (70^{o}F, differential specific gravity = 0.1)	
for 30 micron particles -- 10 gpm (37.8 L/min)	
for 60 micron particles -- 38 gpm (143.8 L/min)	
Maximum storage capacities	
Readily separable solids -- 48 cu ft (1.4 m^3)	
Fine solids -- 20 cu ft (0.6 m^3)	
Free oil (before overflow to storage) -- 150 gal (567.8 L)	

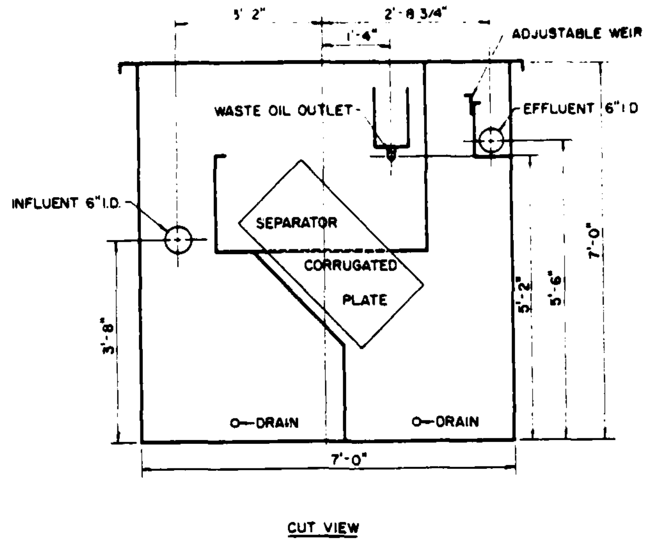

Figure 5. Oil/water separator.

Pilot Facility Description

The oil/water separator was tested at the 2/77th Armored Battalion motorpool. To simulate anticipated field conditions, a reinforced concrete slab was constructed by DFAE personnel immediately adjacent to the existing motorpool wash facilities. The slab was designed to keep storm water runoff away from adjacent hardstand areas during rainfall. To make the task of cleaning vehicle undercarriages easier, the bridge portion of an Armored Vehicularly Launched Bridge (AVLB) was placed perpendicular to the long axis of the slab; this made it impossible to clean engine packs on the slab surface. Wastewater drained from a concave curvature in the slab's surface to an integrally constructed concrete collection trough on the slab's downstream side. Wastewater collected in the trough was then conveyed via PVC pipe to the nearby pilot oil/waste separator. Figure 6 shows the layout of the pilot facility.

All equipment was cleaned with a hot water washer and without detergent. Initially, a kerosene-fired, gasoline engine unit (Hotsey Model 5800) adjusted to deliver 5.5 gpm (20.8 L/min) at 1100 psi (7.58 x 10^6 Pa) pressure was used. The unit was discontinued midway through the testing period because of continual mechanical breakdown. In its place, a kerosene-fired, electrically driven unit (Hydroblitz[8] Model 1500) rated at 3 gpm (11.4 L/min) at 700 psi (4.8 x 10^6 Pa) pressure was used. This latter unit, much simpler in design than the former, performed satisfactorily during the remainder of the test period. Wash water temperature for both units was maintained at between 150 and 170°F (66 and 77°C).

[8] Hydro Systems Company, Cincinnati, OH.

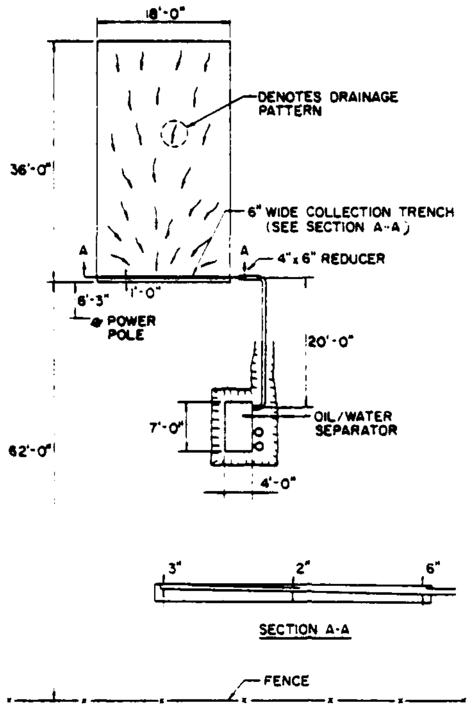

Figure 6. Pilot maintenance cleaning facility.

Test Procedures

The testing program collected data on the following parameters:

1. Water usage and cleaning times for various items of tactical equipment.

2. Average and peak daily water usage.

3. Oil/water separator effluent quality.

4. Sludge accumulations per unit of flow volume.

5. Skimmed oil volumes and characteristics.

6. Oil/water separator maintainability characteristics.

Water usage data were collected by taking readings from a potable water meter placed between the potable water source and hot water washer. Equipment cleaning times were determined by noting the start and stop times for each equipment type cleaned. Effluent quality was measured by taking grab and composite samples periodically throughout a given day's operation. Influent grab and composites were also collected intermittently to characterize wastewater inputs to the separator and for comparison with results of the initial wastewater characterization. No attempt was made to directly relate influent and effluent sampling times because of the intermittent nature of the cleaning operation.

Collected samples were analytically tested mainly by taking measurements of total and volatile suspended solids, total oil and grease, and pH value. Less frequently, analyses were made of chemical oxygen demand, BOD_5, and influent and effluent wastewater temperatures.

Average sludge accumulation per unit volume of flow was determined by making an indirect measurement of sludge depth and noting the total volume of water used to the time of measurement. Sludge volume was computed by assuming that the measured depth was uniform over the surface area of the primary sedimentation basin.

Analytical Results

Tactical Equipment Cleaning Operations

Data on cleaning times and water usage per equipment type were collected from 19 to 21 September, 24 to 26 September, and 4 to 5 October 1979. A data summary is in Table 6.

Hourly and Daily Water Use

Table 7 gives the water usage data corresponding to each day's cleaning activity. The data indicate that the maximum 1-hour flow should not exceed about 150 gal (569 L) per cleaning machine; the average hourly flow per machine measured over a typical 8-hour period should not exceed 100 gph (379 L/hour). Based on this latter figure and a 3 gpm (11.4 L/min) machine, the maximum average use rate for the machine is 61 percent. From these data, it is estimated that the maximum daily use rate per cleaning machine will not exceed 70 percent and the average daily usage will not exceed 50 percent.

Wastewater Characteristics and Oil/Water Separator Performance

Table 8 summarizes wastewater and oil/water separator effluent characteristics. For the flow rates produced by the cleaning equipment -- i.e., 5.5 gpm (20.8 L/min) and 3 gpm (11.4 L/min), respectively -- the data indicate that the pilot wastewater treatment unit removed a 92 percent of the total suspended solids, 95 percent of the influent total oil and grease, and 79 percent of the influent chemical oxygen demand. These figures are based on the average values of influent and effluent concentrations obtained from an analysis of grab samples.

Table 6

Observed Water Usage and Cleaning Times for Several Types of Tactical Equipment

Tactical Equipment Type	Number of Obser-vations	Water Usage, gal (L)			Cleaning Times (minutes)		
		Max	Min	Avg	Max	Min	Avg
Jeeps	28	60(227)	2(7)	24(90)	23	2	13
APC	11	107(404)	35(132)	65(246)	74	22	42
2-1/2 ton truck	8	50(189)	15(56)	33(124)	27	10	19
Gamma goat	5	59(223)	13(49)	36(136)	42	8	21
Goer	5	191(722)	27(102)	83(314)	150	14	62
Generators	4	44(166)	8(30)	22(83)	25	10	20
MILVAN	2	110(416)	34(128)	72(272)	50	14	32
5-ton truck	2	104(393)	36(136)	70(264)	67	22	45
AVLB	1	----	76(287)	----	----	35	----
M-578 retriever	1	----	36(136)	----	----	20	----

Table 7

Water Usage Data

Date	24-hour Flow volume gal (L)	Flow, gph (4 hour)	
		Max 1-hour	Avg 8-hour
9/19	1242 (4700)	144 (546)	97 (368)
9/20	881 (3334)	116 (440)	90 (368)
9/21	--	118 (447)	83 (315)
9/24	582 (2202)	95 (360)	82 (311)
9/15	441 (1669)	39 (148)	--
9/26	69 (261)	53 (201)	46 (174)
10/4	2000 (7570)	120 (455)	110* (417)

* Based on 4-hour data.

Table 8

Wastewater and Separator Effluent Characterization Data

Total Suspended Solids (mg/L)

Characteristic	Influent	Effluent
No. of grab samples	8	8
Maximum	4118	548
Minimum	163	100
Average	2005	171
Average of composites	1379	103

Volatile Suspended Solids (mg/L)

Characteristic	Influent	Effluent
No. of grab samples	8	8
Maximum	1105	308
Minimum	295	50
Average	721	109
Composite average	---	64

pH Value

Characteristic	Influent	Effluent
No. of samples	7.00	8.00
Maximum	7.95	7.61
Minimum	4.80	6.05
Composite	6.81	6.80,6.45

Grease and Oil (mg/L)

Characteristic	Influent	Effluent
No. of samples	9	
Maximum	2599	147
Minimum	268	about 0
Average	821	41

Chemical Oxygen Demand (mg/L)

Characteristic	Influent	Effluent
No. of grab samples	2	2
Average	1692	348
Average of Composites	2763	311

Temperature

Characteristic	Influent	Effluent
Average (^{o}C)	22.3	21.6
Average (^{o}F)	72.0	70.9

Miscellaneous Data

Average effluent BOD_5 -- 49 mg/L

Sludge volume -- 1.9 cu ft (0.05 m^3) in 10,110 gal (38 266 L)

Average skimmed oil specific gravity -- 0.94

Average % oil in skim -- 54% single composite

Projected Frequency of Sludge Removal

Based on a measured sludge accumulation of 1.9 cu ft (0.5 m^3) in 10,110 gal (38 266 L), an average usage rate of 50 percent, an assigned readily separable sludge storage capacity of 48 cu ft (1.4 m^3) and the potential use of two 3 gpm (11.4 L/min) machines at the cleaning facility, sludge would have to be removed from the separator every 18 weeks on the average.

Summary of Phase 2 Testing Results

As a result of the Phase 2 testing program, the following information was obtained:

1. Commercial hot water wash equipment was available that can meet the maintenance criteria given in Chapter 3.

2. Adequate cleaning of all tactical equipment and large components can be achieved at flow rates as low as 3 gpm (11.4 L/min) under operating pressure and temperature conditions of 700 psi (4.8 x 10^6 Pa) and 150 to 170°F (66 to 77°C).

3. A commercial oil/water separator is available that can meet the established effluent criteria when operating under a hydraulic overflow rate of between 35 and 63 gpd/sq ft (1428 to 2570 L/day/m^2).

4. Sludge storage capacities of the pilot oil/water separation unit appear to satisfy installation maintainability requirements.

6 PHASE 3 INVESTIGATION

This phase of the investigation determined the maximum hydraulic capacity of the pilot oil/water separation unit before effluent quality became unacceptable for discharge to the sanitary sewer system. In addition, hot water wash equipment from another manufacturer was evaluated, and further data were collected on cleaning performance and water usage. Cleaning performance and water used to carry out maintenance cleaning operations were tested using existing washrack equipment. These data were necessary to quantitatively compare the two methods for cleaning Army tactical equipment.

Pilot Facility Description

To increase the hydraulic loading to the treatment unit, the pilot facility was expanded to three bays by connecting the drainage of two existing wash pads to the separator as shown in Figure 7. All three of the wash pads were equipped with hot water wash equipment. Two of the pads had Big Rig[9] equipment operating at a flow of 3 gpm (11.4 L/min), a pressure of 750 psi (5.1×10^6 Pa), and a boiler temperature maintained at between 150 and 170°F (66 to 77°C). The third wash point was equipped with the same Hydroblitz Model 1500 as before. A potable water meter was placed between the incoming potable water line and the cleaning machine at each respective wash point.

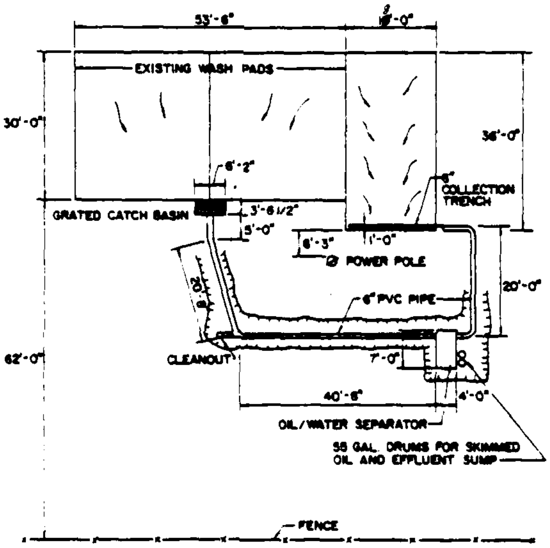

Figure 7. Expanded pilot maintenance cleaning facility.

[9] American Kleaner Manufacturing Co., Inc., Pico Rivera, CA.

Test Procedures

Test procedures for determining cleaning performance characteristics, potable water usage and oil/water separator performance were the same as those used in Phase 2. To determine the cleaning performance of existing washrack facilities, a 1-1/2 in. (38 mm) Badger[10] cold water meter was plumbed into an existing washrack riser pipe for potable water use measurement. The military users were then requested to clean several items of tactical equipment and components using the available 2-in. (51-mm) diameter wash hose (supplemented, if necessary, by any cleaning agents), scrub brushes, etc. that they required. Cleaning times, potable water usage, and solvent usage were recorded for each piece of equipment or component processed.

Analytical Results

Evaluation of Cleaning Equipment

Both types of machines cleaned very well without cleaning aids. The machine manufactured by American Kleaner, Inc., however, required periodic maintenance during the test programs. The machine manufactured by Hydroblitz, Inc., did not require maintenance at any time during the evaluation.

Tactical Equipment Cleaning and Potable Water Usage

Cleaning times and potable water usage were measured for 170 items of tactical equipment and various components (Table 9). Kerosene usage was 101 gallons (42 L). The distribution of kerosene usage by machine indicates the degree of operational dependability found for each machine type (Table 10).

Table 9

Summary of Observed Water Usage and Cleaning Times

Vehicles/ Equipment	Item(s) Cleaned	No. of Observations	Cleaning Times (minutes)			Water Usage, gal (L)		
			Max	Min	Avg	Max	Min	Avg
Jeep	Int, ext, & eng	29	20	4	10.1	54(204)	6(22)	23.7(89.7)
	& Trailer	1	15	-	-	29(109)	-	-
	Engine	2	6	5	5.5	12(45)	10(37)	11.0(41.6)
	Transmission	1	4	-	-	3(11)	-	-
	Misc parts	1	8	-	-	3(11)	-	-
Jeep Trailer	-	1	10	-	-	30(113)	-	-
AVLB	Engine	1	18	-	-	27(102)	-	-
	Engine & exterior	1	42	-	-	85(321)	-	-

[10]Badger Meter Manufacturing Co., Milwaukee, WI.

Table 9 (Cont'd)

Vehicles/ Equipment	Item(s) Cleaned	No. of Observations	Cleaning Times (minutes) Max	Min	Avg	Water Usage, gal (L) Max	Min	Avg
M-88 (medium tracked retriever)	Exterior	1	47	-	-	96(363)	-	-
	Engine compartment	1	71	-	-	71(268)	-	-
	Engine pack in compt	2	15	15	15.0	48(181)	35(132)	41.5(157)
Light vehicle retriever	Exterior	1	17	-	-	35(132)	-	-
	Interior eng & exterior	1	45	-	-	95(359)	-	-
	Engine & transmission	1	24	-	-	64(261)	-	-
Goer	Exterior	2	21	11	16.0	57(215)	18(68)	37.5(141.9)
	Engine & exterior	1	15	-	-	37(140)	-	-
APC	Interior, eng & exterior	4	58	26	38.3	108(408)	60(227)	76.5(289.5)
	Eng,Eng,Comp & interior	5	47	23	32.6	96(363)	42(158)	68.0(257.3)
	Eng,Eng,Comp & exterior	2	46	15	30.5	94(355)	28(105)	61.0(230.8)
	Engine	2	25	5	15.0	47(177)	11(41)	29.0(109)
	Interior, eng & track	1	28	-	-	48(181)	-	-
	Interior	1	40	-	-	42(158)	-	-
	Exterior	1	10	-	-	23(87)	-	-
	Interior & exterior	1	25	-	-	81(306)	-	-
Gamma-goat	Exterior	2	13	6	9.5	24(90)	14(52)	19.0(71.9)
	Exterior & engine	1	20	-	-	43(162)	-	-

Table 9 (Cont'd)

Vehicles/ Equipment	Item(s) Cleaned	No. of Observations	Cleaning Times (minutes) Max	Min	Avg	Water Usage, gal (L) Max	Min	Avg
5-ton truck	Int, Ext & engine	4	53	20	34.5	149(563)	43(162)	80.8(305.8)
	Exterior	3	23	15	20.0	49(185)	35(132)	43.7(165.4)
	Front axle	2	5	4	4.5	14(52)	10(37)	12.0(45.4)
	Wheels & axles	1	8	-	-	11(41)	-	-
2-1/2-ton truck	Exterior & engine	3	26	15	21.0	64(242)	40(151)	50.7(191.8)
	Engine	2	13	5	9.0	34(128)	6(22)	20.0(75.7)
	Engine & underside	1	58	-	-	126(476)	-	-
M-60 (tank)	Exterior	16	117	15	44.4	222(84)	15(56)	100.1(378.8)
	Interior & exterior	17	200	16	65.6	361(1366)	42(158)	113.5(429.5)
	Engine rack	20	164	13	44.3	293(1109)	21(79)	85.2(322.4)
	Engine compartment	14	94	21	48.2	189(715)	40(151)	99.9(378.1)
	Interior	5	45	13	27.8	79(299)	21(79)	40.2(152.1)
	Int, Ext, & Eng comp	2	140	52	96.0	229(866)	124(469)	176.5(668.0)
	Road wheels	3	26	13	18.0	61(230)	31(117)	42.0(158.9)
	Engine pack & exterior	2	61	50	55.5	102(386)	84(317)	93.0(352.0)
	Engine comp & interior	1	80	--	--	135(510)	--	--
	Engine pack in tank	1	12	--	--	31(117)	--	--
	Engine pack & comp	1	95	--	--	198(749)	--	--
	Heat shields	3	28	6	15.7	39(147)	13(49)	27.7(104.8)
	Misc fans, heat shields, etc.	2	5	4	4.5	6(22)	5(18)	55(208)

Table 10

Kerosene Consumption in Gallons by Cleaning Machine Type*

Date 1980	Cleaning Machine Big Rig 1	Hydroblitz	Big Rig 2
Jan 17	--	10.0	5
18	--	5.0	--
21	--	10.0	--
22		2.5	2.5
23	2.5	5.0	10
24	2.5	7.0	
Feb 4	5.0	5.0	5
6	5.0	5.0	5
7	4.0	9.0	6

*1 gal = 3.785 L

Oil/Water Separator Performance

Table 11 summarizes the data obtained on the performance of the oil/water separator under various levels of hydraulic loading. Daily rainfall data are also included because the two existing wash platforms used during the test were susceptible to storm water intrusion from adjacent hardstand areas. Figures for maximum hourly flow rate were computed from superimposed plots of cleaning times for each cleaning machine under the assumption that each machine was delivering wash water at its rated capacity. Data presented for total suspended solids and total grease and oil concentrations for September to October 1979 generally represent the average of two grab samples -- one taken in the late morning and one taken in the late afternoon -- for each day's run. Data for January to February 1980 represent the results of single grab samples of influent and effluent concentrations taken in the late afternoon. Because of the highly variable nature of the cleaning operation and the characteristics of the generated wastewater, a mean residence time for wastewater within the separator was not computed. Therefore, the percent removal figures can only be considered qualitative measures of the unit's performance.

Plots of effluent total suspended solids and total grease and oil concentrations and their variation with maximum potable water flow rate for the combined September to October 1979 and January to February 1980 periods are in Figures 8 and 9, respectively. The maximum allowable concentration limits established for the wastewater characteristics are also plotted. It should be noted that the separator plates were cleaned once during the January to February 1980 test period because it was noted that separator effluent quality was deteriorating. Analysis of the data plotted on Figures 8 and 9 indicate that the separator's corrugated plate pack did not need cleaning at that time and that the falloff of separator effluent quality was caused by hydraulic inputs

Table 11

Data Summary of Pilot Oil/Water Separator Performance**

Date 79-80	Daily Prec. (in.)	Potable Water Use (gal)	Max. Hourly Flow Rate (gph)	Total Suspended Solids			Total Oil & Grease		
				Influent (mg/L)	Effluent (mg/L)	Percent Removal	Influent (mg/L)	Effluent (mg/L)	Percent Removal
9-20	0.00	669	134	--	--	--	1505	51	97
9-21	0.00	514	131	2124	134	94	428	147	66
9-24	0.00	513	95	445	103	77	286	26	91
9-25	0.00	335	70	2120	121	94	1243	37	97
10-4	0.00	472	122	7144**	54**	99	268	<3	99
10-5	0.00	150	120	4118	548	87	575	19	97
1-15	0.89	232							
1-16	0.87	69							
1-17	0.00	160							
1-18	Trace	645			63				
1-21	0.00	759							
1-22	0.00	935	212	375	217	42	1240	116	91
1-23	0.00	738	279	445	265	40	1346	80	94
1-24	0.02	530	337	468	12	97	114	7	94
1-25	0.00	1280	431	26660	580	98	>1000	234	--
1-29	0.00	882							
2-4	0.00	854	400	1180	361	69	4834	248	95
2-5	0.44	1538	454	6530	1830	72	232	314	--
2-6	0.28	1680	430	1100	890	19	1265	102	92
2-7	0.00	1191	385	1500	530	65	116	177	--

*Metric conversions = 1 in. = 25.4 mm; 1 gal = 3.785 L
**Composited samples

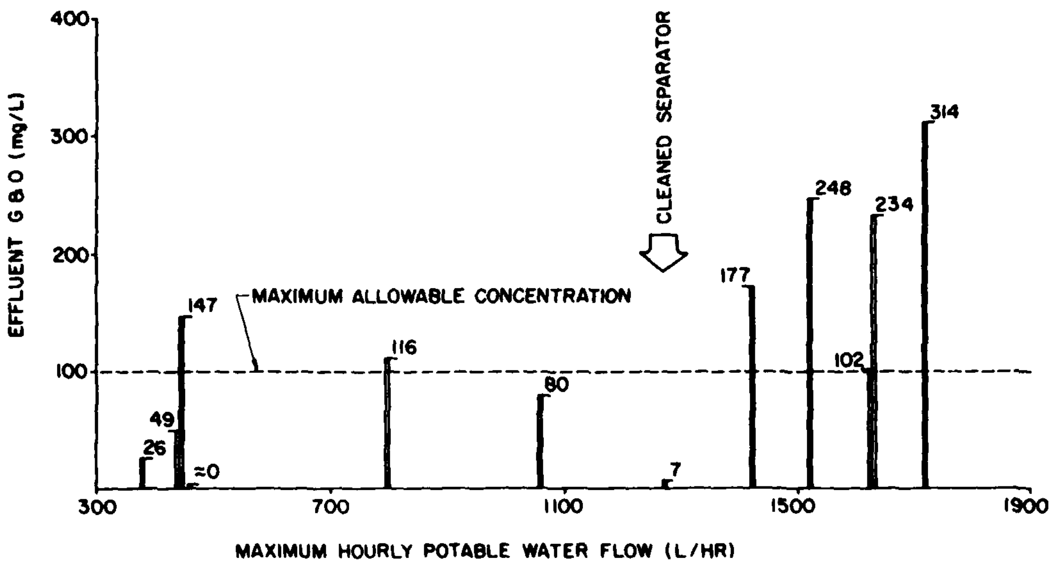

Figure 8. Total suspended solids in separator effluent vs. synthenzized maximum hourly potable water flow.

TOTAL OIL & GREASE IN SEPARATOR EFFLUENT
vs
SYNTHESIZED MAXIMUM HOURLY POTABLE WATER FLOW

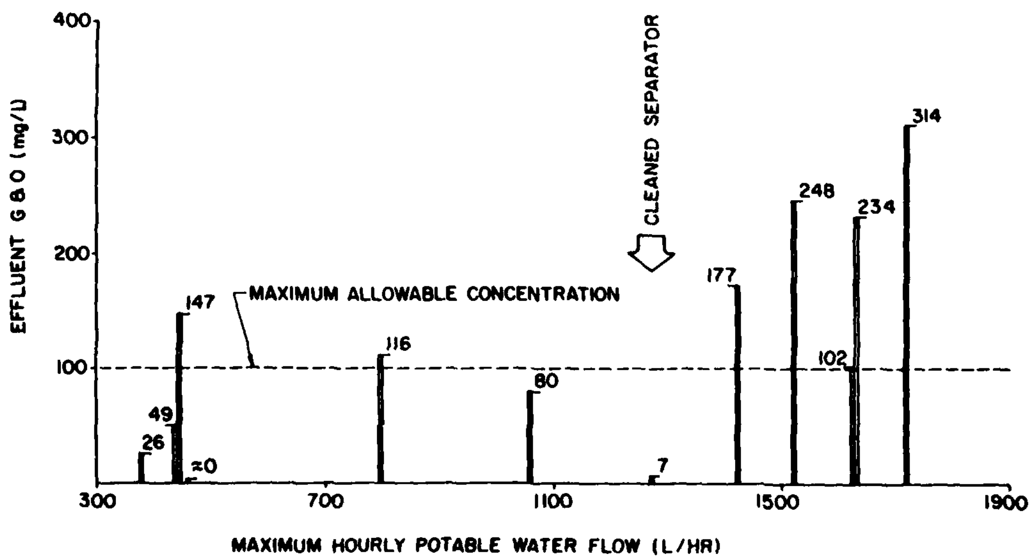

Figure 9. Total oil and grease in separator effluent vs. synthesized maximum hourly potable water flow.

in excess of the unit's capacity. At hydraulic inputs less than 300 gal/hour (1137 L/hour), the effluent from the separator meets pretreatment standards. At hydraulic inputs in excess of 380 gal/hour (1440 L/hour), the effluent from the pilot separator definitely did not meet standards. Therefore, the hydraulic capacity of the separator, as determined by test results, was established at 5 gpm (19 L/min). It is also interesting to note that the hydraulic overflow rate computed at the design capacity of 5 gpm (19 L/min) is 58 gpd/sq ft (1366 L/day/m^2), which approximates the results established by the sedimentation column test data.

Cleaning Performance Using Existing Washrack Facilities

To quantitatively demonstrate the difference between the capabilities of the new maintenance cleaning equipment and that of existing washrack facilities, a test was conducted in June 1980 involving the cleaning of two M-60 tracked vehicles being prepared for maintenance service. Each vehicle was put on an individual wash pad and its engine pack removed before the pack and engine compartment were cleaned. Water use on one of the pads was measured using a 1-1/2 in. (38 mm) Badger cold water meter. Before the test, the users were told they could use any chemical cleaning aid or piece of equipment available in the motorpool, except the hot water wash equipment. Results of the cleaning test are shown in Table 12. A comparison of these results with average cleaning times and water usage established for similiar cleaning tasks using hot water wash equipment (Table 9) shows that existing wash equipment requires 2.5 times as much cleaning time and about 15 times as much water as that required when using the hot water wash equipment. A compilation of all maintenance cleaning data obtained during the course of this investigation is in Appendix B.

Table 12

Tactical Equipment Cleaning Using Existing Wash Facilities

Equipment Cleaned: M-60 Engine Pack Plus Engine Compartment

Observation Number	Water Use, gal (L)	Time to Wash (minutes)	Solvent Type	Solvent Usage, gal (L)
1	5400 (20 439)	235	Type II dry cleaning	4 (15)
			Diesel fuel	2 (7)
2		235	Type II dry cleaning	15.5 (58.6)
			Diesel fuel	2 (7)

7 CONCLUSIONS

1. Commercial hot water wash equipment using potable flow rates of less than 5 gpm (19 L/min) can meet the maintenance cleaning requirements of the military user without cleaning aids.

2. Commercial equipment is efficient in terms of manhours of effort expended and potable water usage.

3. At least one commercial manufacturer can supply equipment with the operational and maintainability characteristics needed by military personnel.

4. Wastewater discharges from improved tracked vehicle maintenance facilities which use high-pressure, low-volume hot water wash equipment can be pretreated to acceptable levels by simple gravitational techniques to remove suspended solids and free oils. For Fort Lewis, acceptable pretreatment levels were defined as an effluent having an average and maximum total suspended solids of 200 and 300 mg/L, respectively, and an average and maximum total free oil content of 50 and 100 mg/L, respectively, under all conditions of service.

5. Heavy metal concentrations, organic loading, pH value, and effluent temperature were not a factor for consideration in the discharge of treated wastewaters to the sanitary sewer system.

6. To meet the established effluent criteria by gravitational methods, the hydraulic overflow rate has to be maintained below 100 gpd/sq ft (4080 L/day/m^2); the wastewater must be given a detention time in excess of 8 hours.

7. The established effluent criteria are only achieved when the overflow rate does not exceed about 58 gpd/sq ft (2978 L/day/m^2).

APPENDIX A:

EXPERIMENTAL METHOD FOR QUANTITATIVELY DIFFERENTIATING BETWEEN FREE, EMULSIFIED, AND DISSOLVED OIL IN WASTEWATER

Discussion

Existing standard procedures for analytically determining the oil content of wastewaters are based on the establishment of total oil concentrations in the wastewater under investigation.[11] Although this determination is significant for purposes of regulating effluent quality, its usefulness as a parameter for oil/water separator design is extremely limited. A method establishing the various states in which oil is found in a given sample would indicate whether gravity separation alone was adequate to achieve a desired effluent quality or whether more sophisticated emulsion-breaking unit processes would have to be used.

The method described in this appendix assumes all oily constituents, regardless of state, can be quantitatively solubilized in freon and that existing oil/water emulsion can be completely broken by acid treatment. The weakness of the test method is that the analysis depends on simultaneously collecting three identical grab samples from the wastestream. For wastewater containing considerable quantities of free oil, three identical samples probably cannot be collected.

Experimental Method

1. Simultaneously obtain three grab samples of wastewater (about 1 L each). Designate as samples A, B, and C.

2. On Sample A, perform total oil determination in accordance with standard procedures.

3. For Sample B, acidify the sample to pH 1-2, and filter on a Buckner funnel using Whatman No. 40 filter paper that has been treated with filter aid.[12] Extract filtrate obtained with Freon, separate using standard procedures, evaporate and weigh residue. This value corresponds to the dissolved oil concentration of the wastewater.

4. Pour the contents of Sample C into a straight-walled separatory funnel. Allow to settle for 2 hours. After settling, acidify the sample to pH 1-2, and extract with Freon using standard procedures. The results of this determination represent the sum of the emulsified and dissolved oil concentrations.

---

[11] Methods for Chemical Analysis of Water and Wastes (U.S. Environmental Protection Agency, 1974).

[12] Hyflo Super-Cel, Johns-Manville Corporation, or equivalent.

5. The emulsified oil concentration is obtained by subtracting the results of Step 3 from Step 4.

6. The free oil concentration is determined by subtracting the results of Step 4 from Step 2.

APPENDIX B:

SUMMARY OF ALL OBSERVED WATER USAGE DATA AND CLEANING TIMES OBTAINED DURING STUDY

Vehicle/ Equipment	Item(s) Cleaned	No. of Observations	Cleaning Times (minutes) Max	Min	Avg	Water Usage, gal (L) Max	Min	Avg
Jeep	Int, ext, & eng	62	23	2	11.5	60(227)	2(7)	25.7(97.2)
	& Trailer	1	15	-	-	29(109)	-	-
	Engine	2	6	5	5.5	12(45)	10(37)	11.0(41.6)
	Transmission	1	4	-	-	3(11)	-	-
	Misc parts	1	8	-	-	3(11)	-	-
Jeep Trailer	-	1	10	-	-	30(113)	-	-
M-88 (Medium Tracked Retriever)	Exterior	2	47	22	34.5	96(363)	71(268)	83.5(316.0)
	engine pack (in compartment)	2	15	15	15	48(181)	35(132)	41.5(157.0)
	Engine compartment	1	71	-	-	71(268)	-	-
M-60 (Tank)	Exterior	17	117	15	45.5	222(840)	15(56)	104.7(396.2)
	Interior & exterior	17	200	16	65.6	361(1366)	42(158)	113.5(429.5)
	Engine pack	23	164	13	44.0	293(1109)	21(79)	82.6(312.6)
	Engine compartment	15	94	21	47.0	189(715)	40(151)	98.1(371.3)
	Interior	5	45	13	27.8	79(299)	21(79)	40.2(152.1)
	engine pack (in tank)	1	12	-	-	31(117)	-	-
	Interior, exterior & eng comp	2	140	52	96.0	229(866)	124(969)	176.5(668.0)
	Engine pack & compartment	1	95	-	-	198(749)	-	-
	Heat shields	3	28	6	15.7	39(147)	13(49)	27.7(104.8)
	Road wheels	3	26	13	18.0	61(230)	31(117)	42.0(158.9)
	Engine pack & exterior	2	61	50	55.5	102(386)	84(311)	93.0(352.0)
	Engine compartment & interior	1	80	-	-	135(510)	-	-
	Misc parts, fans, heat shields, etc.	2	5	4	4.5	6(22)	5(18)	5.5(20.8)
APC	Int, ext, & eng,	15	74	22	41.2	108(408)	35(132)	68.3(258.5)
	Eng, eng comp & interior	5	47	23	32.6	96(363)	42(158)	68.0(257.3)

Appendix B (Cont'd)

Vehicle/ Equipment	Item(s) Cleaned	No. of Observations	Cleaning Times (minutes) Max	Min	Avg	Water Usage, gal (L) Max	Min	Avg
	Eng, eng comp & exterior	2	46	15	30.5	94(355)	28(105)	61.0(230.8)
	Engine	2	25	5	15.0	47(177)	11(41)	29.0(109.7)
	Interior, engine & track	1	28	-	-	48(181)	-	-
	Interior	1	40	-	-	42(158)	-	-
	Exterior	1	10	-	-	23(83)	-	-
	Interior & exterior	1	25	-	-	81(306)	-	-
2-1/2-ton truck	Exterior & engine	11	27	10	19.5	64(242)	15(56)	37.5(141.9)
	Engine	2	13	5	9.0	34(128)	6(22)	20.0(75.7)
	engine & underside	1	58	-	-	126(476)	-	-
5-ton truck	Int, Ext, & engine	4	53	20	34.5	149(563)	43(162)	80.8(305.8)
	Exterior	4	23	15	20.5	80(302)	35(132)	52.8(199.8)
	Front axle	2	5	4	4.5	14(52)	10(37)	12.0(45.4)
	Wheels & axles	1	8	-	-	11(41)	-	-
MILVAN & Trailer	-	2	31	25	28.0	90(340)	56(211)	73.0(276.3)
Gamma-Goat	Exterior	7	42	6	17.4	59(223)	13(49)	31.1(117.7)
	Engine & exterior	1	20	-	-	43(162)	-	-
Goer	Exterior	7	150	11	48.6	191(722)	18(68)	69.9(264.5)
	Engine & exterior	1	15	-	-	37(140)	-	-
AVLB	Engine	1	18	-	-	27(102)	-	-
	Engine & exterior	1	42	-	-	85(321)	-	-
Light vehicle retriever	Exterior	1	17	-	-	35(132)	-	-
	Int, & Ext, &	1	45	-	-	95(359)	-	-
	Engine & transmission	1	24	-	-	64(242)	-	-

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