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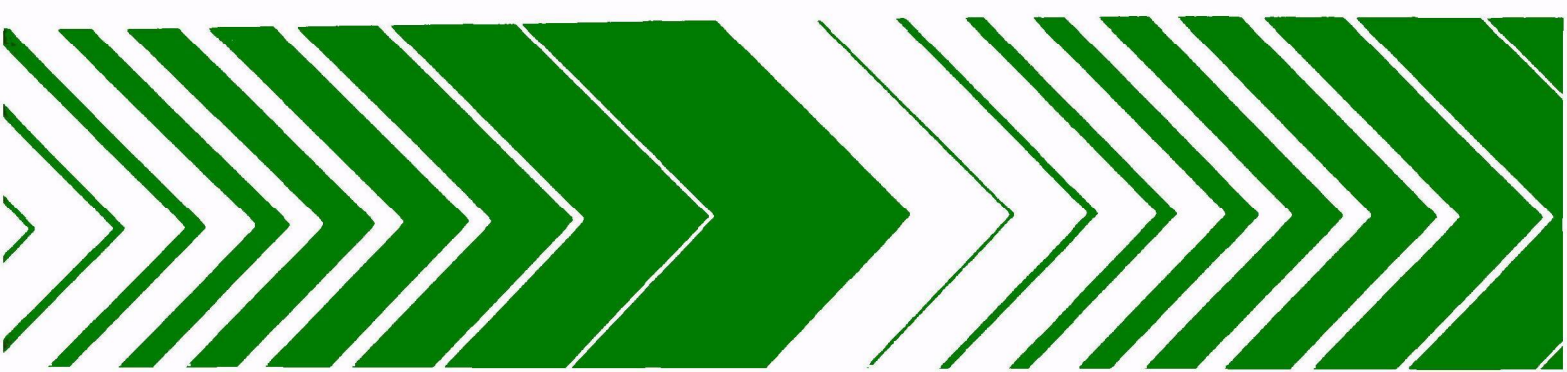
Treatment of Combined Sewer Overflows by High Gradient Magnetic Separation

On-Site Testing With Mobile Pilot Plant Trailer



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TREATMENT OF COMBINED SEWER OVERFLOWS BY HIGH GRADIENT MAGNETIC SEPARATION

On-site Testing With Mobile Pilot Plant Trailer

by

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Contract No. 68-03-2218

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the hazardous water pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Combined sewer overflows cause substantial pollution of major waterways and coastal areas in the U.S. The associated large surge volumetric flow rates in combination with the exponentially increasing solids loadings which often occur during a "first flush" storm situation are at best difficult for even the most advanced current integrated wet and dry weather sewage treatment facilities to handle. It is also very costly using conventional technologies to have on hand reserve capacity of this magnitude for such infrequent events. The use of magnetic filters and a seeding technique, however, offer an alternative to reserve capacity inherent in the magnetic nature of the separation itself. Increased storm solids can be handled simply by increasing chemical and seed dosages, while increased flows can be accommodated either by bringing on additional separators and/or by increasing the magnetic field to compensate for higher surface loadings. Such adaptability is attractive in the treatment system both from a capital cost and an operation and maintenance point of view.

This report describes a preliminary on-site stage of testing of this technology in which specific problems were addressed and overall feasibility was studied.

Francis T. Mayo
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ABSTRACT

Seeded water treatment using a SALA-HGMF® high gradient magnetic separator pilot plant system was conducted on CSO and raw sewage at Sala Magnetics, Inc. in Cambridge, Massachusetts and at on-site locations in the Boston area. These tests built further upon the data base collected during the first phase of this contract (see EPA Publication 600/2-77-015) with special emphasis on specific design and operational parameters, long-term durability and maintenance problems, and system adaptability to integrated wet and dry weather flow conditions. The on-site results reported, although not equaling those obtained on uniform batch samples in-house, were nevertheless good and proved that SALA magnetic filters are effective on fresh CSO and raw sewage dynamic solids loading and flow rate conditions typically associated with storm water and integrated wet and dry treatment systems, even where tidal salinity intrusion is experienced.

This report was submitted in fulfillment of Contract #68-03-2218 by Sala Magnetics, Inc. under the sponsorship of the U.S. Environmental Protection Agency. The work covers a period from August 1976 to December 1977.

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Also deserving of thanks are EPA Project Officers Hugh Masters and Richard Traver and Chief Richard Field, all of the Storm and Combined Sewer Section of the USEPA. They have provided guidance and support throughout the project.

This project was conducted under the supervision of Dr. John A. Oberteuffer of Sala Magnetics, Inc. In-house and on-site pilot plant testing and overall project organization was carried out by David M. Allen, Project Engineer. Richard L. Sargent contributed in the section on cost estimation and was active in trailer design. Assembly of the mobile unit was directed by installation engineer, Robert Vinton.

SECTION I

CONCLUSIONS

The test results reported here on magnetic filtration of CSO and raw sewage have given valuable information on system performance. A mobile trailer pilot plant capable of processing 6 gpm at 100 gpm/ft^2 was constructed and used successfully for the bulk of the testing performed, including the actual profiling of three individual storm flows at an on-site location.

Although initial problems were encountered in obtaining adequate stabilization of the flocculation train due to tidally induced salinity fluctuations in the incoming waste water, it was found that these problems could be overcome by the use of additional magnetite, a less salinity-sensitive flocculant, and some other minor changes in the process stream and operation procedure.

By incorporation of these refinements in monitoring and technique, essentially all process problems were overcome and the technology was demonstrated as one capable of handling even the most adverse of the dynamic surge flow circumstances. This represents a major step in the proving of seeded water treatment as a viable process for the treatment of CSO.

The best practical backflush technique for optimal solids removal and concentration was found to be a combination of air-water flush with independent air and water sources (50 psi constant air and 35 psi initial charge on the hydrotank water source). This flushing technique was shown to prevent any significant build-up within the matrix from occurring in the rather short term test runs performed. To ensure a clean matrix over long intervals, a periodic chemical rinse is necessary, and extremely effective. Water backflush pressure was found to be optimal when kept to > 25 psi initial charge on the hydrotank. A 5 second backflush time was shown to be sufficient in all cases tried for complete solids removal, and even shorter flushes (of down to 2 seconds) gave consistently excellent results.

Chemical flocculation techniques were studied to determine the best chemical addition sequence, the optimal flocculant and starting pH, and the minimum residence time necessary for best floc formation and clarification of the waste water studied. It was found that although it made no noticeable difference when in the sequence magnetite was added, alum had to be added prior to polyelectrolyte addition ($\sim$ 2 minutes), with a total residence mixing time of more than 4 minutes. Prolonged residence times of up to 20 minutes were found to enhance clarification only slightly ($<$ 5%) while decreasing the average floc size (unless much slower mixing rates were used). Optimum starting pH (as in the previous EPA-funded study) was found to be at natural pH (6.74) for the flocculation procedure used.

A number of different Hercofloc and Betz flocculants were tested on the same effluent in a comparative test. It was found that the most effective in removing turbidity was an anionic polymer, Hercofloc 831. Betz 1160 (used for all testing in this report) and Hercofloc 849 were also found to give relatively good results.

Matrix loading tests were used to help determine the minimum seed-to-solids ratio necessary for good magnetic separation. It was found that this ratio should be at least 2.5:1 for unsieved, commercial grade magnetite in order to achieve adequate separation efficiency and cycle length. This proportion perhaps could be cut in half by grinding the commercial magnetite to a finer size. A matrix design comparison using a matrix loading test was unable to delineate differences between two similar designs due to fluctuations in incoming solids loadings created by rainy weather.

Flow velocity tests showed that seeded water treatment efficiency decreases rather sharply above 200 gpm/ft^2, although significant deterioration in results occurs between 90 and 200 gpm/ft^2 as well. At 90 gpm/ft^2, controlled results approached 95% removal in a batch-type continuous pilot plant run indicating that slower process rates could not possibly improve results enough to compensate for the resulting loss in capacity in most applications.

A limited evaluation of sludge character showed the thickener underflow to have a solids concentration of 28% (with a 3:1 seed-to-solids ratio) and a density of 1.13 g/cc. The backflush water as it came into the thickener ranged from 0.8 to 14 g/ℓ, depending on the solids loading and flushing technique used.

SECTION II

RECOMMENDATIONS

In order to adequately demonstrate the feasibility of magnetic separation techniques for the treatment of CSO and raw sewage, more and larger scale testing must be undertaken. The following outline gives a simplified version of our recommendations for future work.

Step I: Additional Testing with SALA Mobile Trailer at EPA Location

A. Modification of 6 gpm Mobile Trailer.

1. Make suitable for continuous unattended runs of 12 hours.

2. Improve analytical and monitoring facilities.

3. Upgrade sludge handling system.

B. On-Site Pilot Testing of 6 gpm Mobile Trailer at EPA Location.

1. Establish performance on specific waste water.

2. Obtain design criteria for a 1 MGD system.

3. Evaluate sludge characteristics.

4. Initiate seed recycle evaluation.

5. Study long-term separator matrix maintenance requirements.

6. Profile storms to evaluate system adaptability and performance on CSO.

Step II: Design, Construction and Testing of a 1 MGD Magnetic Filter Pilot Plant

A. Design of the 1 MGD, skid-mounted system.

B. Construction and Installation of the 1 MGD Pilot Plant.

1. Assembly of major subsystems at Sala Magnetics, Inc.

2. Transport and final assembly at EPA location

C. Testing of 1 MGD Pilot Plant.

1. Demonstrate system performance.

2. Treat sludge with traditional existing facilities.

3. Finalize design and implement equipment for the following studies:

a. Magnetite seed disinfection and recycle.

b. Sludge densification and disposal.

Step III: Design and Construction of a 25 MGD Permanent Demonstration Seeded Wastewater Treatment Pilot Plant at a High-Visibility Location

Step IV: Full-Scale Municipal Integrated Wet and Dry Weather Treatment Facility

SECTION III

INTRODUCTION

OVERVIEW OF HIGH GRADIENT MAGNETIC FILTRATION

The use of magnets to separate substances of varying character is not new. Magnetic separation techniques have been used since the nineteenth century to remove tramp iron and to concentrate iron ores. A variety of conventional magnetic separation devices is in wide use today. These devices generally separate relatively coarse particles of highly magnetic material containing large amounts of iron from nonmagnetic media (direct filtration).

In recent years magnetic devices have been developed which are capable of separating even weakly magnetic materials of micron size at inherently high flow rates. These so-called "high gradient magnetic separators" have been designed to maximize the magnetic forces on fine, paramagnetic materials. They are capable of efficient separation of even weakly magnetic suspended solids or precipitates for which conventional magnetic separation techniques are ineffective. This capability is the result of the development of a filamentary ferromagnetic matrix and a large volume, high-field magnet. The combination of an efficient magnet and high gradient matrix permits the economical production of strong magnetic forces over a large surface area in the active volume of the separator. The separations may be carried out economically, and at process rates of up to several hundred gpm/ft^2.

For normally nonmagnetic colloidal material in polluted water, the addition of magnetic iron oxide (magnetite) along with a flocculating agent can render these colloids sufficiently magnetic to be removed by high gradient magnetic separators (indirect filtration). The machines provide the rapid filtration of many pollutants from water with a small expenditure of energy. Removal is much more efficient than with sedimentation because the magnetic forces on fine particles may be many times greater than gravitational forces. This technology has a high potential for use in water pollution control.

High gradient magnetic separation is used in the kaolin clay industry to remove weakly magnetic impurities of less than 2 micron size from clay. Industrial-size high gradient magnetic separators treat up to 60 tons per hour of dry clay, as a 30 percent slurry.

Other proven applications for HGMS magnetic separators include iron ore, feldspar, and many other types of mineral beneficiation. Waste reclamation and recycling, ultra purification of chemical refractories and powders,

removal of smoke stack particulates, cleaning of refueling pool waters at nuclear power plants, steam purification and other thermal power applications, and steel mill waste water purification are some of the recent problems that HGMS magnetic separators are or will soon be handling. All are direct applications and do not require the addition of a seed or flocculant to be effective.

Besides CSO and raw sewage, high gradient magnetic separation is applicable to numerous nonmagnetic waste waters such as paper mill wastes, electroplating waters, secondary effluent polishing, potable water processing, on board ship treatment of gray and black water, and almost any polluted stream in which the goal is to remove all solids from the water portion.

PRINCIPLES OF HIGH GRADIENT MAGNETIC FILTRATION

Magnetic and Competing Forces

High gradient magnetic separators, like all magnetic separators, utilize the interaction of magnetic and competing forces on a mixture of magnetic and nonmagnetic particles to provide separation based on the magnetic susceptibilities of the particles. The magnetic forces of attraction in a high gradient magnetic separator hold the magnetic particles to the edges of the matrix fibers while the competing hydrodynamic forces carry the fluid and nonmagnetic particles through the separator. For small particles the forces of hydrodynamic drag are larger than gravitational forces, and increase with slurry velocity in the separator. The magnetic forces necessary to trap these particles must therefore be large.

Maximizing the Magnetic Forces

High gradient magnetic separators effectively maximize the magnetic force on even weakly magnetic particles. The magnetic force (F_m) on a particle is given by the following expression:

$$F_m = vM \text{ grad } H$$

where v is the volume of the particle, M is its magnetization, and grad H is the magnetic field gradient that acts on the particle. The magnetic field gradient appears in the expression for magnetic force for the following reason. Placed in a magnetic field, all particles develop north and south poles at either end as shown in Figure III-1. In a uniform field the net force on a particle will be zero, since the field exerts an equal and opposite force on either end of the particle. In a gradient magnetic field, however, the force exerted by the stronger field at one end of the particle will produce a net force on the particle. Therefore, the larger the change in field across the particle (magnetic field gradient), the greater the force on the particle.

The magnetization of ferromagnetic fibers, like those in the high gradient magnetic separator matrix, produces extremely high magnetic field gradients. It turns out that the greatest force is produced on the particles when

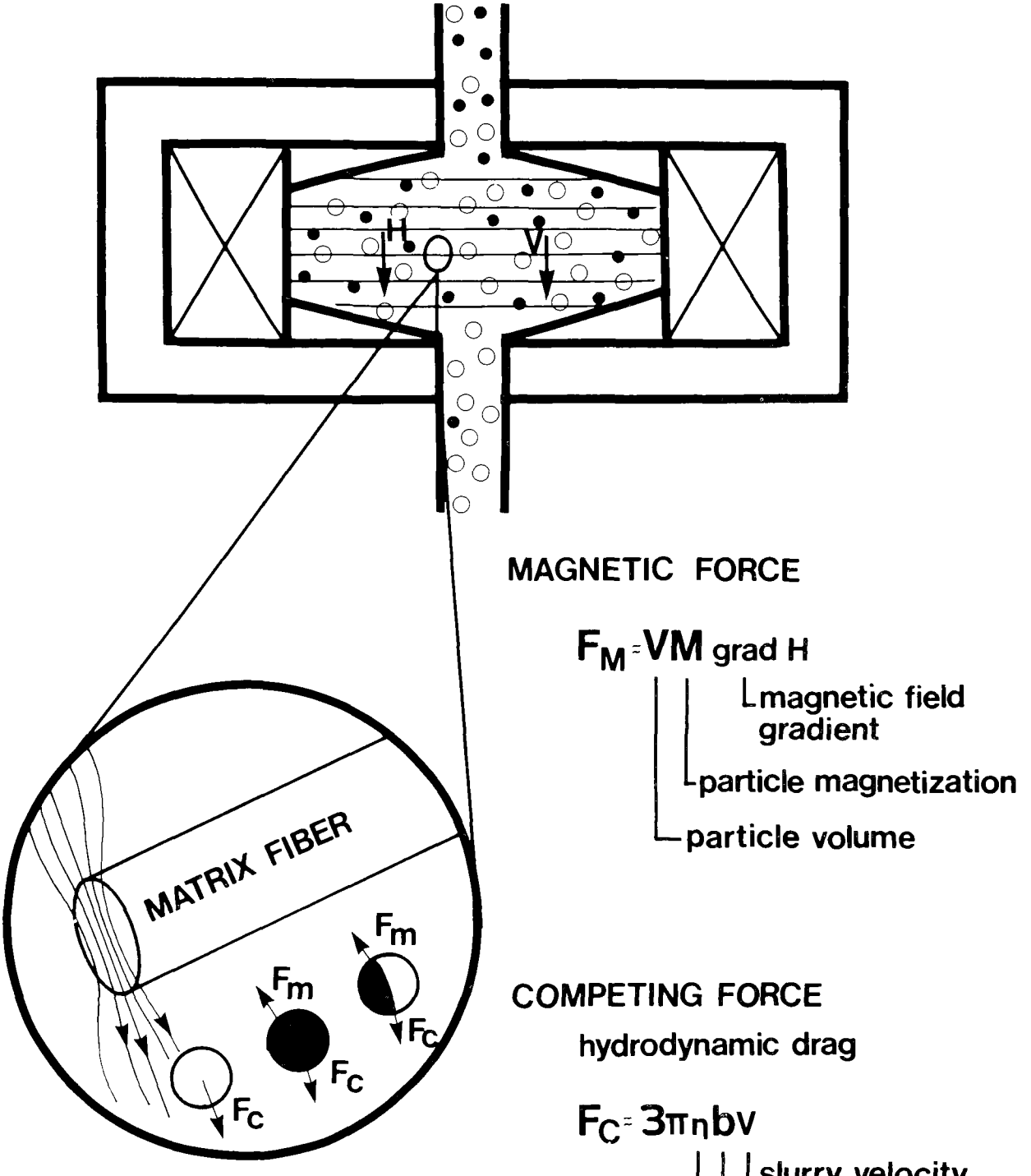


FIGURE III-1 CUT-AWAY VIEW OF HIGH GRADIENT MAGNETIC SEPARATOR

the diameter of the magnetized wire is approximately the same size as the particle to be trapped. This matching of the fiber diameter to the particle size is utilized in high gradient magnetic separators to produce extremely large forces on even weakly magnetic particles.

Ferromagnetic Matrix

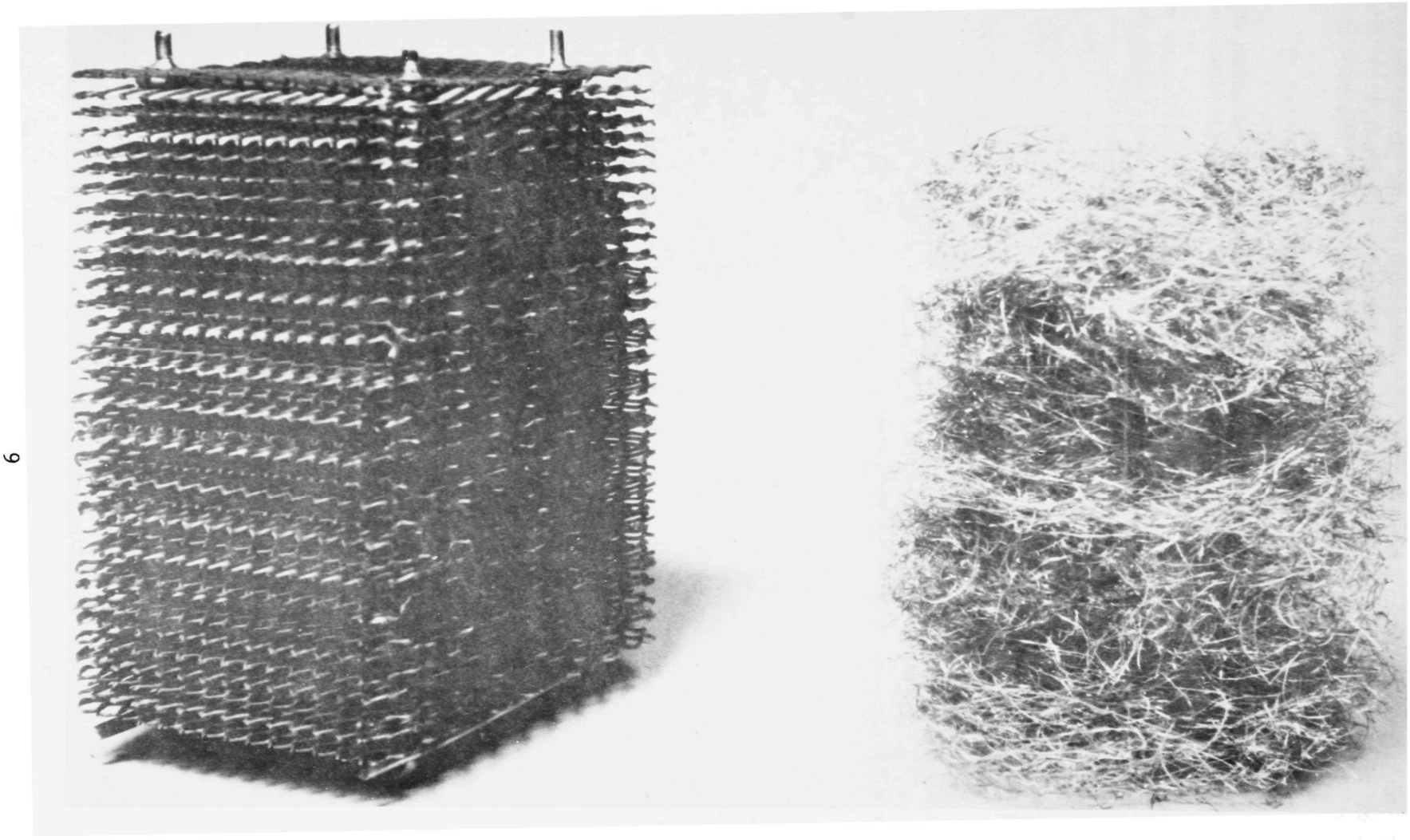
In order to produce strong magnetic forces over a practical surface area, a filamentary ferromagnetic matrix is used, magnetized by a strong applied magnetic field. The effective trapping volume of this type of matrix is many times larger than that achieved by the use of tacks, balls, or other small ferromagnetic objects which also produce large field gradients when magnetized. As shown schematically in Figure III-1, the introduction of the ferromagnetic matrix into a uniform magnetic field produces a multitude of high gradient, strong forces within the volume of the separator. A strong applied magnetic field is required to magnetize these fibers, and when the field is turned off the residual magnetization of the fibers is very low. For this reason, even strongly magnetic particles are easily washed out when the applied field is reduced to zero. Typical matrix materials are shown in Figure III-2.

Production of Strong Magnetic Fields

The ferromagnetic matrix is a relatively difficult magnetic structure to magnetize; that is, a strong applied magnetic field is required to produce the high field gradients along the matrix filament edges. The magnetic fields in conventional magnetic separation devices are not sufficient to magnetize the ferromagnetic matrix. Therefore, practical realization of high gradient magnetic separation depends as much on the production of an economical, intense magnetic field as it does on the ferromagnetic matrix. The SALA design accomplishes this goal by placing the electromagnetic coil directly around the working volume of the canister, and a steel magnetic flux return frame around the coil. This not only enhances the field created, but also increases the efficiency of the magnet and lowers its material cost.

Operating Variables of the Magnetic Separator

The efficiency of magnetic particle trapping in a high gradient magnetic separator depends heavily upon the operating variables of the separator as well as the size and magnetic susceptibility of the particles. The basic operating variables in direct filtration are: the strength of the applied magnetic field, the velocity of the feed passing through the matrix, the type and configuration of the matrix, and the accumulated feed solids in the working volume of the separator (matrix loading). The recovery of the magnetic particles increases with an increasing magnetic field because the magnetic forces are stronger. The recovery of the magnetic particles decreases with increasing feed flow velocity because the competing hydrodynamic drag forces are larger. The recovery of magnetic particles decreases with increased matrix loading since the high gradient trapping sites within the matrix become filled, leaving fewer and weaker available trapping sites. For indirect filtration applications (seeded water treatment), the additional factors of seed and flocculant type and concentration, residence time and mixing rate, pH, and other physical and chemical characteristics of the substances being



Expanded Metal

Stainless Steel Wool

FIGURE III-2 MATRIX MATERIALS USED IN HIGH GRADIENT MAGNETIC SEPARATORS

separated are important operational variables in addition to those cited above. Thus, seeded water treatment is dependent upon the maintenance of a delicate chemical balance in order to achieve an effective union of suspended solids and seed particles before their magnetic removal.

MAGNETIC SEEDED WATER TREATMENT AS APPLIED TO CSO AND RAW SEWAGE

The seeded water treatment (mag-seed) process is a unique application of high gradient magnetic separation to the removal of nonmagnetic suspended and colloidal-sized particles suspended in a liquid medium (usually water). It has considerable potential in a large number of effluent waste water cases where certain standards must be met before disposal, as well as in some closed loop operations where corrosion products or contamination may result in degradation of liquid quality within the system. The system is of particular interest for its possible application to CSO and raw sewage and a number of other areas. Calculations for effectiveness of separation, economics of capital investment and operating costs, land requirements, dependability, process flow rates, and detention times, etc., have so far been favorable in comparison with presently available technology.

PREVIOUS WORK

This report is a continuation of Report #600/2-77-015 (March 1977) entitled, "Treatment of Combined Storm Overflows by High Gradient Magnetic Separation." In that portion of the study, full descriptions and references are provided for the physics and concepts involved in magnetic filtration. In completing that work, both bench and continuous pilot plant runs were performed at Sala Magnetics, Inc. in Cambridge on CSO and raw sewage trucked in from the Cottage Farm Chlorination and Detention Facility (Cambridge) and the Deer Island Sewage treatment Plant (Boston). These tests showed clearly that the seeded water treatment process could effectively and efficiently treat these waste water samples. However, limitations in the pilot plant system and lack of freshness in the sample volume suggested that an on-site test with a slightly larger and more flexible system would be necessary before jumping to demonstration size. A mobile system also would allow the performance of on-site testing with several different effluent situations in order to provide a maximum amount of design and cost estimating input. Whereas in the previous study CSO had been slightly aged and relatively static within the test period, with a mobile trailer on location it would be possible to profile an actual storm event, as it occurred, in order to study in detail the possible problems and solutions unique to combined storm overflows (e.g., first flush loadings, multiple separator storm function, required influent monitoring systems, etc.).

PRESENT CONTRACT GOALS

The present effort is designed to demonstrate the pilot-scale effectiveness of SALA-HGMF® magnetic filter treatment of CSO, and to use this information as a basis for further larger scale tests. Various design criteria and

basic operating characteristics of the separator system were studied in some detail in order that accurate costing projections could be made for full-size integrated wet and dry weather treatment systems.

The extension of EPA Contract #68-03-2218 was performed in two parts: Effort I extended the data base of the previous work on the then-existing 1 gpm pilot plant with several specified tests, and upgraded that original pilot plant by means of a dual-magnet system, with more advanced controls, installed in a mobile unit; Effort II included on-site testing of the mobile unit, including several storm flows, as well as completion of the necessary backflushing, cleaning and sludge evaluations. With the information gained from these efforts and from previous testing using the seeded water technique, basic design and operating characteristics could be developed as a basis for the generation of costs and criteria for a demonstration-scale system.

SECTION IV

DESCRIPTION OF THE PILOT PLANT TRAILER*

PHYSICAL LAYOUT

The EPA Seeded Water Treatment Mobile Pilot Plant Trailer is shown in Figure IV-1. This 28 foot vehicle was constructed by Relco Corporation of Billerica, Massachusetts and was furnished with interior pilot plant and lab facilities by SALA. A simplified floor plan and pilot plant flow sheet are shown in Figure IV-2. General specifications and requirements are listed below.

General Dimensions

Trailer Dimensions: 8'W x 28'L x 11'H (2.4m x 8.5m x 3.5m)
Laboratory-Office: 8'W x 13'L (2.4m x 4m)
Gross Weight: 7000 lb (3000 kg)

Pilot Plant Specifications

Flow Capacity: 10 gpm (0.6 ℓ/sec)
Sludge Production: 1 lb/hour (0.5 kg/hour)

Utilities Requirements

Electric Power: 8.8-22 kW
Tap Water: 5-25 gpm (exclusive of feed)
Compressed Air: 1-3 cfm at 40-60 psi
Appropriate Drainage

Typical Chemical Requirements

Magnetite: 0.6 lb/hour (0.25 kg/hour)
Alum: 0.25 lb/hour (0.1 kg/hour)
Polyelectrolyte: 0.04 oz/hour (0.001 kg/hour)

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*For further descriptions and detailed schematics refer to the operating manual for the Sala Magnetic Filtration Pilot Plant.

FIGURE IV-1 MAGNETIC FILTRATION
PILOT PLANT TRAILER

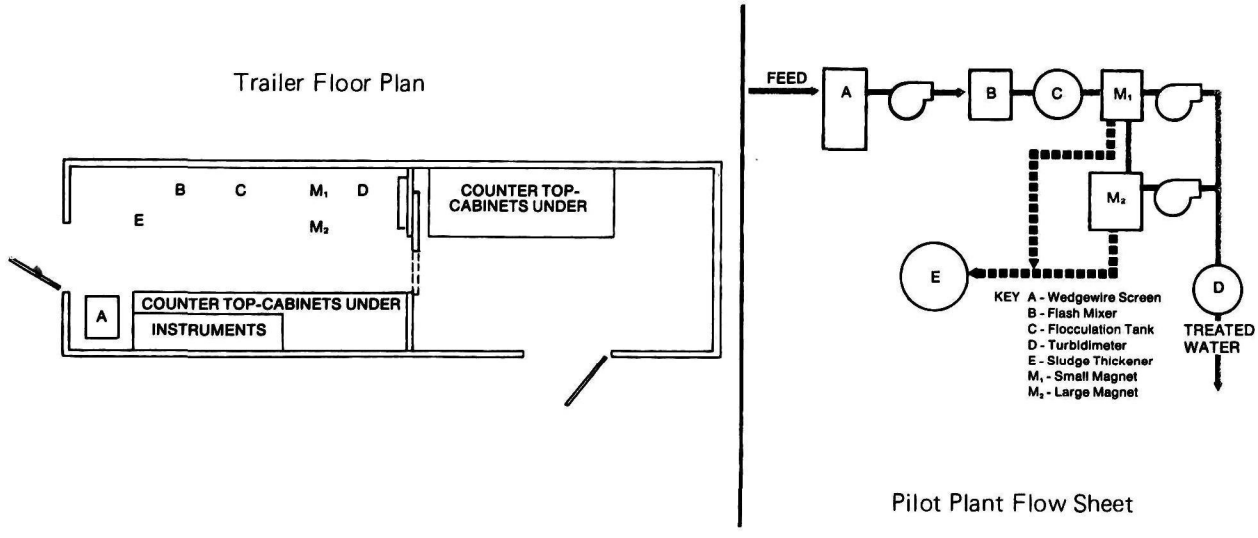

FIGURE IV-2 SIMPLIFIED PILOT PLANT FLOOR
PLAN AND FLOWSHEET

As can be seen in Figure IV-2, the trailer is divided into two sections, the forward portion being for laboratory analysis and office space and the larger, rear portion containing the SALA-HGMF® Magnetic Separator pilot plant system, sink and jar testing and millipore filter apparatus set-ups. Other SALA laboratory equipment includes pH and conductivity meters, spectrophotometer, incubator, oven, balance, and magnetic stirrer. These facilities allow for immediate processing of test samples giving the experimenter quick feedback on the process (through turbidity measurements) and assuring that post-collection contamination or aging does not take place. Other relevant tests that can be performed easily with the presently available equipment are total suspended solids, color, and fecal coliform.

Figure IV-3 shows a more detailed floor plan of the EPA Trailer, including the major process components of the pilot plant. Figure IV-4 shows a portion of the mobile trailer interior containing the majority of this equipment.

The mobile unit is fully insulated and may be heated by electric baseboard heaters located in each of the two rooms. Running water is supplied for pilot plant cooling and backflush water as well as for laboratory uses. A floor drainage system leads to an external sump pump with a capacity of about 35 gpm. Ceiling fans provide ventilation for each room and numerous cabinets and cupboards supply generous storage space for chemicals, glassware, hardware, tools, spare parts, and other necessary equipment. Once in place, the trailer is supported by four Simplex jack stands set on heavy steel blocks. The tires should also be blocked for added safety.

The trailer is protected against burglary in several ways. Double locks have been installed on each of the two doors and lexan storm panels have been added to both of the front windows to prevent possible breakage and for extra insulation. Inside, an ultrasonic alarm system capable of running off AC (normal) or DC (emergency battery) adds a further deterrent to break-ins. A first-aid station and fire extinguisher are wall mounted in the pilot plant section.

FLOW DIAGRAM AND DESCRIPTION OF PILOT PLANT SYSTEM

Figure IV-5 shows the process flow sheet for the seeded water treatment system. Untreated waste water is pumped into the trailer system by a submersible pump (P-A) or any facility sampling pump. As it enters it passes through a wedge wire screening device (where it is screened to -35 mesh size) and into a 55 gallon drum with low- and high-level float switches to maintain a sample reservoir for treatment. A variable speed mixer prevents settling within the 55 gallon barrel.

The feed pump (P1) draws sample from the drum and pumps it through a rotameter (FMI) for process flow rate monitoring. The rate of pumping is determined directly by the operator who sets the master control knob on control panel #2. A float switch in the flocculator tank also shuts P1 off when the filtering throughput is unable to keep up with feed pumping rate.

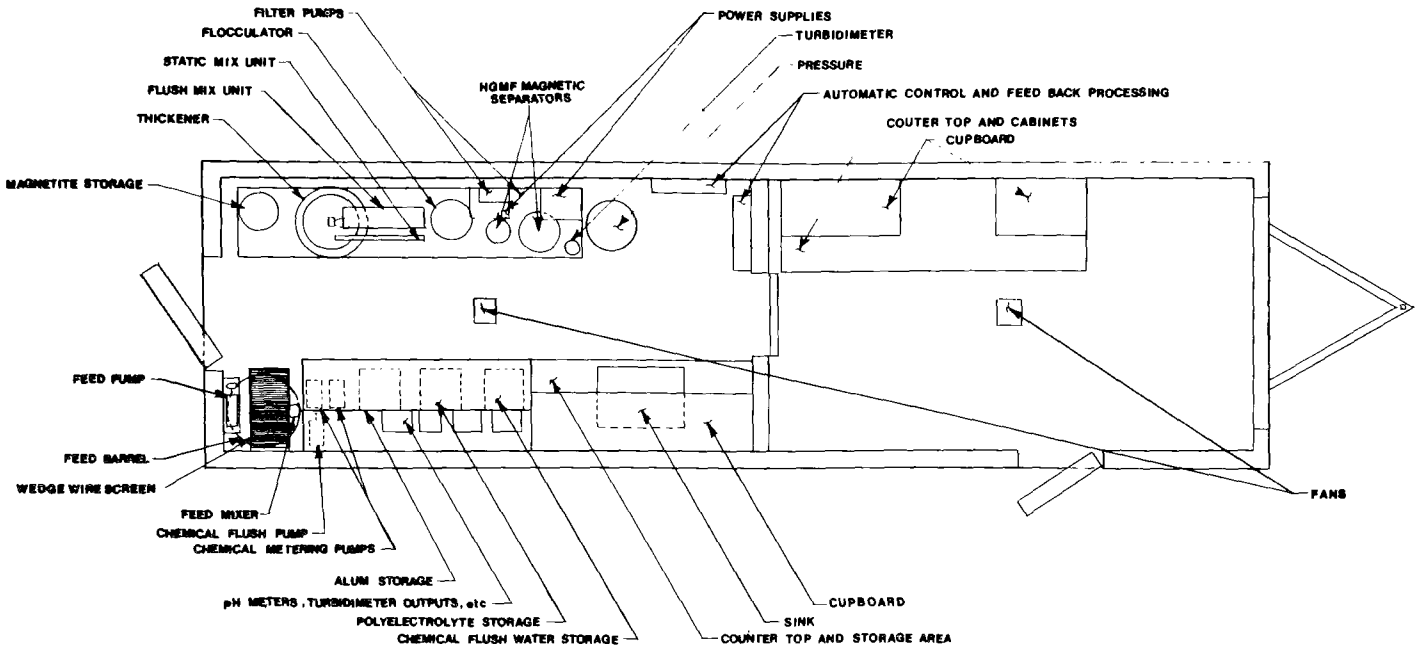

FIGURE IV-3 DETAILED FLOOR PLAN OF MOBILE TRAILER

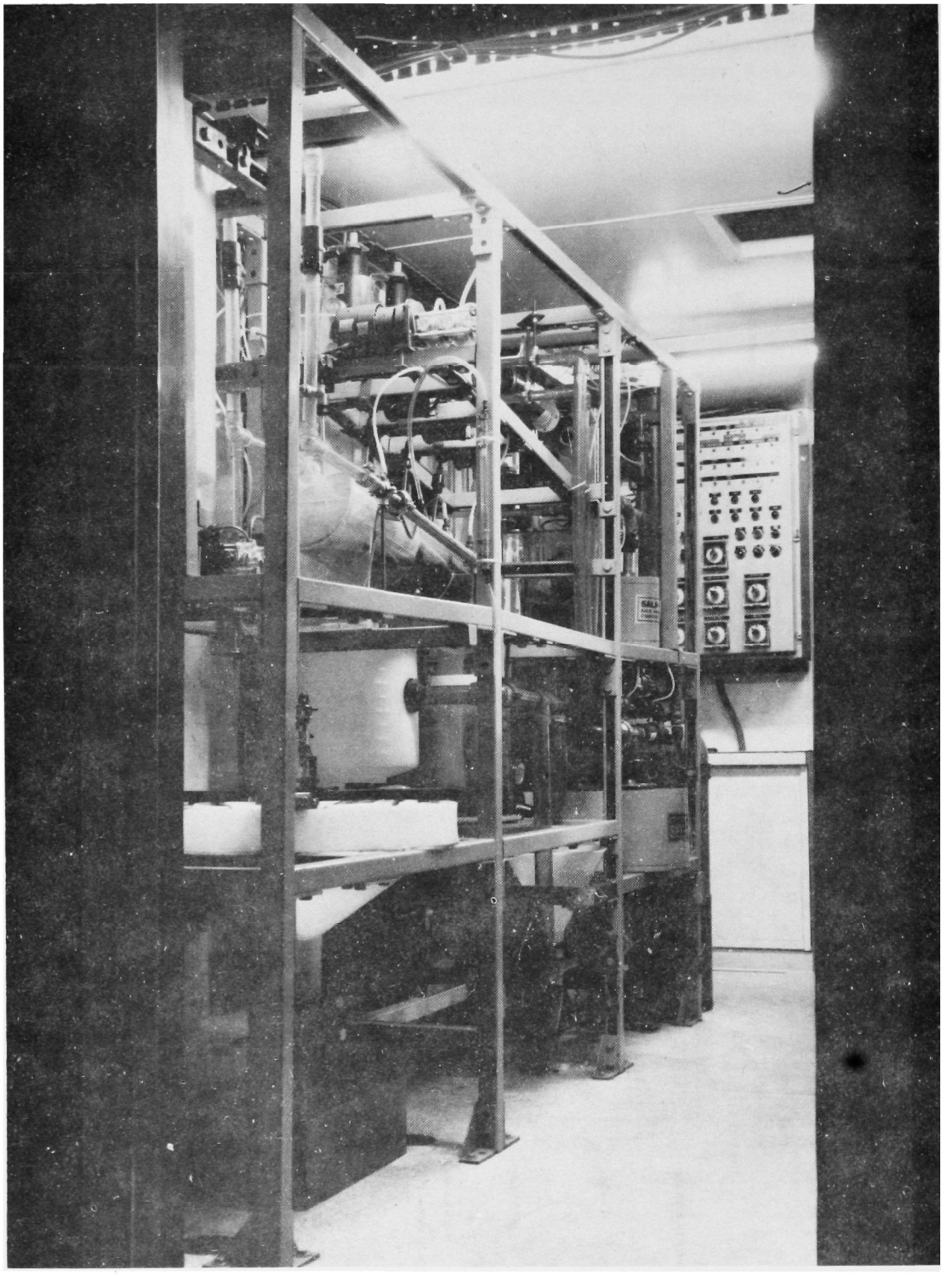

FIGURE IV-4 PILOT PLANT TRAILER INTERIOR

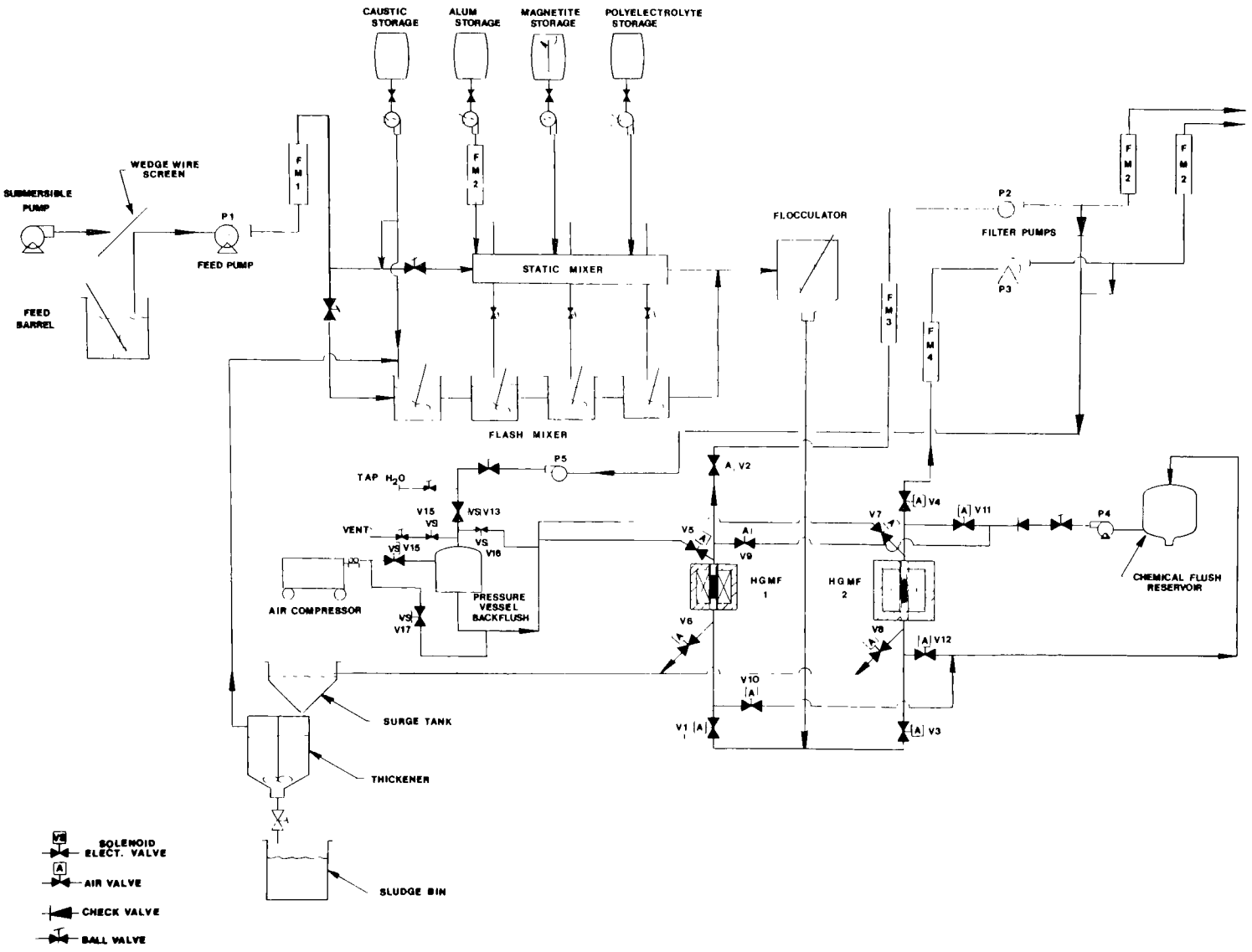

FIGURE IV-5 PROCESS FLOW SHEET FOR SEEDED WATER TREATMENT PILOT PLANT

Process water passes through one of two alternative chemical mixing units before entering the flocculator. The first, a conventional flash mixer, consists of a large (8 inch diameter polysulfate) cylinder mounted on a slant and compartmentalized into four sections by three, toothed weirs. The water passing through each compartment is agitated by a variable speed paddle mixer which disperses the chemical(s) being added in that section. In general, the first compartment is reserved for pH monitoring and adjustment (if necessary), the second is for alum addition, the third for magnetite, and the fourth for polyelectrolyte. The alternative system is a static mix unit (1 inch diameter) made by KOMAX. This 24-element unit disperses the chemicals (which are added in the same order as above through ports in the statix mixer) by repeated division and rejoining of fluid flow throughout the 18 inch length. In this way, no moving parts are needed, and considerable space is saved in the system. This unit is designed for flow rates on the order of 1 gpm and is less effective for substantially faster process rates.

Both chemical mixing units dump into the flocculator which is a large (30 gallon) polyethylene tank agitated by a variable speed mixer. This provides contact time for flocs to form before magnetic filtration. Also located in this chamber are the flocculator feedback control unit and the feed pump shut-off float. The feedback control unit provides an indirect contact between the manually set feed pump (P1) and chemical metering pumps and the filter pumps for systems I and II (pumps P2 and P3 respectively). This is done by a mechanical linkage between a level float in the flocculator and a series of microswitches. The microswitches, responding to flocculator water level, control which system (I or II) is on and how fast that system is filtering. Thus, when the incoming stream remains constant, the filtering rate will seek that rate and hold it, as well as track any changes (surge simulation) imposed on the feed pump and associated chemical metering pumps. The rate of flow through the filters can therefore be controlled directly by flocculator level which in turn is a function of the (manually controlled) feed pump rate. A lag time is present due to the plumbing (flash mixer, etc.) preceding the flocculator. A small cyclical fluctuation in level occurs due to the cyclic operation of the magnetic filter (filter and backflush modes alternate). An alternate manual control of filter pump operation (P2 and P3) is also provided which is independent of the feed pump (P1) rate.

The pre-treated waste water then passes up through the magnetic filter(s) via the suction action of the filter pump(s) (P2 and/or P3) and opening of air valves V1 and V2 and/or V3 and V4. These variable speed pumps have practical capacities of 1.5 gpm (P2) and 5.5 gpm (P3), yielding flow flux rates of 100 gpm/ft^2 for each, and pump through their respective rotameters before discharge into the drain at the sample station. A small portion of this flow may be tapped for continuous monitoring of turbidity through a Hach Model 1720 Low Range Turbidimeter when good separation is being achieved, and the turbidity recorded on a Rustrak chart recorder.

Cooling water from the tap is provided to magnetic separators I and II and to their power supplies through control and solenoid valves. Water flow through these valves should be approximately 0.2 gpm for V20 (system I) and 0.4 gpm for V21 (system II), or not hotter than 60^{o}C at the drain.

Backflush is accomplished by a pressurized vessel (20 gallons) about one-third filled with water and with the remaining volume air-pressurized to $\sim$ 35 psi when fully charged. The water refill is normally accomplished by tap water addition (via solenoid valve V13) but the system can be altered to allow treated process water to be pumped (by P5) into the pressure vessel for normal cycling (preferably at high process rates). A float switch inside the vessel controls water level.

After water addition, the tank is automatically pressurized (via solenoid valve V14) to a pre-set pressure as gauged by a Honeywell air switch. Should the air-water recharge described above not be completed before the filter cycle times out, the next step will be delayed until recharge is accomplished to avoid inadequate matrix flushing. The tank may be manually vented by opening solenoid valve V15 and a manual ball valve near the top of the pressure vessel. This operation is necessary before shutting down the system in order to release the pressure in the tank before the normally open valves become de-energized.

Backflush through the separators occurs when air valves V5 and V6 or V7 and V8 open with all other valves closed. This allows the pressurized water to excape (via the demagnetized magnetic separator matrix) to the vented surge tank which integrates the flow of the sludge-filled backwash water to the thickener. Air is mixed with the backflush water as it leaves the pressure vessel from one of two alternative sources. Solenoid valves V16 or V17 are opened allowing an amount of air to enter the backflush stream. V16 allows air to escape from the pressurized vessel itself, and thus the relative ratio of air to water over the backflush interval is constant. When V17 is used, the air pressure used to aerate the backflush water is independent of the pressure in the vessel and the relative proportion of air in the water can be regulated. Thus the air-to-water ratio will increase over the backflush interval for this operational mode.

The backflush water in the 5 gallon surge tank drains slowly into the 15 inch thickener where the sludge settles out and the backflush water overflows the weirs to be pumped (by P6) back into the process stream at the flash mix unit or drained out of the system. Sludge in the thickener is raked towards the cone shaped bottom of the tank where it must be periodically manually discharged into a collecting vessel. (A sludge pump would, in a full-scale system, deliver this material to a vacuum filter, incinerator, or other means of disposal and/or recycle).

The third set of air valves associated with each magnetic separator are the chemical backflush valves (V9 and V10 for HGMF I and V11 and V12 for SALA-HGMF®II). These valves open only during chemical backflush which occurs once every (x) cycles as determined by the manually set counter (chemical backflush occurs only on the final step of the counter prior to its resetting, i.e., step 0). The (Parcolene) rinse used for chemical backflush is circulated in a loop by pump P4 through the demagnetized matrix as with normal backflush, but with much lower velocity and for a longer interval. Normal backflush follows the chemical rinse before the next filter cycle is again initiated.

SECTION V

TESTING SITES

During the span of the present modifications (4 and 5) of EPA Contract #68-03-2218 testing has taken place at several different sites. Effort I was spent at SALA using a slightly modified version of the 1 gpm continuous pilot plant described in EPA Report 600/2-77-015, while Effort II was completed by work done with the newly constructed mobile pilot plant trailer on-site at the Cambridge Cottage Farm Chlorination and Detention Facility and at the MDC Columbia Park Headworks in Dorchester. All testing was completed between October of 1976 and the same month of 1977, with mobile trailer construction and debugging taking a large portion of this time span, from late December to mid June.

TESTS AT SALA MAGNETICS

Effort I testing was essentially completed with the 1 gpm continuous pilot plant upon the collection and running of two storm activations from Cottage Farm. In the first, on October 20, 1976, 400 gallons of unscreened CSO was trucked to SALA in 55 gallon barrels and tests were performed which included the evaluation of the maximum permissible matrix loading over a range of seed-to-solids ratios and a preliminary static versus flash mixer comparative run.

Dry weather prevented further activations until December 7, 1976 when 300 gallons of CSO was once again carried to SALA for pilot plant evaluation. Further seed-to-solids runs were carried out on this water, as well as tests designed to determine the maximum practical flow flux rate at a given condition of solids loading and seed addition rate.

Due to the delay caused by infrequent storms, and the expectation that collection and running of storm water would be more efficient and relevant on-site than after aging with transport and set up times, it was decided that further Effort I specified testing be deferred until mobile trailer unit operation under Effort II.

COTTAGE FARM WORK

After many months of design and construction, the trailer-mounted pilot plant was moved to the Cottage Farm facility on May 19, 1977 for testing and debugging. (See Figure V-1.) This was accomplished soon thereafter at

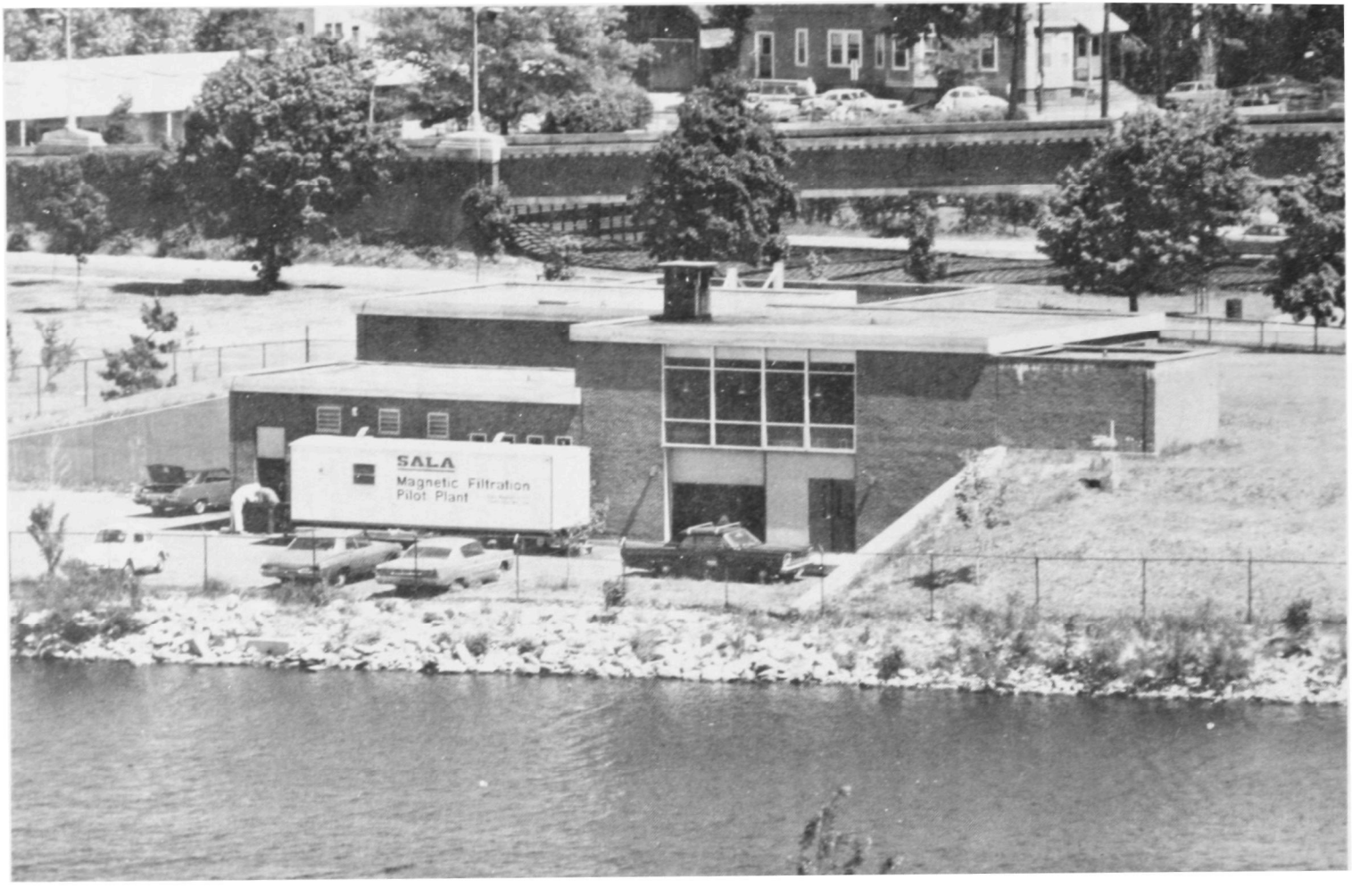

FIGURE V-I COTTAGE FARM CHLORINATION AND DETENTION FACILITY, CAMBRIDGE, MASSACHUSETTS

which time the system was made ready to accept storm water for Effort II testing. Once again the weather did not cooperate and a storm testing was not possible until July 11, 1977. By this time, the trailer had already been scheduled to be moved to Columbia Park Headworks where raw sewage is continuously available as well as CSO during rain storms. This storm provided an opportunity to test the workability and capabilities of the pilot plant system under real storm water running conditions.

The above static flow rate CSO run showed that suspended solids and turbidity were significantly lowered ($\sim$ 75-80%) with this on-site process, using an admittedly roughly controlled operating procedure. However, this first run was a necessary prerequisite to the tests that followed as a system was developed during the run for monitoring and checking all pilot plant parameters and physical components.

COLUMBIA PARK TESTING

On July 18, 1977, the pilot plant trailer was moved to a site at the Columbia Park Headworks in Dorchester. This was done so that some of the less critical tests could be completed, using raw sewage, in the intervals between storm flows. The new site was chosen on the basis of the expected storm water dilution factor as compared with the Cottage Farm activation character, the adaptability of our system to their available facilities, and the relative security of the location.

Unfortunately, essentially all of the MDC-run Boston sewerage system is beset by the problem of tidal inundation, and the resulting periodic fluctuating salinity of the incoming waste water. This problem, originally thought to be of minor significance, turned out to be a major obstacle to a systematic comparative study of parameters related to seeded water treatment of CSO and raw sewage, as the system is basically one of chemical coagulation, a technique sensitive to such changes in water salinity. Fluctuations in raw sewage conductivity of between 2000 and 20,000+ μmhos/cm occur regularly with the tides, causing significant changes not only in the dosages required, but also in the very nature of the reaction which takes place in destabilizing the suspended matter. Because flocculation is, under normal conditions, dependent in a complex way upon water characteristics which are difficult to monitor or adjust for, the additional imposed variable of a dynamic salinity scheme, dependent upon relative tidal height and raw sewage and storm water volumes, makes precise system regulation and maintenance of optimum running conditions nearly impossible. For this reason, tests that are best performed using a stable waste water input for comparative analysis of various pilot plant parameters were difficult to interpret in light of the constantly changing conductivity measured in this case. Even storm water runs were affected by this overlayed factor (although to a somewhat lessened extent) due to the large CSO dilution volumes involved.

At Columbia Park, all remaining tests were completed and several additional experiments were performed. Testing included optimal backflush technique, backflush velocity, time and pressure requirements, matrix cleaning

and sludge evaluations, minimum residence time needed, optimum chemical addition sequence, and the pilot plant profiling of three storm water flows. A further flash versus static mixer comparative test, pH jar tests, and the trial of a variety of different flocculants were also performed during this stage at Columbia Park Headworks. Most of the above testing (excluding the three storms profiled) was performed using raw sewage.

SECTION VI

DISCUSSION OF RESULTS

SUMMARY OF RESULTS

The overall results obtained in this study were highly satisfactory and shed much light on the advantages of high gradient magnetic separation techniques as applied to CSO. Several minor difficulties were overcome, and the work led to improvements in both technique and system design to better suit this particular application. The feasibility of the seeded water treatment system for handling dynamic situations such as are encountered in integrated wet and dry weather installations was clearly demonstrated.

The practicality of using seeded water treatment variable flows and multiple separators to handle storm surges while maintaining process effectiveness was shown by our storm profile tests. The importance of adequate seed in the system was made clear in these and other matrix loading-type tests. Best chemical addition techniques were reconfirmed as well as the assertion that pH adjustment is not necessary for raw sewage or CSO with this treatment method. Backflush and matrix cleaning requirements were explored and optimal techniques proposed. Preliminary examination of the generated sludge tends to indicate that it is easily handled, dried or recycled for possible seed recovery and reuse. The static mixer shows some promise in the system as an energy saving and maintenance-free chemical disperser. The effects of increased flow velocity at a certain set of conditions were determined to be rather mild up to a flow flux rate of about 200 gpm/ft^2, higher than was expected. These results and others have helped us to better project costs and optimal designs for larger size systems.

OVERVIEW OF TEST CONDITIONS

In the previous study, the seeded water treatment technique was shown to be highly effective in removing on the order of 90^+% of all suspended solids, turbidity, BOD, fecal coliforms, etc. from CSO and raw sewage. These tests were carried out after the collection and storage of the waste water (usually a lapse of at least one day) by drawing samples from large, well-mixed vessels all of exactly the same age. In some instances, sample alteration (e.g., bacterial growth due to warm temperatures inside the building, etc.) did take place (for example, when it was necessary to run for more than one day with the same sample). These changes usually involved a straightforward conversion of available BOD to biomass, and only minor changes were noticed in the chemical balance of the water (i.e., relative doses of chemicals needed to achieve proper flocculation did not change and little self-destabilization was noticed over these short durations). The result of all this was that

rather controlled conditions existed in the waste water stream entering the pilot plant allowing optimization to be precise. Further, the time lapse necessary before processing of the sample undoubtedly had some effect on the chemical interactions taking place in the system.

On-site tests, however, proved to be much different. CSO, by nature, is a highly dynamic waste water. The "first-flush" phenomenon, where the sewer system is flushed of sediment laid down during dry weather by the initial gush of rain water, can result in an order of magnitude jump in suspended solids passing through the system in a very short time. Depending upon the relative rate and source (i.e., rain, snow, melt-off) of flow, the time of year and time of day (relative raw sewage flow), the duration of the storm, and the frequency of recent precipitation, the CSO in a given sewer system will vary tremendously. Local inputs of industrial wastes can also cause periodic fluctuations in waste water chemistry serious enough to upset both biological- and chemical-clarification-based treatment systems. Finally, CSO varies with the individual sewer system. Each has its own unique character depending on numerous factors among which are: the nature of the drainage area included, the type and relative proportion of industry, population density, climate, and sewer pipe age and construction. All this means that most on-site tests tend to be more rigorous than batch sample tests, and this situation is even further accentuated with the dynamic combined storm overflow waters. The fact that the SALA on-site tests were able to deal successfully with this situation is a major step in demonstration of the applicability of the technology.

The majority of the on-site testing under this contract was done at Columbia Park where the additional complication of constantly changing conductivity of the waste water overlayed the above-mentioned variables. This problem, along with other operational troubles, made testing at this site difficult, necessitating the repetition of most tests. The outcome of this was that progressive results showed considerable refinement as well as improvement in separation effectiveness. By careful monitoring of the system and proper chemical dosing, essentially all process problems were overcome and the technology was demonstrated as one capable of handling even the most adverse of the dynamic surge flow circumstances.

BACKFLUSH TESTS

Optimal Backflush Technique

The object of the magnet backflush is to purge all solids trapped during the filter cycle from the filamentary magnetic matrix to free up sites for further magnetic separation and prevent buildups from occurring which could lead to filter clogging. Several possible techniques were chosen for comparison including single-surge, air-water flush from the pressure vessel; single-surge, water-only flush; pulsed air-water backflush from the pressure vessel; single-surge, air-water backflush using independent (constant) air source; and single-surge, air-water flush from the pressure vessel with a drained matrix. Previous tests had indicated that air-water flushing techniques could solve matrix build-up problems associated with oily waste waters.

The tests performed here attempted to determine whether the optimum backflush technique for CSO is similar to that for other applications and to further define the critical parameters involved. The tests were performed on raw sewage using the following pilot plant running conditions:

Flow Rate: 5.3 ℓ/min, 115 gpm/ft^2 (SALA-HGMF® I)
Magnetic Field: 1.9 kG
Residence Time: 6 minutes
Backflush: 2.5 seconds, 1800 gpm/ft^2 @ 35 psi

Chemical addition rates were as follows:

Alum: 125 mg/ℓ
Polyelectrolyte: 1 mg/ℓ (Betz 1150)
Magnetite: 260 mg/ℓ

The raw sewage had a suspended solids concentration of 110 mg/ℓ, a turbidity of 97 FTU, and a conductivity of 18,600 μmhos/cm at the start of these tests. The pH was 6.8.

TABLE VI-1 BACKFLUSH TECHNIQUE COMPARISON

Backflush Technique	Solids Concentration in Backflush (g/ℓ)	Backflush Volume (ℓ)	Backflush Solids (g)
1. Air-water backflush from pressure vessel, decreasing air pressure*	2.8	3.2	8.9
2. Water backflush only	2.3	3.7	8.4
3. Air-water backflush in pulses from pressure vessel	4.9	2.5	12.3
4. Air-water backflush with independent constant air supply (50 psi)	7.8	1.6	12.4
5. Air-water backflush from pressure vessel after matrix drain**	2.0	3.5	7.0

*Air-water flush with decreasing pressure was accomplished by re-combination of air from the top of the pressure vessel with water from the bottom at a point in the backflush line before the matrix.

**Some solids lost in test.

Table VI-1 shows the solids concentration in the backflush water, total solids collected in the backflush and the total volume for each backflush tried. It can be seen from this that of those methods tried the air-water flush with constant 50 psi air pressure appears to have removed the most solids at the highest concentration.

Backflush Velocity, Time and Pressure

Several tests were performed in order to determine minimum backflush requirements for the system. The first of these was done using a simple 35 psi pressure vessel air-water backflush while varying the backflush time (and therefore the volume of backflush water used). The backflush times used on this treated raw sewage were 10, 5, 2.5, and 1 second with the 2.5 second run repeated as a check on technique. Each test run was followed by an unsampled run with a 10 second backflush to avoid residual build-up between tests. Other pilot plant and chemical addition statistics were identical to those previously found for the optimal backflush technique tests.

Table VI-2, below, shows the results of this test.

TABLE VI-2 BACKFLUSH TIME TESTS

Backflush Time (seconds)	Solids Concentration in Backflush (g/ℓ)	Backflush Volume (ℓ)	Backflush Solids (g)
10.0	0.94	15.0	14.1
5.0	1.6	9.4	14.8
2.5	3.0	3.6	10.8
1.0	14.0	0.83	11.6
2.5	2.7	3.9	10.4

As is to be expected, and can be visually observed in the pilot plant, the vast majority of solids wash freely from the matrix in the very first slug of backflush water. However, from the above table, it seems evident that a significant amount of suspended solids in addition to the initial slug are removed with increased backflush duration (at least with the backflush technique being used). The difference between the backflush solids recovered in the 10 second and 5 second flushes is essentially unchanged while the 2.5 and 1 second flushes seem to have been somewhat less effective. Due to the lack of control samples, however, these tests are not conclusive as differences observed could conceivably be attributable to changes in the raw sewage itself. Also, an even shorter backflush may result in superior flushing effects when the air-water flush with constant pressure is used.

A second, more involved series of tests was run to further try to pinpoint the minimum backflush parameter values. In this experiment, the air-water flush with constant 50 psi air pressure (optimal technique) was used

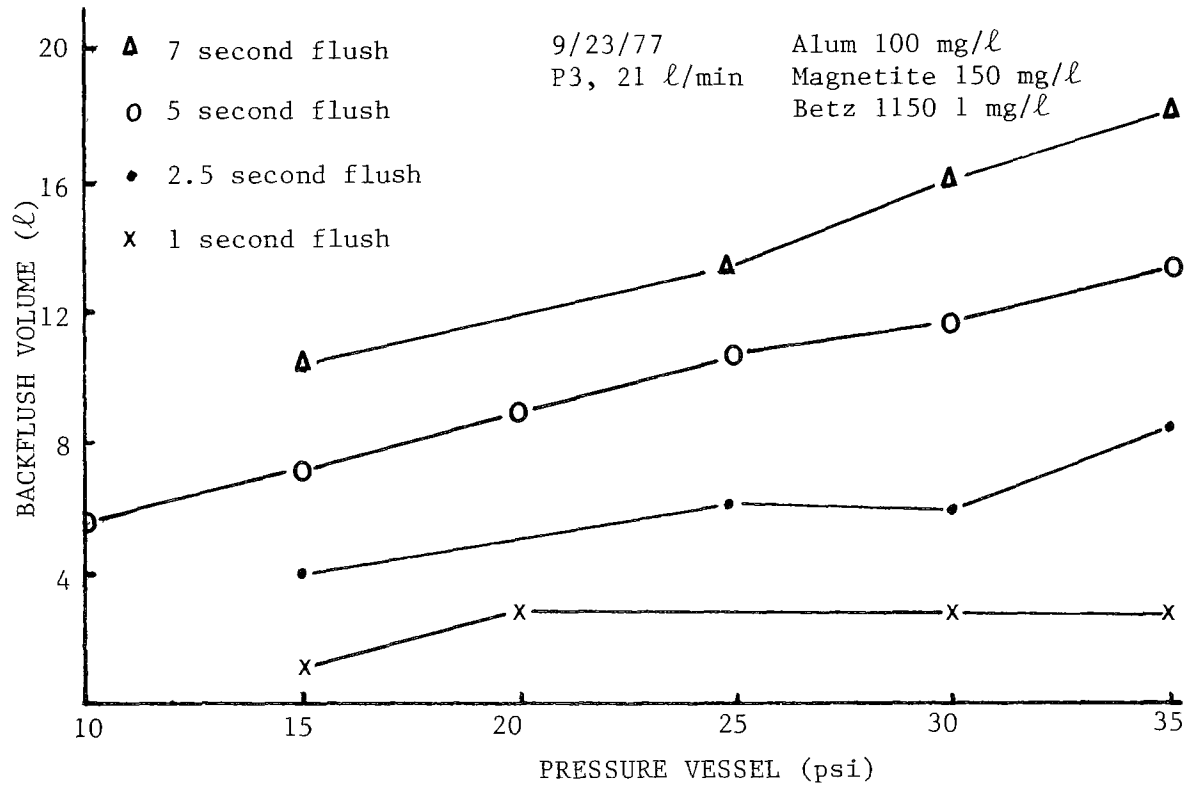

FIGURE VI-1 BACKFLUSH VOLUME VERSUS HYDROTANK PRESSURE

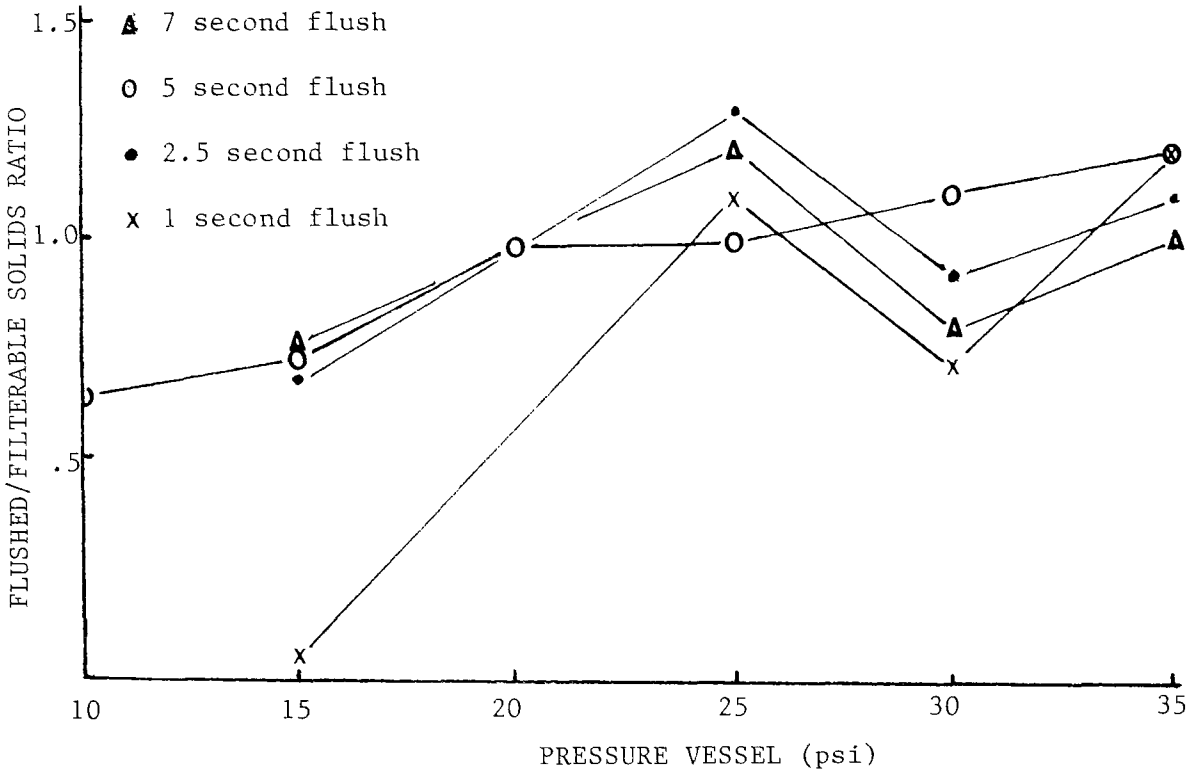

FIGURE VI-2 BACKFLUSH EFFECTIVENESS

TABLE VI-3A BACKFLUSH PRESSURE AND DURATION DATA

Sample Type/#	Flush Condition psi/seconds	Concentration (mg/ℓ)	Total Flushed Solids (g)	Average Floc Tank Solids (g/cycle)	Treated Solids Lost (g/cycle)	Average Filtered Solids (g/cycle)	Flushed/ Filtered Solids Ratio
Feed 1		92					
Treated 1		61			6.4		
Floc Tank 1-1		83					
" 1-2		153		21.1			
" 1-3		230				14.7	
" 1-4		337					
Flush 1-1	35/7	829	14.9				1.0
" 1-2	35/2.5	1900	16.3				1.1
" 1-3	35/1	6010	17.4				1.2
" 1-4	35/5	1320	18.0				1.2
Treated 2		46			4.8		
Floc Tank 2		206		21.6		16.8	
Flush 2	30/5	1640	18.5				1.1
Feed 2		135					
Treated 3		80			8.4		
Floc Tank 3-1		263		27.3			
" 3-2		258					
" 3-3		---				18.9	
" 3-4		---					
Flush 3-1	25/7	1240	17.0				.90
" 3-2	25/2.5	3120	18.7				1.0
" 3-3	25/1	5430	15.5				.82
" 3-4	25/5	1450	15.4				.81
Treated 4		80			8.4		
Floc Tank 4		300				29.4	
Flush 4	20/5	2850	26.2*	37.8			.89

*Total flushed solids after 6 minutes filter cycle instead of 5 minutes

TABLE VI-3B BACKFLUSH PRESSURE AND DURATION DATA

Sample Type/#	Flush Condition psi/seconds	Concentration (mg/ℓ)	Total Flushed Solids (g)	Average Floc Tank Solids (g/cycle)	Treated Solids Lost (g/cycle)	Average Filtered Solids (g/cycle)	Flushed/ Filtered Solids Ratio
Feed 3		71					
Treated 5		56			5.9		
Floc Tank 5-1		367					
" 5-2		337		36.1			
" 5-3		330				30.2	
" 5-4		340					
Flush 5-1	15/7	2220	23.3				.77
" 5-2	15/2.5	5180	20.7				.69
" 5-3	15/1	2330	3.1				.10
" 5-4	15/5	3230	22.6				.75
Treated 6		60			6.3		
Floc Tank 6		347		36.4		30.1	
Flush 6	10/5	3510	19.3				.64
Feed 4		56					
Treated 7		66			6.9		
Floc Tank 7-1		245					
" 7-2		---		28.0			
" 7-3		280				21.1	
" 7-4		276					
Flush 7-1	30/7	1050	16.8				.79
" 7-2	30/2.5	2880	19.6				.93
" 7-3	30/1	5490	15.5				.73
" 7-4	30/5	---	---				---
Feed 5		68					
Treated 8		67			7.0	14.0	
Floc Tank 8		200		21.0			

throughout, while varying the pressure vessel pressure and the total flushing time. This was done in a systematic manner, using pressure vessel pressures of 35, 30, 25, 20, 15, and 10 psi and backflush times of 7, 5. 2.5, and 1 second. The 20 and 10 psi runs were done with a 5 second flush only, while all the others were repeated for each of the above flush times. An uncollected 7 second flush was performed in between each test run to ensure maintenance of a clean matrix. Not only were backflush waters collected but feed water, flocculator water, and treated water were all sampled and analyzed periodically Figure VI-1 gives the running conditions used and shows the relation of backflush volume to backflush pressure for different backflush durations.

Table VI-3A and 3B show the results obtained in these tests. From these data, the average flushed suspended solids to filtered suspended solids ratio (backflush effectiveness) has been calculated and is plotted in Figure VI-2. This figure shows a clear trend of increasing backflush effectiveness with increased air charge on the pressure vessel over the interval tested.

Matrix Cleaning Requirements

The cleaning requirements for the matrix (in addition to normal backflush) were investigated to determine what if any special attention needs to be given to this possible problem. CSO and raw sewage have been shown to be relatively free of the grease and oil which have caused some problems in other magnetic separation applications. Preliminary results have indicated that although minor build-ups may occur, these easily can be eliminated by better backflushing techniques and periodic chemical (caustic) rinsing. In tests done on a similar application, a number of cleaning solutions were compared for overall effectiveness. Several of these (one in particular) were found to be extremely effective in maintaining a "like new" appearing matrix with rather infrequent, low-velocity rinsing. As prolonged testing over a period of months has not as yet been done, conclusions about a permanent solution for matrix maintenance can not presently be made with certainty. The two matrix examinations performed during this study to determine cleaning requirements showed that build-ups were practically nonexistent when compared to those observed in the past in other magnetic separation applications. Experience has shown that these problems can be eliminated by the use of a periodic chemical rinse in addition to an air-water back and forward flushing technique. The chemical rinse frees up the trapped particles by dissolving the greasy slime surrounding them and the reversal of flush direction midway through provides equally high shear forces at both ends of the matrix. This combination has been shown to maintain the matrix in a very clean state virtually indefinitely. Further tests should be done, however, using the present pilot plant (as well as the next, scaled-up version with modified plumbing for reverse backflush) to determine frequency and duration requirements of such flushing techniques on CSO effluent. The chemical flush system is already incorporated within the present system and needs only to be tested over extended time intervals for detailed evaluation of its effectiveness on CSO.

CHEMICAL ADDITION TECHNIQUES

A number of jar test-type tests were performed to investigate the effects of residence time on flocculation, to determine the optimal chemical addition sequence to promote good flocculation, and to compare previous test results on optimal pH for clarification in seeded water treatment with newly generated data done on site. These tests were all done with fresh raw sewage or CSO using a standard jar test procedure. A turbidity measurement after 5 minutes of settling provided all quantitative results, while visual observation of the flocculation as it occurred gave added input to the analyses. Although the quantitative measurements cannot be translated directly into what we can expect from magnetic separation, these tests do give us a relative baseline from which the most likely to succeed techniques can be determined.

Chemical Addition Sequence

Table VI-4 gives the variety of chemical addition sequences tested and results obtained. The test procedure was designed to give all samples a total of 4 minutes of mixing before clarification was begun. This mixing was broken up into 2 1/2 minutes at 110 RPM and 1 1/2 minutes at 60 RPM, simulating the flash mix-flocculator situation to some extent. All samples were of one liter size.

TABLE VI-4 CHEMICAL ADDITION SEQUENCE

Test #	Addition Sequence	Floc Characteristic	Turbidity(FTU)
1	Magnetite + Alum - Polyelectrolyte	large	4
2	Alum + Polyelectrolyte + Magnetite	medium-fine	5
3	Polyelectrolyte - Alum + Magnetite	stringy	18
4	Alum + Polyelectrolyte - Magnetite	very fine	4
5	Polyelectrolyte + Magnetite - Alum	stringy	15
6	Alum - Polyelectrolyte + Magnetite	large	4

In test #1, magnetite and alum were added together and mixed for two minutes before polyelectrolyte was added. After 30 seconds more, the mixing rate was turned down to 60 RPM. In test #2, all chemicals were added simultaneously, while test #3 was the inverse of test #1. Similarly, in tests #4 and #5, polyelectrolyte was added simultaneously with alum and magnetite, respectively, and mixed for two minutes before the addition of the remaining chemical. Finally, in test #6, alum was added first followed two minutes later by polyelectrolyte and magnetite.

These results confirm what has been known intuitively and demonstrated scientifically, and what experience has indicated in the past: Firstly, when polyelectrolyte is added before the alum, flocs are stringy, weak and incompletely formed (tests #3 and #5). Secondly, alum must be added to the waste water sufficiently in advance to permit the coagulation process to be completed (destabilization) before polyelectrolyte bridging is initiated. In tests #1 and #6, this optimum sequence was present, while in tests #2 and #4, the flocs were finer and took longer to settle as polyelectrolyte and alum were added simultaneously.

The theories of coagulation and flocculation are complex and do not fully explain what may happen in any specific instance or with a particular type of water. Basically, coagulation is a process in which particles suspended in water are destabilized, enabling their transport to one another where they may attach if the right conditions exist. The term "flocculation" is usually used to describe the transport and eventual bridging of destabilized particles by a polymer.

Destabilization can occur in waste water by adsorption of a coagulent species or, more rarely, by enmeshment within hydroxide or carbonate precipitants. In the case of adsorption, as in seeded water treatment, polymers are the chief agents involved in the adsorption process. They may be present naturally in the waste water (i.e., biopolymers), they may be added to the water (i.e., synthetic polyelectrolytes), or they may be generated within the process from salts added to the waste water (i.e., alum). A combination of the latter two conditions plays a major role in the chemical addition technique used with the magnetic separation system.

The addition of alum ($Al_2(SO_4)_3 \times 18\ H_2O$) to water results in hydration of the complex and the creation of acidic aquocomplexes such as $Al(H_2O)_6^{3+}$, chemically known as ligands. This can then be further hydrated to hydroxo-metal polymers depending on how close their concentration in the water is to its solubility limit. (This limit is a function of pH.) These polymers are then responsible for precipitation of colloidal particles in waste water in the form of metal hydroxides. The necessary alum concentration is dependent on the amount of colloid present in the waste water (stoichiometric dependence).

Two mechanisms have been proposed for destabilization using alum. When the pH of the water is below the isoelectric point (the pH at which positively and negatively charged particles are equal) for alum ($\sim$ pH 6), positively charged polymers are absorbed by charge neutralization with the dominant ·

negatively charged colloids found in waste waters. Above the isoelectric point, as is normal with seeded water treatment, anionic polymers are thought to function by adsorption and interparticle bridge formation. Characteristic of alum destabilization is its dependency on colloid concentration. When this concentration is low, even though alum dosage is less, detention time for complete destabilization increases significantly. The reverse is true for high colloid concentration. Detention times required are low but necessary alum doses are increased. In seeded water treatment, the addition of magnetic seed tends to act as a coagulant aid, especially in low solids situations, thus increasing the reaction rate and decreasing the necessary detention time.

Besides pH and colloid concentration, alkalinity of waste water is also of importance in water treatment because, when present, it acts as a buffer preventing pH change with alum dosing (alum is an acid). Depending on the colloid concentration present, the relative degree of alkalinity may be an advantage or a hindrance to destabilization. In general, when a high solids loading is present, high alkalinity is a disadvantage to alum destabilization as it holds the pH near neutral (for sewage and CSO) where hydroxometal polymers are not so highly charged and therefore higher alum doses are needed. When low colloid concentrations are present the situation is reversed, as high alkalinity is advantageous for destabilization of low colloid suspensions. In this case, the alkalinity holds the pH at a near neutral point where high alum doses result in the enmeshment of particles in an aluminum hydroxide precipitate known as a "sweep floc." When both alkalinity and colloid concentration are low, pH depression due to the alum can inhibit this phenomenon. In this case, either additional colloid (to speed reaction rate) or alkalinity (to allow sweep floc formation) must be added. In CSO and sewage treatment, conditions intermediate to those described above are the most common and (especially with CSO) the water may move from one extreme to the other in a short time.

The above discussion considers alum destabilization only, and does not take into consideration the modification of final water chemistry with synthetic polyelectrolytes. Soluble phosphorus concentration in the waste water is a further consideration in alum dosing as alum reacts preferentially with this substance, limiting the amount of metal available for solids destabilization. This is not a minor consideration, as domestic sewage generally requires about 60 mg/ℓ just to precipitate out the phosphorus present.

Depending on the charge on the ionizable group of a polyelectrolyte, it can be classified as being anionic (negatively charged), nonionic (no ionizable group present) or cationic (positively charged). This quality, along with others such as its molecular weight and the degree of branching, affect the polyelectrolyte's qualities and usefulness in any particular application. Water characteristics affecting polyelectrolyte performance include pH, (the net charge changes with pH) and the concentration of divalent cations in solution. Polyelectrolytes are generally thought to act as bridges, binding together destabilized particles or groups of particles (e.g., alum flocs) with their long chain structure. When used alone they may, by their own nature, result in destabilization, but in seeded water treatment they are much more effective after alum destabilization has already occurred as they facilitate generation of large, uniform and strongly bound agglomerations amenable to separation. Precautions must be taken when using certain polyelectrolytes

as some will tend to restabilize (as, for example, with a high dosage of cationic polyelectrolytes on a system lacking divalent cations), while some are of limited use when their molecular weight is less than 1 million (i.e., low molecular weight anionic polyelectrolytes may be unable to overcome the potential energy barrier between negatively charged particles), and most polyelectrolyte flocs will tend to rupture if mixed too strenuously.

The collision and final attachment of colloidal particles (particle transport or flocculation) is successful only after destabilization has occurred. The destabilization stage takes only up to a few seconds to be completed, provided conditions are favorable. While vigorous agitation promotes uniform coagulent dosage, water pH, and alum adsorption, the resulting break up of colloidal particles in the sewage or other waste tends to increase the surface area exposed, thus demanding higher alum concentrations. Likewise, synthetic polymers rupture easily and have a slower rate of adsorption due to their large size, making moderate mixing and longer retention times more effective in the system. It should be noted that stirring will only increase the aggregation rate of particles greater then 1 μ size* with the exception of viruses which in magnetic separation have been shown to actively seek and adsorb to the magnetite seed surfaces, ensuring their efficient removal.

Flocculant Evaluation

In previous studies on the use of high gradient magnetic separation seeded water technique for treating CSO and raw sewage, and for most of the present study, flocculant type has not been considered as a possible system variable. Alum is a well proven coagulant and although ferric chloride, ferric sulfate, ferrous chloride, ferrous sulfate, and lime are also used in similar applications, preliminary subjective jar tests have shown alum likely to be the most universally applicable and cost-effective coagulant for seeded water treatment of CSO and raw sewage. Further jar test-type studies are needed for every different waste stream, along with consideration of chemical availability and cost. This applies even more strongly to the optimal polyelectrolyte chosen for a particular seeded water treatment application.

A jar test comparison of synthetic polyelectrolytes was attempted on a single batch of raw sewage at the close of the present study in order to try to determine what (if any) polyelectrolyte type might prove most effective in this instance (normally high, varying conductivity due to salt water inundation). Nine different Hercules polyelectrolytes were compared along with the Betz 1160 used for most testing reported herein. The polyelectrolytes tested, their ionic natures, and the summarized results (subjective floc descriptions and turbidity measurements of the supernatants) are given in Table VI-5. In these jar tests, the conductivity of the sewage was 6000 μmhos/cm. All 1 liter samples were treated with 100 mg/ℓ alum, ∿.25 g/ℓ magnetite, and after two minutes of mixing at 120 RPM, 1 mg/ℓ of polyelectrolyte. After 30 seconds, the mixing rate was reduced to 60 RPM for the remaining 1 1/2 minutes before the settling period of 5 minutes.

* For particles smaller than 1 μ, Brownian motion is the dominant force.

TABLE VI-5 POLYELECTROLYTE COMPARISON

Test #	Polyelectrolyte Flocculant	Ionic Character	Floc Size	Turbidity (FTU)
1	Betz 1160	Cationic	Medium	4
2	Hercofloc 849	Med. High Cationic	Medium	4
3	Hercofloc 855	Med. High Cationic	Medium-fine	3
4	Hercofloc 874	Med. Cationic	Extremely fine	4
5	Hercofloc 815	Med. Cationic	Extremely fine	3
6	Hercofloc 812	Low Cationic	Extremely fine	3
7	Hercofloc 827	Nonionic	Very fine	3
8	Hercofloc 818	Low Anionic	Huge	4
9	Hercofloc 831	Med. Anionic	Very large	2
10	Hercofloc 821	High Anionic	Medium-fine	5

It was immediately apparent from these jar tests that the majority of the flocculants tried were not suitable (at least at the concentration tried) for seeded water treatment. Most formed only tiny flocs late in the mixing process and settled very slowly. Experience has shown that for optimal high gradient magnetic filtration of coagulated suspended solids, flocs should be on the order of from 1 to 4 millimeters in size and of compact, uniform shape. This large size tends to lower magnetite demand by increasing the probability that some seed is incorporated into every floc agglomeration. When the flocs get any larger than this, their tendency to rupture in the flocculator as well as in the matrix makes them less easily handled. Also, extremely large flocs (such as were experienced with Herfloc 818) tend to drop out of suspension so rapidly that not all turbidity is removed from the water with the bulk of the solids and magnetic seed, making the small amount of remaining solids less likely to contact a seed particle. Because of the mixing rate limit imposed by the large-sized flocs, the short contact time caused by the rapid settling of most of the water volume cannot be extended.

In the tests described above, Betz 1160 and Hercofloc 849 seemed to work very similarly while Hercofloc 831 was shown to be superior to any tried on this effluent sample in rapidly removing the most turbidity. Turbidity differences measured after 5-10 minutes of settling did not clearly differentiate between the various polyelectrolytes' effectiveness, as all were able to settle by the end of this time interval. However, the rate of floc formation and the size and shape of these flocs were clearly distinguishable and gave the experimenter a good indication of how effective they might be. A bench test magnet set-up might be more appropriate for obtaining a "supernatant"

for turbidity measurement as this technique would take into account the seed-to-solid distribution in the flocs and the resistance to shear imposed by flow past the matrix fibers, as well as relative clarification of the waste water by the flocculant. Low color is also of importance in treated water but may not necessarily coincide with best turbidity removal by a flocculant. Also, before any one polyelectrolyte is completely discounted for a particular waste water it should be tested over a wide range of concentrations (preferably at least four orders of magnitude), since overdosing often can cause restabilization of the colloidal particles. It is important to emphasize the necessity of flocculant evaluation before other test work is attempted so that the best possible magnetic separation conditions can be achieved. Unfortunately, this was not done at the start of the present study, and apparently less-suitable polyelectrolytes (Betz 1150 and 1160) were used throughout. Although the preparation of a large number of stock solutions of different polymers is somewhat time consuming, the jar tests are easily run and the results may save many hours of work later on in a test program. An extensive evaluation is, of course, necessary for any location considering a permanent installation. Other tests, such as zeta potential, may further help to determine (or maintain) optimal flocculants and concentrations for the waste water stream.

Effects of Residence Time

As mentioned earlier, the detention time needed to achieve complete destabilization is dependent on a number of factors including waste water colloid concentration and alkalinity. Further, the total turnover time necessary for magnetic separation can be expected to be somewhat less than that for chemical clarification, as the final separation is accomplished magnetically rather than by a passive settling of the flocculated particles. Contact detention times for coagulent/flocculent/seed additives to the waste water are, however, very similar to those encountered in chemical clarification flocculating chambers. The use of a rapid mix unit to disperse chemicals followed by a somewhat larger flocculator to provide contact time sufficient to produce aggregates of suitable size for removal is common to both processes, although the desired result may be slightly different. While clarification demands the largest and fastest settling floc, magnetic separation techniques strive to obtain a floc of medium size with good shear resistance and magnetite distribution.

Some simple jar tests were performed to try to determine the minimum residence time necessary for good floc formation in the raw sewage used. The procedure used was as follows. Magnetite ($\sim$ .25 g) was first added to the 1 liter samples while mixing with a paddle stirrer at 100 RPM. Alum (100 mg/ℓ) was then added and the timing begun. After a predetermined mixing time (shown below) Betz 1160 (1 mg/ℓ) was mixed in before turning the stirrer down to 60 RPM for the remaining time interval. These test conditions are given in Table VI-6, following.

TABLE VI-6 RESIDENCE TIME

Test #	Total Residence Mixing Time	Flash Mix (Alum) Mixing Time (100 RPM)	Flocculator (Polyelectrolyte) Mixing Time (60 RPM)
1	15 sec	15 sec	-0-
2	30 sec	30 sec	-0-
3	1 min	30 sec	30 sec
4	2 min	1 min	1 min
5	4 min	2 min	2 min
6	8 min	4 min	4 min
7	12½ min	6½ min	6 min
8	20 min	11 min	9 min

For the first two tests shown, alum and polyelectrolyte were added simultaneously and the mixing rate was left at 100 RPM for the entire span. In all others, polyelectrolyte was added approximately 15 seconds prior to turning down the stirrer to 60 RPM.

Turbidity was taken on the supernatant after a settling period of about 10 minutes, and Figure VI-3 shows the resulting curve. These results seem to indicate that for this raw sewage a minimum mixing detention time on the order of from 3 to 5 minutes is necessary to facilitate the destabilization and transport of a majority of the colloidal particles. After this initial contact period, water quality improved only gradually with mixing time, and it can be assumed that in most cases the additional capacities required for such minor possible benefits would not be deemed desirable.

Observations of the on-going flocculation give some further insight into the significance, as well as the limitations, of this test. For tests #1 and #2, no flocs were apparent. In tests #3, #4 and #5, respectively, the flocs observed were progressively larger, reaching optimal size (and the largest in this experiment) when the mixing was done over a period of 4 minutes. This represents a 2 minute flash mix period for alum destabilization, and 2 minutes for polymer bridging and final agglomeration to take place. In tests #6, #7 and #8, the flocs became progressively finer so that in #8 they were barely visible. This is because shear forces at the higher mixing rate immediately ruptured the largest flocs formed after alum destabilization (i.e., after 2 minutes of mixing) and these floc fragments were then restabilized by the secondary adsorption of the polymer to particle surfaces resulting in smaller agglomerations. In other words, the longer the shearing, the smaller the average floc is likely to be. However, turbidity obtained after settling continues to improve even with increased shearing because particle contact time also increases, and the the shear created in this case is not violent enough to cause break-up and restabilization of individual colloid particles, which by

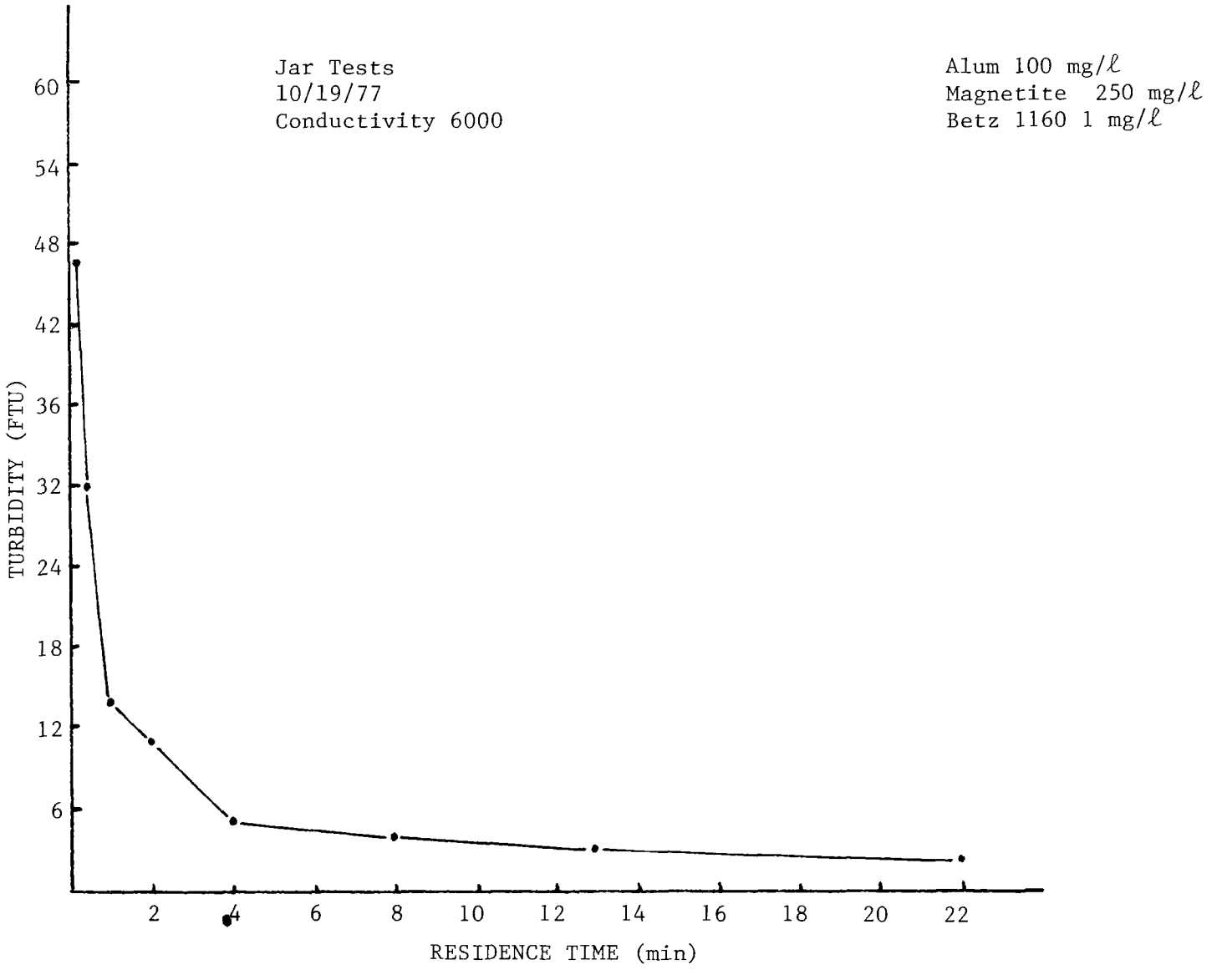

FIGURE VI-3 EFFECT OF RESIDENCE TIME ON TURBIDITY

definition are too small to settle out. It is expected, however, that these smaller flocs would be less effectively removed by magnetic separation than the larger agglomerations. In the trailer-mounted pilot plant, as it now exists, the residence time possible in the flash mix chamber at full-flow capacity for the system is about 1 minute, and about 5 1/2 minutes for the flocculator system. These times correspond well with the test results just outlined although alum contact time may be borderline for some effluents. More complex calculations can be made for sizing-up to larger scale and are available in the literature.*

Effects of pH on Clarification

Jar tests were conducted on a sample of raw sewage at Columbia Park to compare the effects of pH on the seeded water treatment of a waste water with a high salt content to that determined on CSO in earlier studies. The conductivity of the sewage at the time of these tests was 16,300 μmhos/cm, near to levels generally reached at high tide.

For these tests, 1 liter samples were taken and their pH altered to a known (measured) value. Although alkalinity measurements were not available, it is likely that substantial amounts existed as some buffering effects were evident. Figure VI-4 shows the turbidity of the supernatant after a standard jar test procedure for the pH-adjusted sewage samples. It can be seen that, as in previous tests, the optimal clarification with an alum/magnetite/polyelectrolyte flocculation technique was at natural pH (6.74), with flocculation dropping off rapidly below pH 6 and only gradually deteriorating with waters of a more basic pH. At natural pH, flocs were large and distinct and they settled very rapidly compared to the tests where the pH was above 7, showing finer and slower settling agglomerates as pH increased. Tests with a pH below 6.5 were progressively more and more cloudy.

MATRIX LOADING TESTS

A matrix loading-type test proved valuable in helping to delineate physical phenomena occurring within the seeded water treatment process stream. Such tests are done by sampling a single cycle at regular intervals to observe the relative rapidity with which magnetic separation efficiency drops off

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*Camp, T. R. and P. C. Stein. Velocity Gradients and Internal Work in Fluid Motion. J. Boston Soc. Civ. Eng., 30: 219-237, 1943.

Camp, T. R. Flocculation and Flocculation Basins. Trans. Amer. Soc. of Civ. Eng., 120: 1-16, 1955.

Hudson, H. E., Jr. Physical Aspects of Coagulation. J. Amer. Water Works Assoc., 57: 885-892, 1965.

Hudson, H. E., Jr. and J. P. Wolfner. Design of Mixing and Flocculation Basins. J. Amer. Water Works Assoc., 57: 1257-1267, 1967.

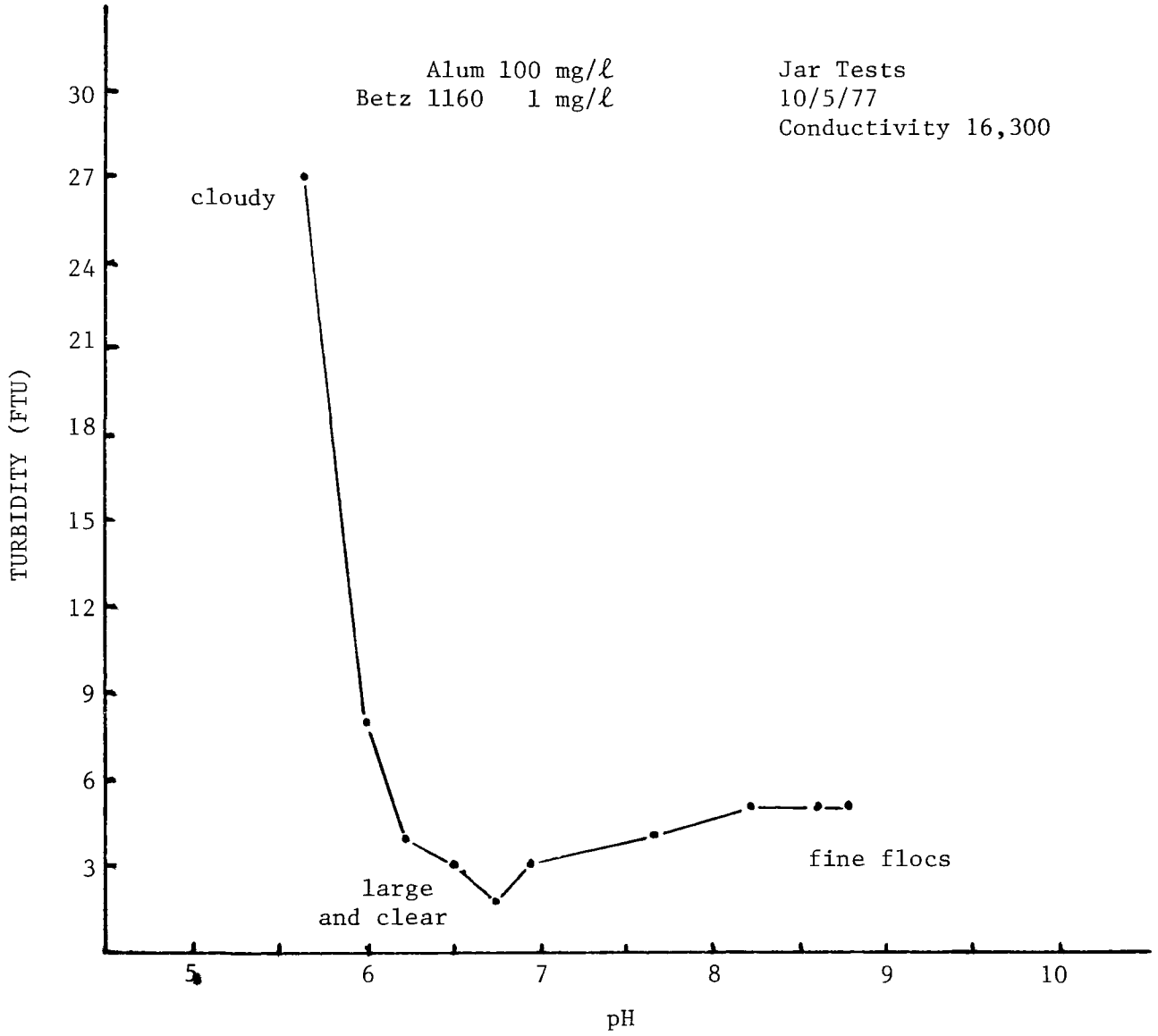


FIGURE VI-4 EFFECT OF pH ON TURBIDITY

under the given conditions. Thus, by varying such things as seed concentration, flow velocity, matrix design, or magnetic field, limits can be determined by observing achievable cycle times and breakthrough characteristics for a given set of circumstances.

Seed-to-Solids Ratio

During Effort I of this study, tests were performed on the 1 gpm continuous pilot plant in order to attempt to determine the effects of varied seed-to-solids ratios on the duty cycle, and the practical matrix loading before breakthrough. In the first test series, seed concentrations of 100 mg/ℓ, 250 mg/ℓ and 500 mg/ℓ were used on a CSO having a suspended solids concentration of approximately 100 mg/ℓ. These yielded seed-to-solids ratios of 1:1, 2.5:1 and 5:1 for runs of 20 minutes each shown in Figure VI-5 as a plot of suspended solids versus time into the cycle. This figure shows that for a low seed-to-solids ratio (i.e., 1:1), breakthrough occurred almost immediately while for runs with progressively more seed added, stable separation continued for longer periods before any deterioration in filtration efficiency was noticeable. Further, in the run with a 1:1 seed-to-solids ratio, even initial separation was not up to par with that accomplished in the runs where more seed was used, hinting that perhaps the magnetite itself was acting as a "filter aid" in those instances.

The 2.5:1 seed-to-solids run had an effective duty cycle of $\sim$15 minutes or, assuming a 5-10 seconds total for backflushing operations, a net 99% filter cycle function. No outer limit is shown for the 5:1 ratio as samples were not collected after 20 minutes of filter time in that test.

A second CSO batch was run using seed concentrations of 135 mg/ℓ, 200 mg/ℓ and 270 mg/ℓ yielding seed-to-solids ratios of 1.3:1, 1.5:1 and 2.8:1, respectively. Figures VI-6 and VI-7 show these results plotted as percent removals of suspended solids and turbidity versus time into the filter cycle. The similarities between these curves and Figure VI-5 are immediately evident. Once again, the run in which the seed-to-solids was lowest (1.3:1 in this case) showed a deterioration in filtration efficiency relatively early in the cycle, while those runs which had higher magnetite loadings maintained excellent results for progressively longer times. Thus, it has been clearly demonstrated that relative magnetite concentration is a critical limiting factor in determining effective duty cycle. In addition, especially where feed solids are low, magnetite may actually aid in flocculation by increasing the frequency of collision of destabilized particles.

At first glance it may seem somewhat contradictory that cycle length is increased with increased total matrix load (high seed-to-solids ratios), but this is a logical result of the magnetic forces involved at the site of capture. If the materials being separated were 100% highly magnetic in nature, essentially the entire canister volume surrounding the matrix material would be available for their retention. This is because when the particles being trapped on the surface of the magnetized matrix are themselves highly magnetic throughout, the net gradient present on the new surface formed by their attachment decreases only gradually with increased layer thickness (and buildup can occur effectively). In this case, each new layer of magnetic material

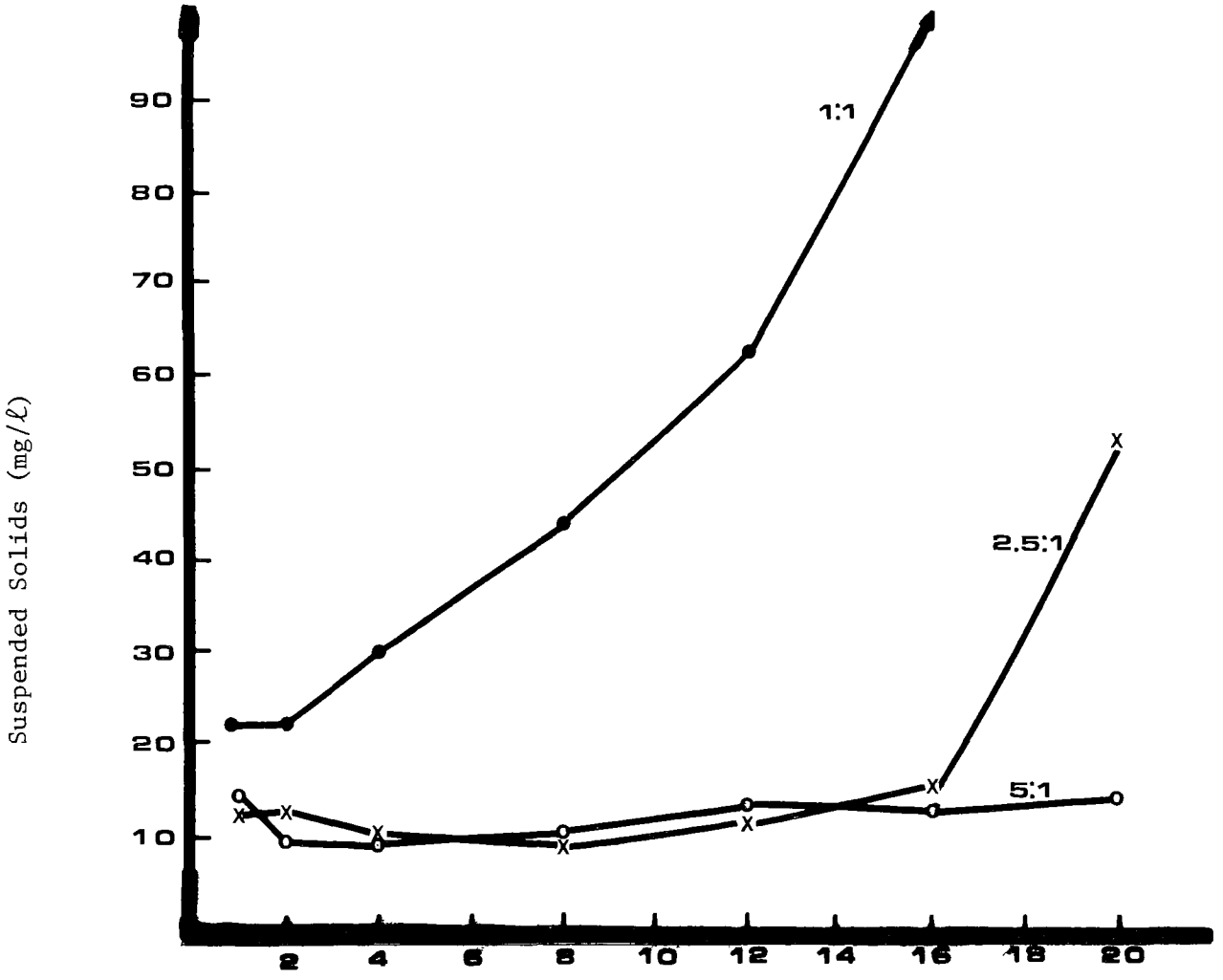


FIGURE VI-5 SUSPENDED SOLIDS VERSUS TIME INTO CYCLE FOR VARIOUS SEED-TO-SOLIDS RATIOS

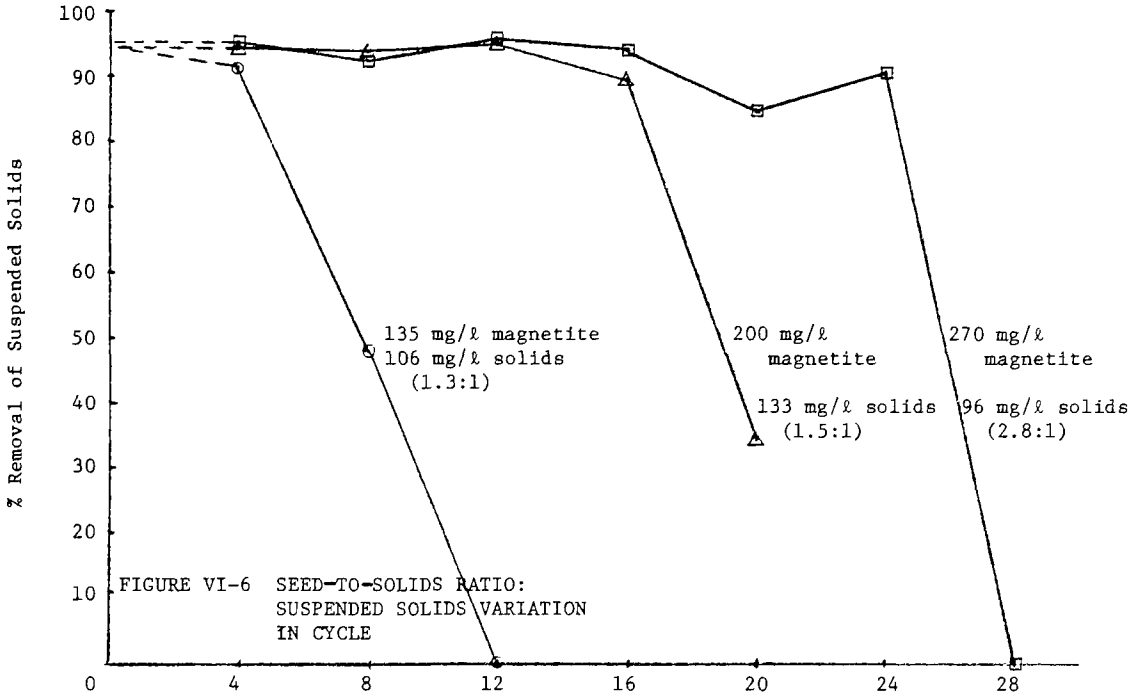


FIGURE VI-6 SEED-TO-SOLIDS RATIO: SUSPENDED SOLIDS VARIATION IN CYCLE

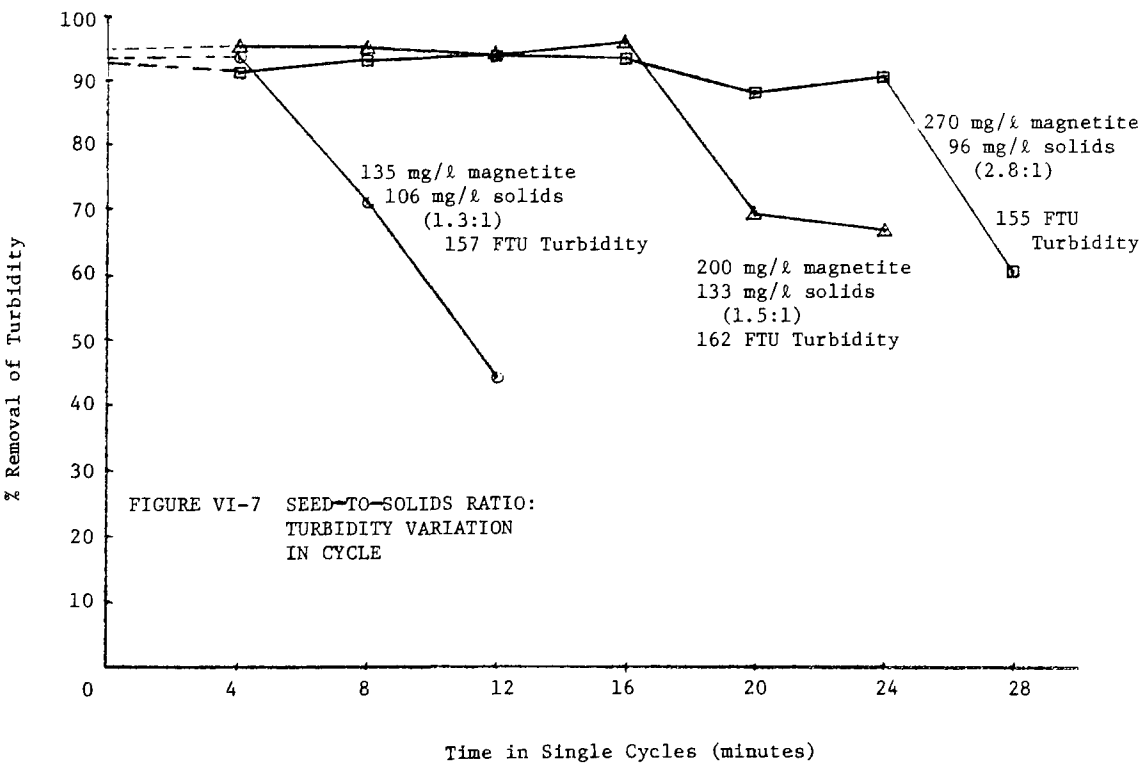


FIGURE VI-7 SEED-TO-SOLIDS RATIO: TURBIDITY VARIATION IN CYCLE

concentrates the magnetic flux nearly as efficiently as the matrix fibers in a clean matrix, being limited only by shearing forces caused by flow or irregularities in the layers themselves.

However, in seeded water treatment, nonmagnetic solids make up a large proportion of the total volume to be held within the matrix. Here the floc as a unit, although containing some magnetite, is considerably less magnetically susceptible and therefore is not only held in the matrix with much less force but also fails to maintain the strong gradients present on the matrix fiber surfaces. Thus, the canister can no longer fill to volumetric capacity but is limited by the relative proportion of magnetite in the flocs as to the layer thickness it can successfully hold before shear forces exceed magnetic forces. Flow velocity, magnetic field, and floc shear resistance also can enter into the picture as this limit is approached, suggesting a need for multiple compensation schemes to increase duty cycle and magnet efficiency.

Matrix Design

Matrix loading tests also were used to attempt to compare two slightly different matrix designs. The two matrices used differed only in the relative proportion of .045 inch and .156 inch spacers between their randomly cut, aligned standard metal disks. In matrix #1, 4½ inches of the length was packed with .156 inch spacers and the remaining 3 inches with .045 inch spacers while in matrix #2 the situation was reversed, with 3 inches of .156 inch spacers followed by 4½ inches of .045 inch spacers.

Figures VI-8 and VI-9 show plots of pilot plant effluent suspended solids versus actual time into the filter cycles and versus matrix loading (calculated weight of sludge accumulated in the matrix) for tests run on the two matrices. The dashed lines in Figure VI-8 show solids levels in the treated stream after a single flush. Figure VI-8 also shows incoming feed suspended solids on samples taken during these runs, and in fact documents the first flush phenomenon that occurred during this storm run. Matrix #2 was run first, and the feed suspended solids started out at $\sim$ 90 mg/ℓ, a normal dry weather flow. But, close to 20 minutes into that test run cycle, the effects of the earlier drizzle and the following rain began to be felt as the suspended solids in the feed rose to $\sim$ 200 mg/ℓ by the end of the run. After changing matrices ($\sim$1 hour), the feed solids seemed to have leveled off at $\sim$ 200 mg/ℓ, and the second matrix loading test was begun. As in the earlier run, the incoming feed suspended solids reacted to increased CSO flow right in the middle of the run, this time jumping to over 550 mg/ℓ as the main rain water flow cleaned the streets and sewers. Conductivity changes due to tidal influences were also present (varying between 8000 and 16,500 μmhos/cm), although somewhat buffered by the rain volume.

Because of the varying input of the feed during these runs, and perhaps because the two matrices tested were so similar in construction, the plots shown in Figures VI-8 and VI-9 do not show any significant differences attributable to matrix design. The fact that matrix #2 lasted longer before breakthrough (Figure VI-8) than did matrix #1 is due simply to the difference in rate of accumulation reflected by the storm water loading. Figure VI-9 shows this, as no significantly different trends in matrix loading are evident.

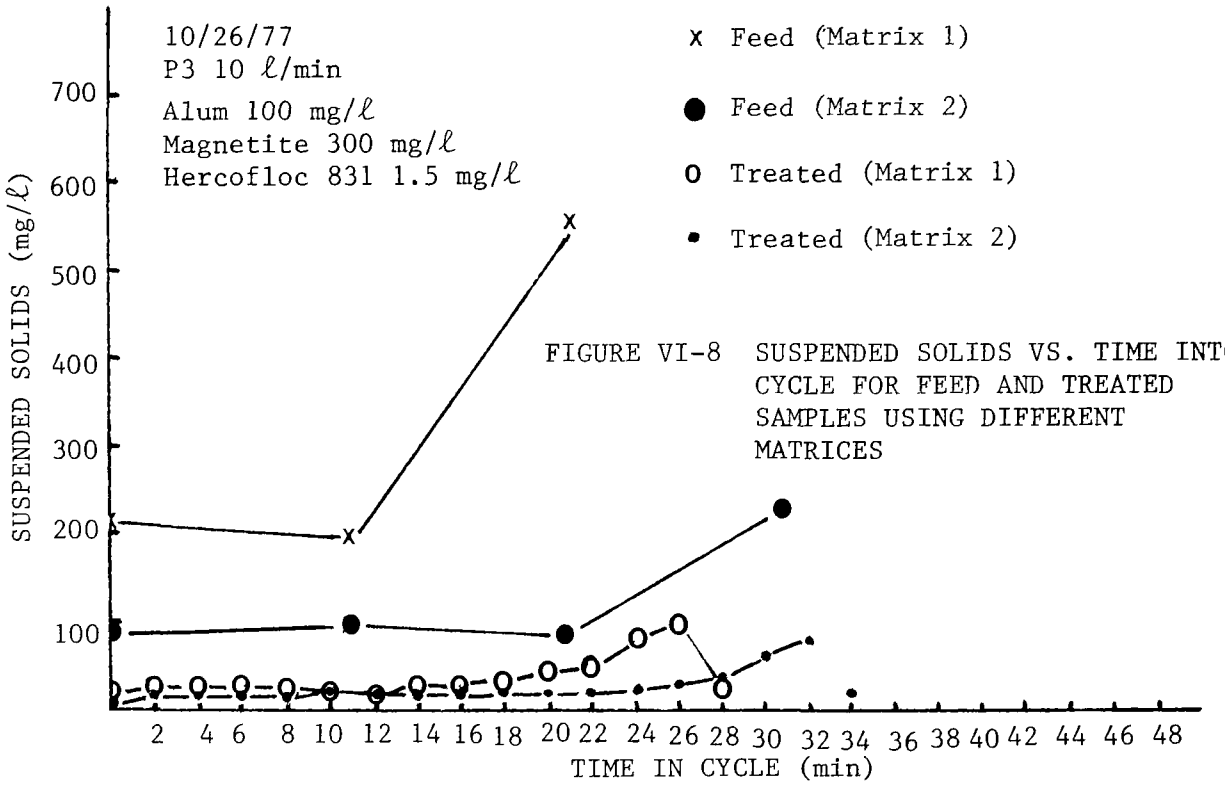


FIGURE VI-8 SUSPENDED SOLIDS VS. TIME INTO CYCLE FOR FEED AND TREATED SAMPLES USING DIFFERENT MATRICES

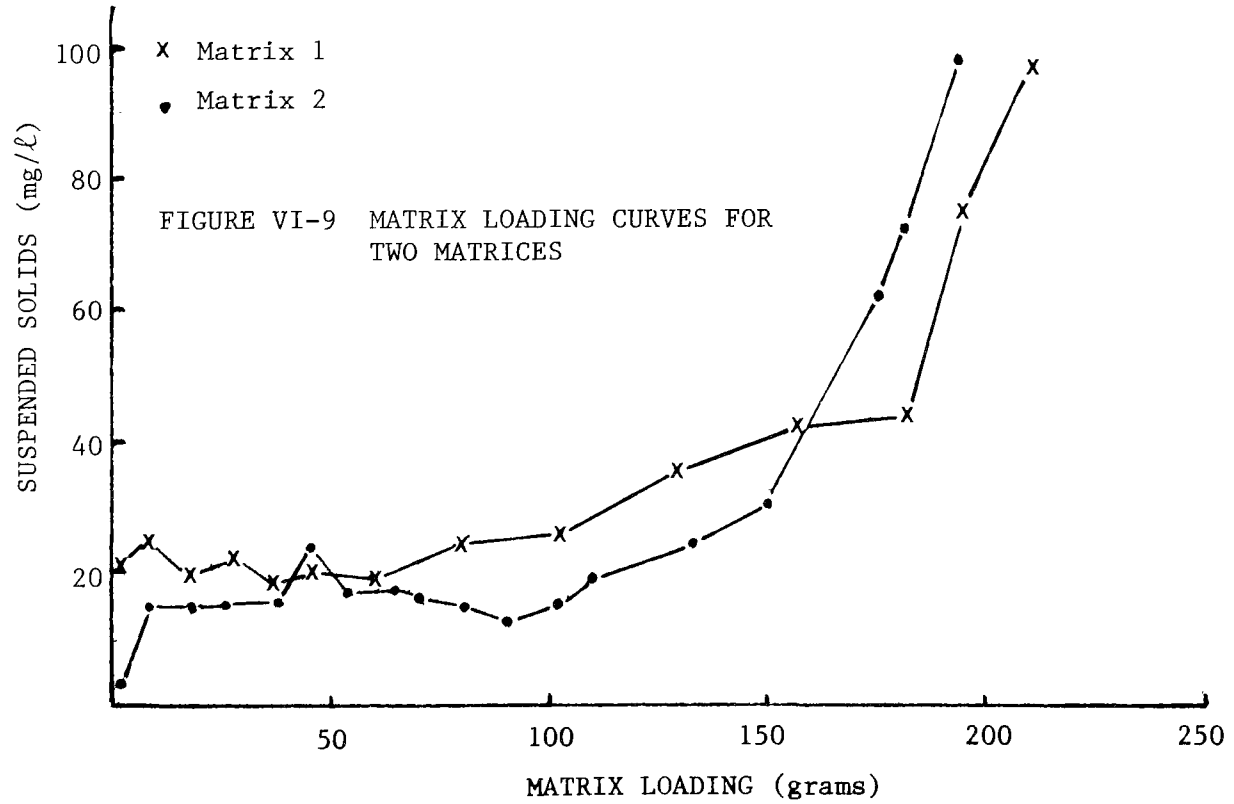


FIGURE VI-9 MATRIX LOADING CURVES FOR TWO MATRICES

LIMITS OF FLOW VELOCITY ON MAGNETIC FILTRATION

Figures VI-10 and VI-11 show results obtained on the 1 gpm pilot plant at Sala Magnetics, Inc. in tests meant to determine the practical flow flux rate limits on a particular batch of CSO from the Cottage Farm facility. The solids loading of this storm water was ∿ 130 mg/ℓ and a magnetite concentration of 200 mg/ℓ was used (a seed-to-solids ratio of 1.5:1). Samples were taken at 2 and 4 minutes into the filter cycle for each flow rate tested in order to indicate the relative rapidity of loading effects likely to occur.

The tests were done using four specially prepared canister/matrix assemblies with identical matrix construction and length but with varied diameters. These were interchanged during a single pilot plant run in which the system was kept under a strictly controlled equilibrium. Since the process rate was kept constant, the flow flux rate through each of the canisters was proportional to its volume (which of course depends on the diameter). This gave flow flux rates at the process flow chosen of 86, 124, 194, and 343 gpm/ft^2 of matrix fiber. In this way not only were all recalibrations of feed, filter and metering pumps avoided, but other system parameters such as total mixing and residence time, and shear factors introduced by the plumbing were kept completely constant.

Figures VI-10 and VI-11 show clearly that as flow rate is increased filtration efficiency is decreased (slope of curves) and effective cycle time is shortened (divergence of curves). These results are predicted and explained in the earlier discussion concerning matrix loading of (nonmagnetic) flocs containing magnetite, and their effect of decreasing the magnetic gradient with increased layer thickness (build-up) around a matrix fiber. When a flow rate is reached in which the shear forces at the capture surface exceed the magnetic holding force for most flocs, they will simply be dragged through. The faster the flow rate, the more rapidly this point will be reached and the earlier in the cycle breakthrough will be evident.

For practical design considerations, a 100-120 gpm/ft^2 limit generally has been used for seeded water treatment systems. Although lower flow rates do result in some increased efficiency under most conditions, these improvements generally are not large enough to justify the extra capital expenditures necessary for such systems. Thus, depending upon the discharge water quality requirements, frequency of peak flow, character of the feed, and economics of the individual situation, the best flow rate can be chosen.

SLUDGE EVALUATION

In the past, SALA's efforts under the present contract have concentrated on the evaluation of treatment effectiveness and process applicability to the purification of storm water using the seeded water process. Prior to undertaking this contract, in-house proprietary studies were conducted by SALA on the subjects of seed and chemical recovery and regeneration. Because of the small scale of the pilot plant existing at that time, sludge generation was inadequate for evaluation of the flow sheets devised.

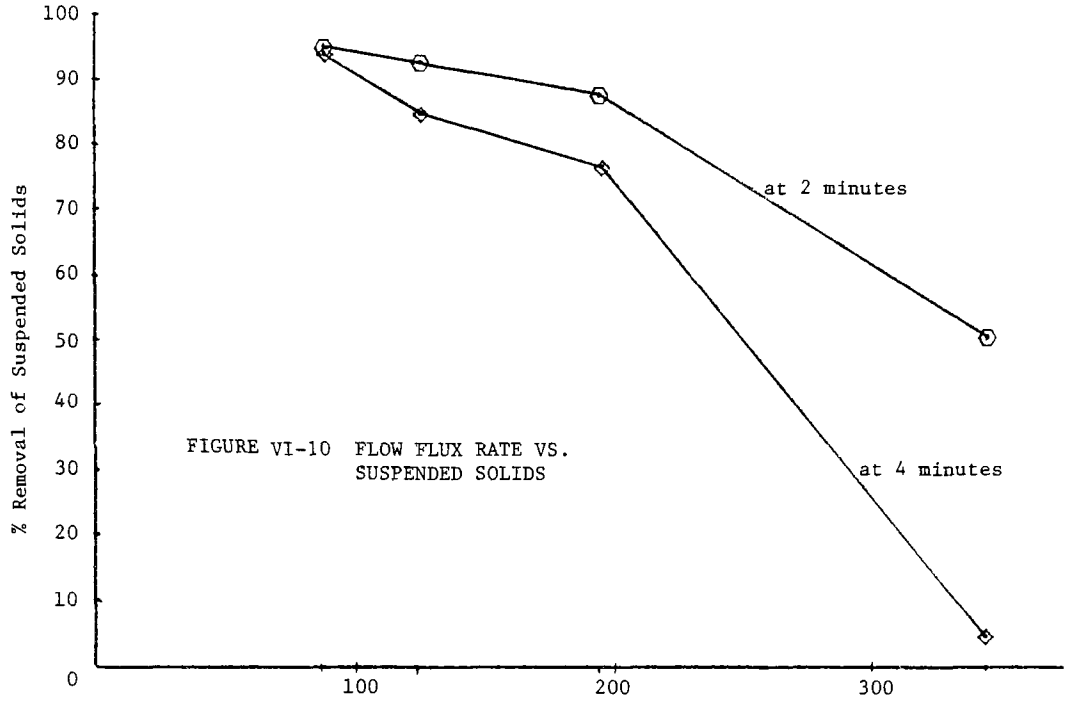


FIGURE VI-10 FLOW FLUX RATE VS. SUSPENDED SOLIDS

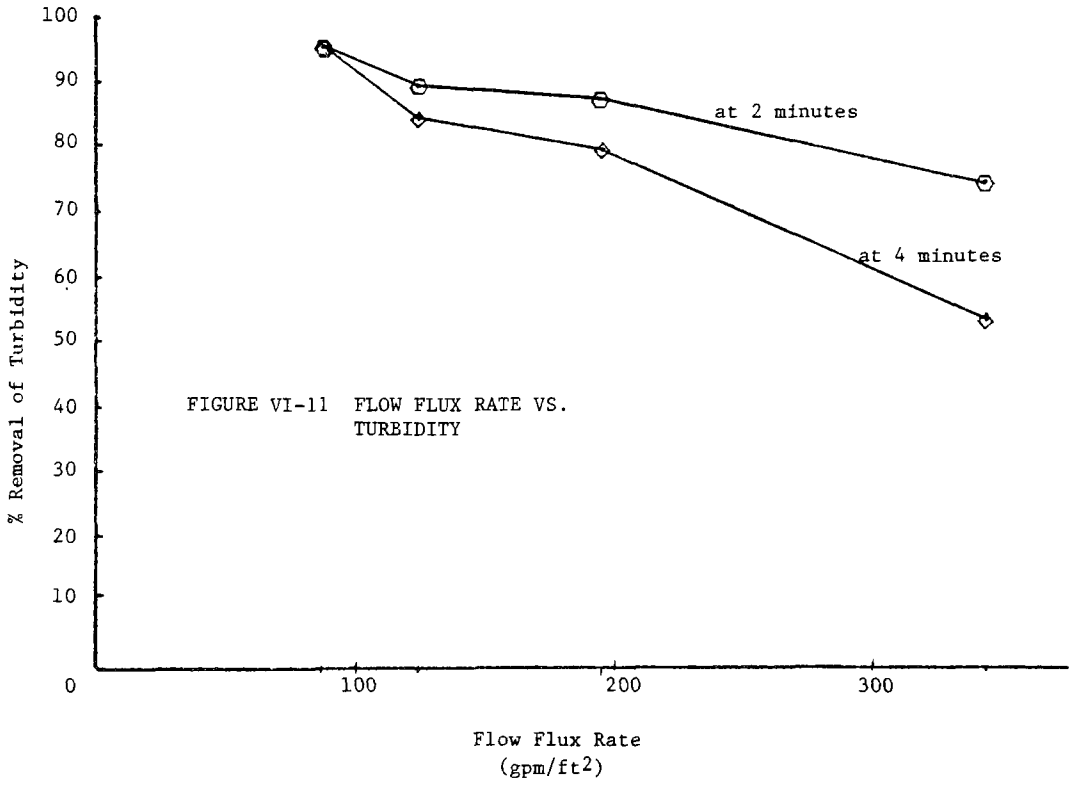


FIGURE VI-11 FLOW FLUX RATE VS. TURBIDITY

A detailed investigation of sludge handling and seed recycle options is beyond the scope of the present study, but should be included in the next scale-up of the system where proper equipment and significant sludge volumes can accurately simulate relevant conditions. Deferment of this work was indicated as neither the required flushing design nor a proper seed-to-solids ratio had been established at the outset for CSO. These factors are most important for determining the character of the sludge to be processed. The data presented below and in other sections of this report constitute a first step towards a determination of the best method for sludge disposal with a concommitant recovery of its economically valuable components.

Nevertheless, a number of measurements were taken during this study on backflush waters and sludges generated during runs on CSO and raw sewage. Backflush solids concentration depends on a number of factors related to the backflush procedure used (flush volume and effectiveness), the concentration of solids, and flow velocity. In other words, only that amount of solids trapped in the matrix during a filter cycle can be concentrated in the flush water, and the water used for backflush, in turn, depends on a number of parameters such as backflush time and velocity, relative amount of air, etc.

Tables VI-7A and 7B display data that was collected over several different test runs showing flush water solids concentrations (in g/ℓ) tabulated against the corresponding flush parameters used to obtain them. Also shown are the seed-to-solids ratios used and the actual number of grams of sludge and liters of backflush water collected for each flush recorded. These figures are given in brackets below each flush water solids concentration datum in the tables.

Several relatively obvious things can be noted upon examination of this collection of data. Although no attempt was made to maintain uniform running conditions while generating these figures, basic correlations are still quite evident when moving across a row or down a column, especially in Table VI-7B. For a constant backflush tank starting pressure, backflush solids concentration increases with decreasing flush time as a result of the decreased diluting volume. The only exception to this is for the 1 second flush at 15 psi. This is explained by the fact that in the present system the plumbing between the magnet and the collection site is always pre-primed with clean water from the end of the previous flush; for such a short, low-pressure backflush surge the solids from the matrix never reach the surge tank where they can be measured. Naturally, when only the initial solids "slug" at the front end of the flush is sampled, solids concentration is even higher than the highest shown in the table (14 g/ℓ), but backflush effectiveness in maintaining a clean matrix may suffer with such abbreviated flushes, thus making them impractical.

In addition, it can be seen that solids concentrations generally increase as one moves across a row from left to right (decreasing backflush tank starting pressure) for a given flush time. This is once again due to the decreasing diluting volume generated for the backflush by this lowered charge pressure, and thus the same exceptional circumstance is evident for the row of 1 second flushes as with the vertical column mentioned previously. Other minor inconsistencies are due to the variety of uncontrolled conditions present.

A sample of the thickener underflow sludge also was taken, and the solids concentration was determined to be approximately 28% (280 g/ℓ). This high value is, of course, mainly a result of the large proportion of magnetite incorporated. A seed-to-solids ratio of 3:1 was used in this case, giving an expected sludge solids concentration of ∿7%. The density of this sludge in wet form (supernatant water decanted) was found to be 1.13 g/cc, and after drying at 200°C it increased to 1.73 g/cc. Incineration at 500°C of a sludge generated at a seed-to-solids ratio of 1.5:1 reduced the mass significantly (on the order of 30% of the dry solids volatilized). However, neither of the dried sludge samples tested was found to be able to sustain a flame on its own (autogenous incineration not detected).

As mentioned earlier, no detailed flowsheet for seed recovery and/or sludge treatment and disposal has yet been defined. Until more information is known about the character of magnetite sludge it is of little value to propose flow sheets or work out material balances for such possible systems. Measurements of this sludge's caloric value, its bacterial and viral content (especially associated with the magnetite surfaces), its specific resistence to filtration, its settling rate and particle size distribution, its compressability, its degree of hydration, and other parameters critical to its handling and dewatering characteristics are necessary in order to be able to properly formulate an experimental framework leading to the identification of the most compatible process options. It seems likely that in order for seeded water treatment to play any major role in the future, recycling of the magnetite must be accomplished within the process, and done so economically. The seed recycle step itself is in its infancy, and the process must be fully refined before sludge treatment methods are even worth considering.

STATIC MIXER VERSUS FLASH MIXER

Several attempts were made to try to establish the applicability of a static mixer to the seeded water treatment system as a replacement for the mechanical flash mixer now used for chemical dispersion. Because of the changing salinity and other dynamic water parameters encountered at Columbia Park, this test, like most of the others, proved difficult. Further, because of the time intervals necessary to make the changeover complete, poor results were difficult to distinguish from changed water character necessitating chemical dosage adjustments. Also, the back pressure caused by the static mixer's resistance to flow made actual chemical addition rates difficult to determine. This combination of factors may have influenced the results negatively to some extent.

In all tests attempted where no adjustments were made in the flocculator, the static mixer produced generally poorer flocs, and on the order of 5 to 15% poorer separation was achieved as compared to the flash mixer under those running conditions. As mentioned above, although these runs were repeated on three different occasions, factors other than the type of mixer used could have had a significant influence on these data, and no final conclusion can be reached at this time.

TABLE VI-7A FLUSH WATER SOLIDS CONCENTRATIONS

TYPE OF BACKFLUSH USED

(35 psi Pressure Vessel)

Flush Time (sec)	Air-Water from Pressure Vessel	Constant Air Pressure (50 psi)	Pulsed Air-Water from Pressure Vessel	Water Only
10	.94 (2.6 14/15)			
7				
5	1.6 (2.6 15/9.4)			
3				
2.5	2.9 (2.6 11/3.8, 9/3.2)	7.8 (2.6 12/1.6)	4.9 (2.6 12/2.5)	2.3 (2.6 8.4/3.7)
1	14.0 (2.6 12/.83)			

Key: g/ℓ flush solids concentration (seed-to-solids ratio used total g/total volume in back flush)

TABLE VI-7B FLUSH WATER SOLIDS CONCENTRATIONS

BACKFLUSH TANK PRESSURE (psi)

Air-Water Flush, 50 psi Constant Air Pressure

Flush Time (sec)	35	32	30	28	25	24	20	18	15	10
10										
7	.83 (.16 15/18)				1.2 (1.1 17/14)				2.2 (2.1 23/11)	
5	1.3 (1.6 18/14)		1.6 (1.6 19/11)		1.5 (1.1 15/10)		2.3 (1.1 20/9.2)		3.2 (2.1 23/7)	3.5 (2.1 19/5.5)
3		3.5 (.88 27/7.6)		3.6 (1.7 26/7.2)		5.4 (2.2 37/6.9)	5.8 (2.4 29/4.9)	5.3 (2.5 26/4.9)		
2.5	1.9 (1.6 16/8.6)				3.1 (1.1 19/6)				5.2 (2.1 21/4)	
1	6.0 (1.6 17/2.9)				5.4 (1.1 16/2.9)				2.3 (2.1 3.1/1.3)	

Key: g/ℓ flush solids concentration (seed-to-solids ratio used total g/total volume in back flush)

When the flocculator mixing rate was increased (20-30%), the static mixer results were comparable to those achieved with the conventional system at a slower flocculator mixing rate. This seems to indicate that, by itself, the static mixer (KOMAX) unit is not dispersing the chemicals adequately. The question then becomes one of economics. This is not a new application for static mixers, and there is little doubt that they will work if designed and sized properly for the system. But there is some question at this time as to whether or not these units will actually save on power and system cost for the seeded water process. For some systems, the savings in system size and/or maintenance costs may dictate a static mixer even if the overall economics are not positive.

STORM PROFILE TESTS

Several storms were actively run on the mobile pilot plant trailer at the Cottage Farm and Columbia Park facilities in order to observe system performance over the duration of a storm event. The runs were designed to profile the storm by monitoring water flow through the MDC facility, and to use the opportunity to make appropriate changes in the process rate of the scaled-down system. In this way, studies could be made on what types of monitoring are needed, what dosage changes are necessary, and what results can be obtained throughout the duration of a storm—especially in the first flush stage. Analyses for turbidity, pH, conductivity, and total suspended solids were made on site, immediately after collection, during three storm runs. The following sections discuss the results of storm profiles made at the Columbia Park location in the fall of 1977.

Storm of 9/20/77

The first CSO storm profile run was for a gentle rain which occurred in the Boston area on September 9, 1977. At the outset of this storm, flow channel #1 in which the submersible pump was located was in the process of being de-gritted, with the result that pilot plant start-up was delayed until about 11:00 AM, just as the first storm flow was beginning to come through. High tide on that day was at 5:40 PM, occurring during the latter portion of the run, which lasted from 11:00 AM until 7:00 PM. No samples were collected between 2:30 PM and 4:00 PM due to an interruption by visitors.

Figure VI-12 and Figure VI-13 show overlaid plots for all pertinent monitored storm water parameters profiled during this pilot plant run, including actual storm water flow through the Columbia Park headworks, pilot plant flow rates used during the storm, feed water suspended solids, turbidity and conductivity, and treated water suspended solids and turbidity.

For this run, the small (1 1/2 inch diameter) magnetic separator was used with a range of process flow rates from .85 to 1.42 gpm, paralleling the observed storm flow of 78 to 180 MGD in a step-type fashion. Jar tests were done regularly (one per hour) in order to assure proper alum dosages, and visual observation of flocculation proved to be most important in detection of disequilibrium in the system. Optimal alum dosages started out at 100 mg/ℓ at 11:00 AM, but decreased steadily to 30 mg/ℓ by 2:30 PM.

By 6:00 PM, the optimal dosage was back to 60 mg/ℓ. Polyelectrolyte concentration was not varied from the 1 mg/ℓ of Betz 1160 normally used. Initially, magnetite concentration was maintained at 85 mg/ℓ, but was increased to 150 mg/ℓ after 2:00 PM as separation seemed to be suffering from seed deficiency. A significantly higher seed concentration later was shown to be the single most critical factor in controlling effluent solids concentration during the first flush situation apparent in many storms. Note that the treated water's solids and turbidity were brought back into control only after the magnetite concentration was raised in the latter part of the storm simultaneous with a lowered storm water solids loading, demonstrating that a minimum seed-to-solids ratio must be maintained at all times for proper magnetic separation.

Figure VI-12 also shows how the rain water accentuated the tidally induced salinity variation during the early part of this storm by diluting the "low-tide CSO" to a conductivity of ∿ 500 μmhos/cm, substantially below the normal low of about 2500 μmhos/cm in this system at low tide. The two to three hour time delay for the Boston sewer system is evidenced by the conductivity plot given, as low tide occurred at 11:21 AM and minimum conductivity was not reached until after 2:00 PM. The salinity effects of the high tide in the late afternoon were also affected by the storm's diluting waters, with the normal conductivity of 20,000+ μmhos/cm at peak being significantly suppressed.

The overall separation achieved during this storm was not particularly good as a result of a number of factors, including lack of magnetite and pertinent feedback regarding storm water character. In successive storm runs, experience proved valuable in the visual evaluation of CSO before and after treatment, permitting more sensitive system adjustments to be made based on changing conditions. Continuous monitoring of turbidity, alkalinity, pH, etc. may be necessary in full-scale systems for CSO in order to maintain proper flocculation.

Storm of 9/26/77

Figure VI-13 shows the monitored parameters plotted for the second storm water profile run performed with the mobile pilot plant on September 26, 1977. Rain started gradually early in the morning and then came down hard for a brief time shortly after 12:30 PM before tapering off in midafternoon. In this instance, the flow rate curve follows the entire storm from start to finish, with actual pilot plant running profiling all but the initial start-up of the storm water flow. Both magnetic separators were used covering a flow rate of from 1.9 to 6.1 gpm.

A definite first flush situation took place after the heavy rain (at about 1:30 PM) as feed solids jumped from ∿ 90 mg/ℓ to over 200 mg/ℓ in just a few minutes. Once again, the sudden solids loading was not detected in time to compensate with added magnetite sufficient to maintain efficient separation, and the effluent solids, therefore, tended to parallel feed solids due to an insufficient seed-to-solids ratio. Magnetite concentration was left at 150 mg/ℓ throughout the run, while alum was varied based on jar tests from 100 up to 140 and back to 80 mg/ℓ during the duration of the storm. Polyelectrolyte was also changed over a range of .87 to 1.5 mg/ℓ during the run.

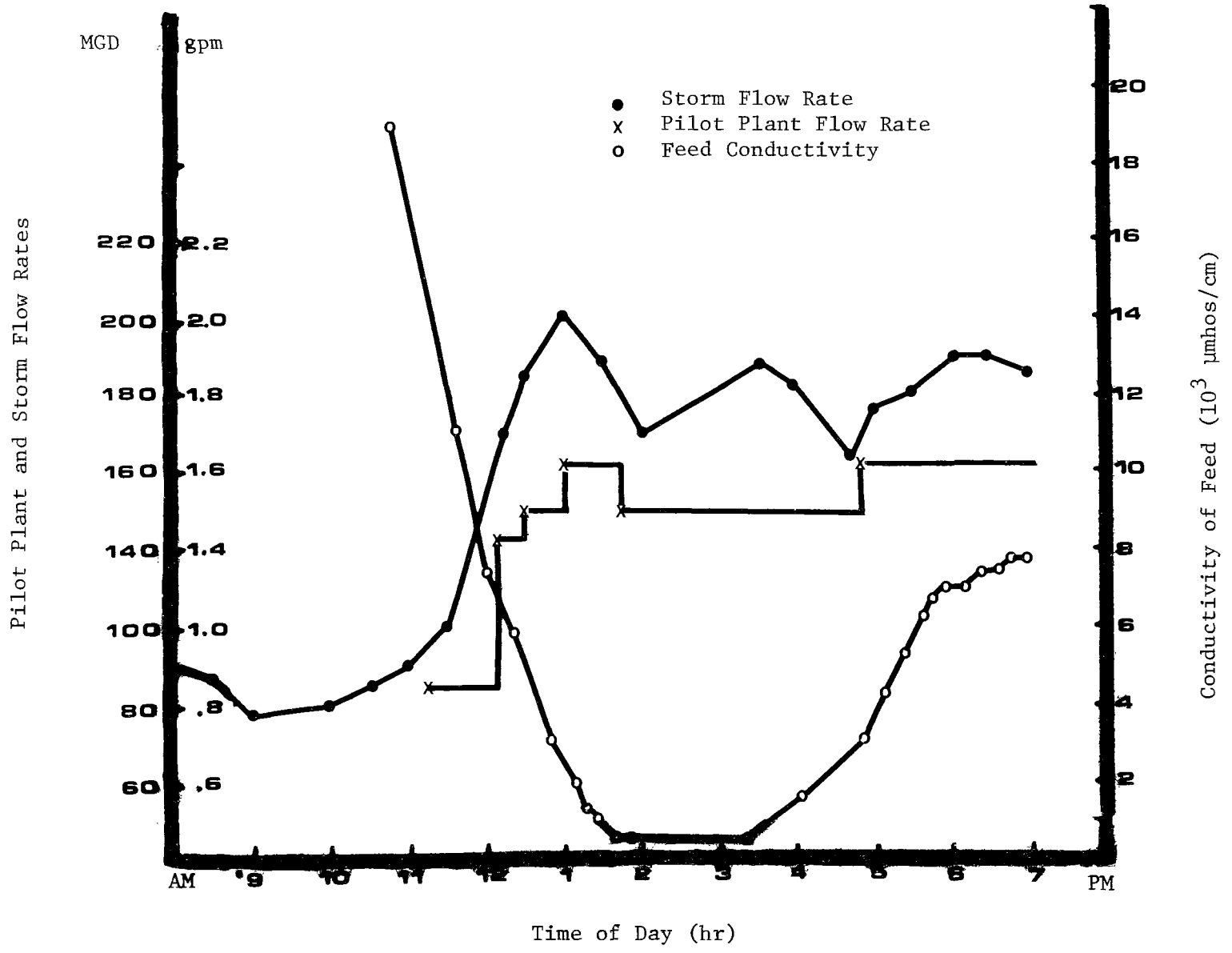


FIGURE VI-12 STORM OF 9/20/77: PHYSICAL PARAMETERS

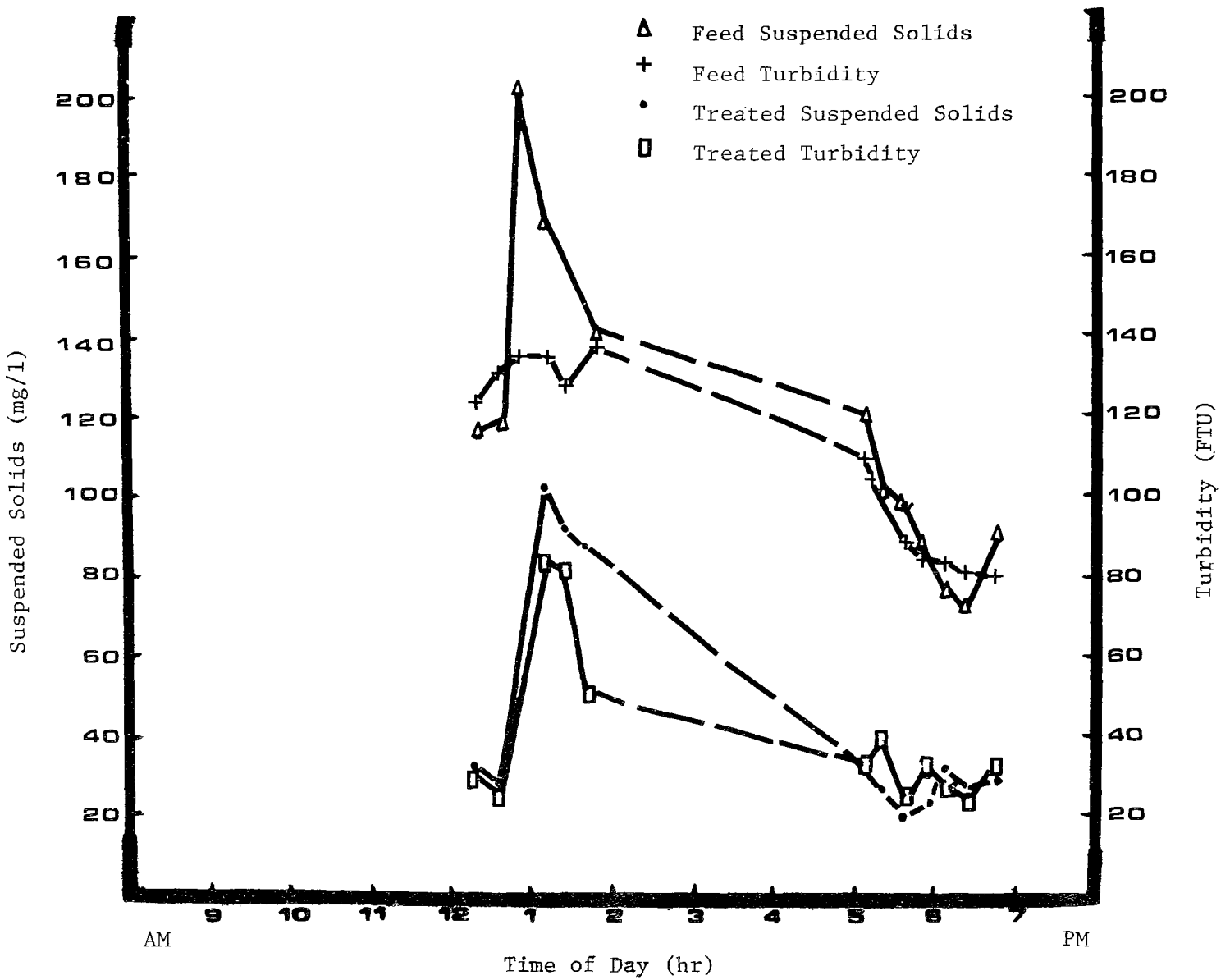


FIGURE VI-13 STORM OF 9/20/77: SUSPENDED SOLIDS AND TURBIDITY OF FEED AND TREATED SAMPLES

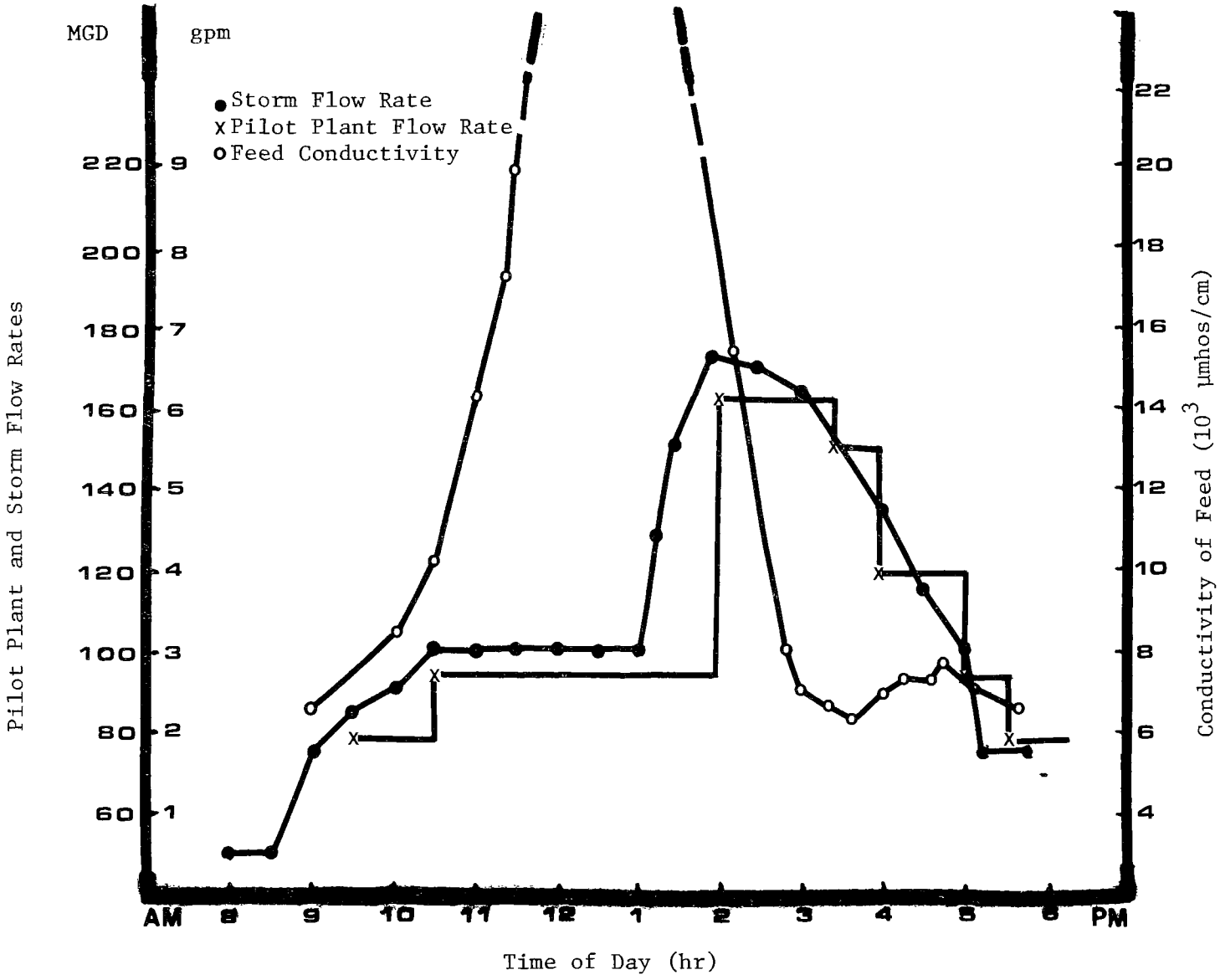


FIGURE VI-14 STORM OF 9/26/77: PHYSICAL PARAMETERS

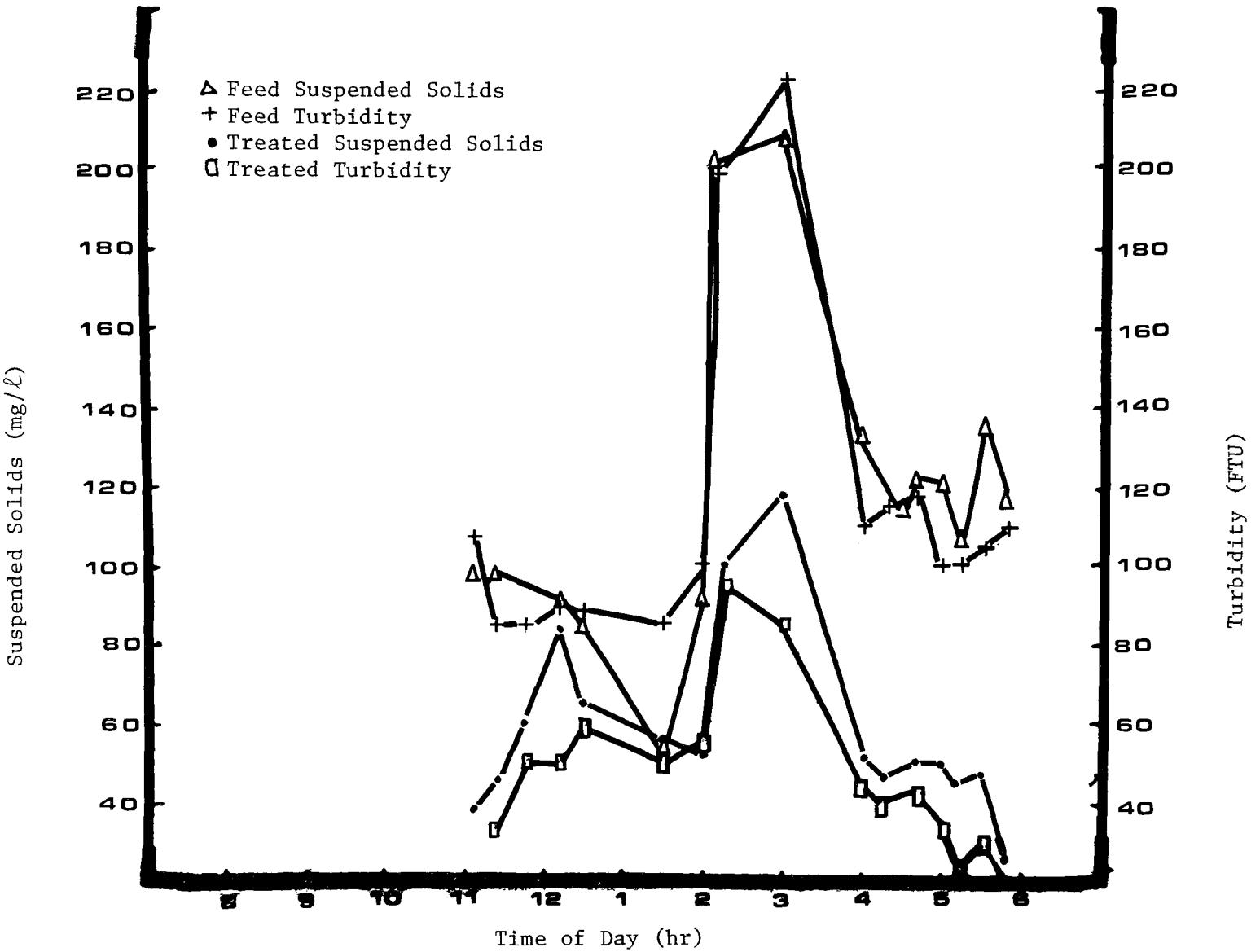


FIGURE VI-15 STORM OF 9/26/77: SUSPENDED SOLIDS AND TURBIDITY OF FEED AND TREATED SAMPLES

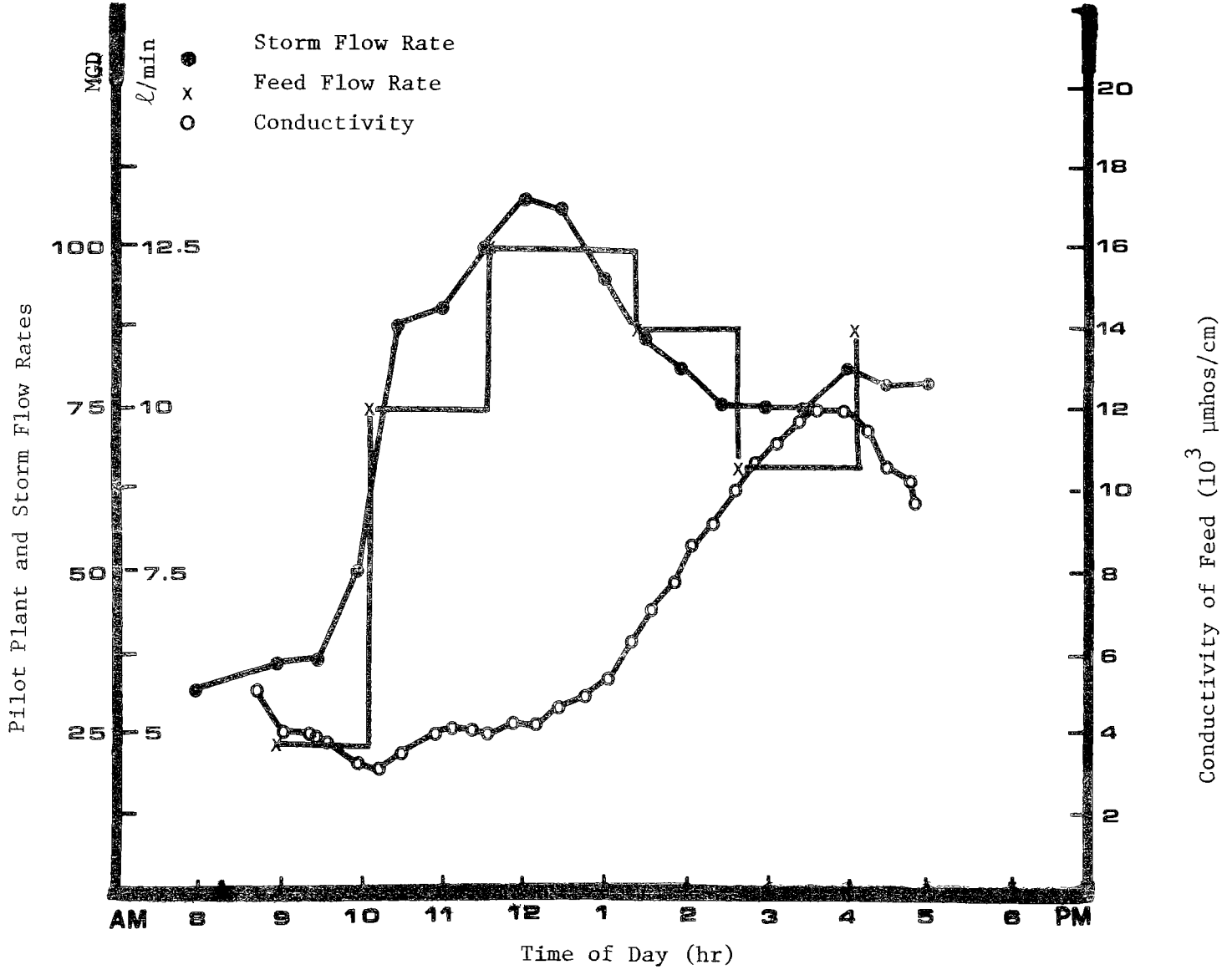


FIGURE VI-16 STORM OF 10/14/77; PHYSICAL PARAMETERS

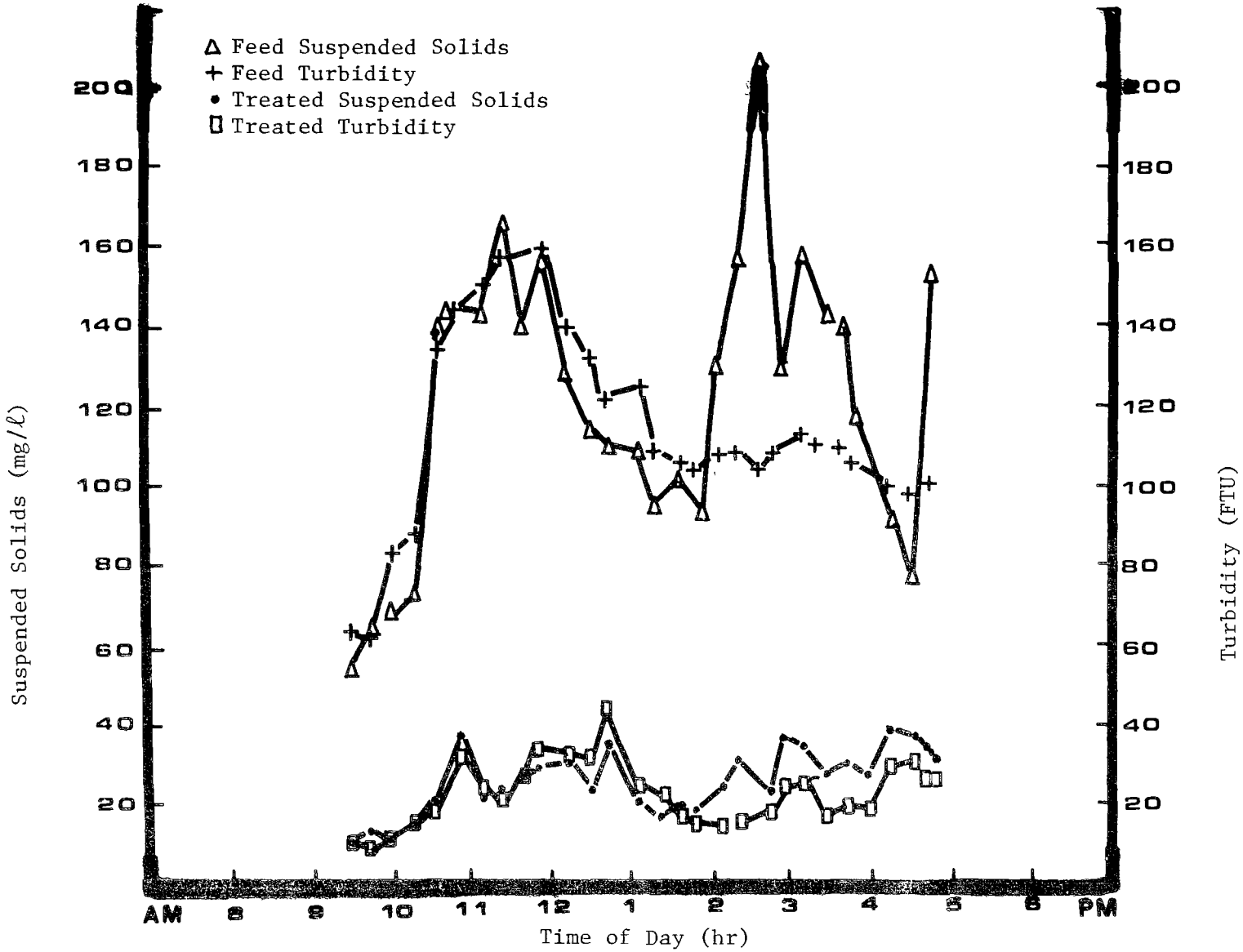


FIGURE VI-17 STORM OF 10/14/77: SUSPENDED SOLIDS AND TURBIDITY OF FEED AND TREATED SAMPLES

From these data, a correlation is evident between high conductivity and poor separation due to flocculation difficulties. High tide was at 11:09 AM on that day, and because the storm was a rather small one, little dilution of the salinity was noticed (the conductivity was 20,000+ μmhos/cm for a large portion of the running time). When the conductivity subsided to < 8000 μmhos/cm later in the day, flocculation, and the resulting magnetic separation, improved significantly. This relationship was even more obvious in the dry weather flow tests described earlier. Thus, lack of magnetite, high feed solids loading, and high conductivity all helped to decrease magnetic separation effectiveness during much of this run.

In the first two storms profiled, magnetic separation water treatment was characterized by a highly unstable system unable to maintain good equilibrium for either pilot plant process equipment or flocculation. This was mainly a result of minor inadequacies in the equipment, the number of operators and lab technicians, and the fact that running a storm is much more chaotic than running under dry weather conditions due to the time limits imposed. Results suffered from this lack of proficiency, but careful evaluation of these results and the problems encountered led to improvements in systems and techniques, and ultimately resulted in a substantial improvement in both system functioning and quantitative results. In the third and final storm, despite similar non-optimal conditions (salinity fluctuation, first flush solids loading, non-optimization of flocculant, lack of monitoring feedback, etc.), seeded water treatment was able to produce impressive results, and a smoothly running operation was maintained for the duration of the run.

Storm of 10/14/77

The third storm event profiled in this study was done on October 14, 1977 on a typical, moderate rainfall which began as a drizzle shortly after 8:00 AM. High tide this day was at 12:50 PM, but because of the relatively large volume of rain, and a low high tide, conductivity did not play as large a role (maximum conductivity reached was only 12,000 μmhos/cm), and jar tests showed that alum concentration remained sufficient during the storm, being kept at 100 mg/ℓ throughout the run. However, magnetite concentration was increased to 400 mg/ℓ in anticipation of the high solids loading associated with the storm water flows normally encountered, and this level was maintained for the duration of the run. (If turbidity monitors for the feed were to be available continuously, magnetite concentration could be varied continuously in response.) Betz 1160 was kept at 1 mg/ℓ.

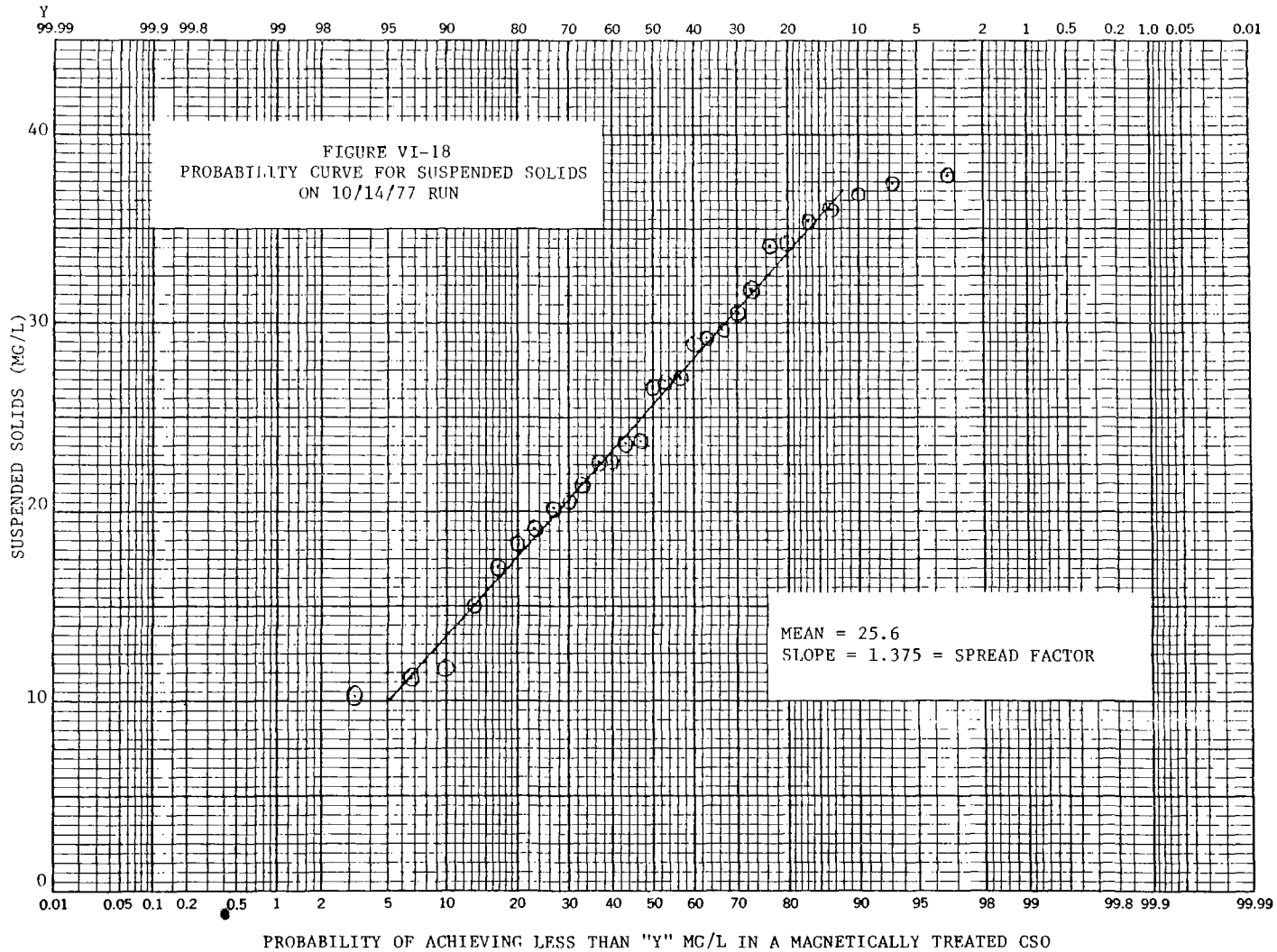
The 3 inch SALA-HGMF® magnetic separator was used in this run, with flow rates ranging from 1.4 to 3.3 gpm, corresponding to actual flows of 32 to 107 MGD. The lower flow rates through Columbia Park on this date were caused by a diversion of part of the sewer flow due to a break in one of the upstream lines.

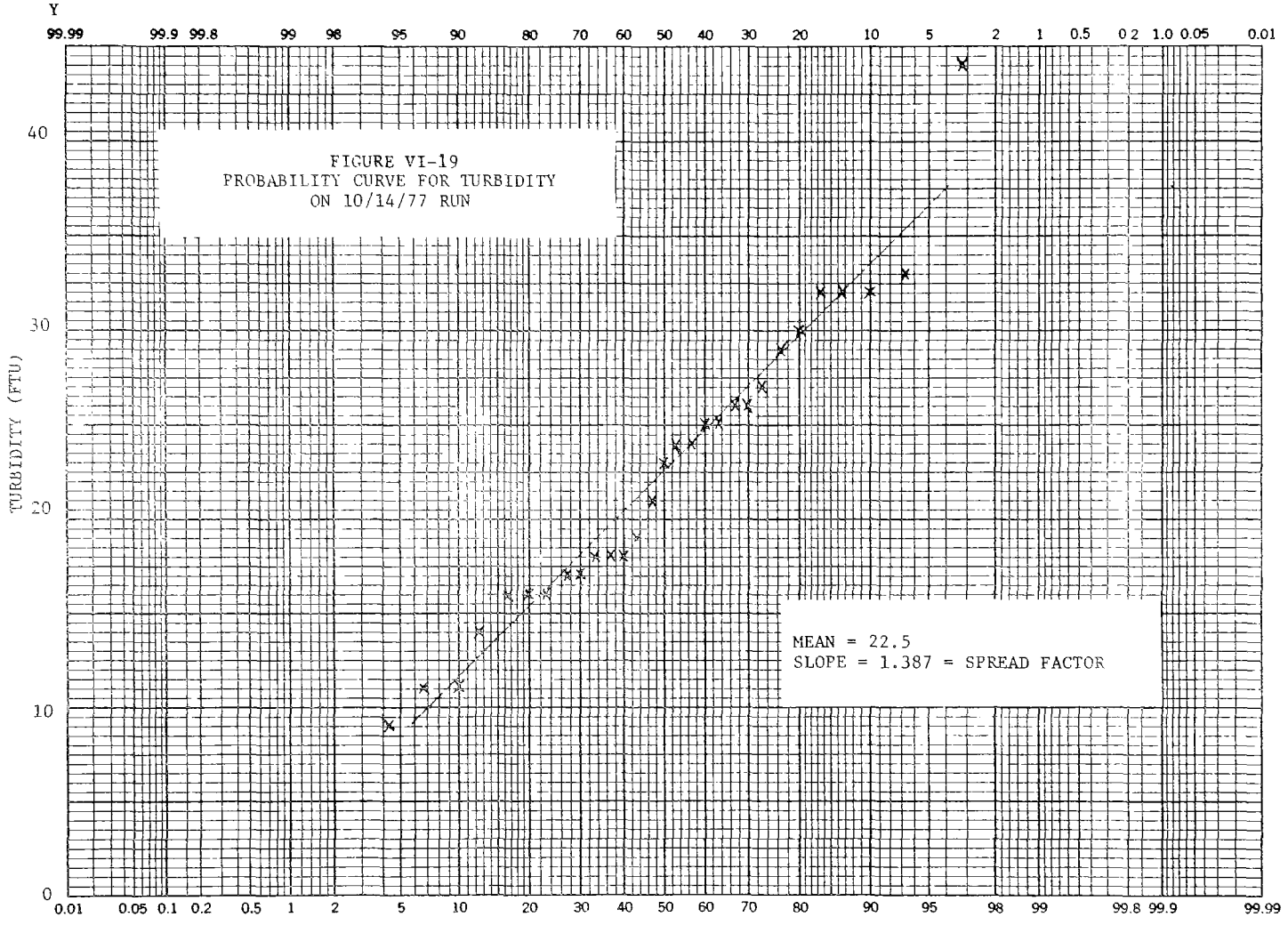
Figures VI-16 and VI-17 show the data collected during this last storm. It is immediately apparent from these curves that the system was much more stable in this case than in the previous two cases. This is attributable mainly to the added experience of the investigators, the increased magnetite concentration used, and the more uniform salinity present during the storm.

Magnetic separation was able to remove, with good consistency, about 80% of the suspended solids and turbidity during this storm. Note that effluent levels achieved did not parallel first flush solids loadings as they did in the previous storms where magnetite was in short supply. By using more magnetite during the first flush, a consistently good effluent can be achieved. It also can be seen from this figure that monitoring the storm flow rate with a simple channel float level meter gives a fairly accurate indication of the actual turbidity and suspended solids concentration of the storm water (at least in this particular case). These curves tend to indicate that a rather simple relation of flow rate to turbidity exists for a storm situation, and a combination of these easily monitored parameters might prove useful in helping to maintain optimal magnetite concentration and flocculation in lieu of more expensive and sophisticated monitoring and feedback systems.

This final storm profile, then, is shown to be successful in meeting essentially all of its objectives. Pilot plant operation was smooth, with no technical difficulties. Equilibrium was maintained in the flocculation train without any chemical concentration adjustment over the full 7½ straight hours of running time in which samples were taken.

Cumulative probability curves for all the magnetically treated total suspended solids and turbidity samples taken during this storm are given in Figures VI-18 and VI-19. The geometric means for these curves are 25.6 mg/ℓ and 22.5 FTU, respectively, and they both have nearly identical spread factors of σ 1.38. The curves are useful in helping to determine how often a particular limit was (or is expected to be) exceeded during the course of operation. These data, although somewhat higher in absolute value than might be possible with an optimized flocculant and a better regulated system, show good consistency and a relatively small spread, demonstrating that seeded water treatment is capable of handling the dynamic combined storm water flows typical of the sewerage systems of a large number of cities in the United States.


Y
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 1.0 0.05 0.01
FIGURE VI-18
PROBABILITY CURVE FOR SUSPENDED SOLIDS
ON 10/14/77 RUN
MEAN = 25.6
SLOPE = 1.375 = SPREAD FACTOR
SUSPENDED SOLIDS (MG/L)
0
10
20
30
40
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
PROBABILITY OF ACHIEVING LESS THAN "Y" MG/L IN A MAGNETICALLY TREATED CSO


Y
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0 2 1.0 0.05 0.01
FIGURE VI-19
PROBABILITY CURVE FOR TURBIDITY
ON 10/14/77 RUN
MEAN = 22.5
SLOPE = 1.387 = SPREAD FACTOR
TURBIDITY (FTU)
0
10
20
30
40
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
PROBABILITY OF ACHIEVING LESS THAN "Y" FTU IN A MAGNETICALLY TREATED CSO

SECTION VII

COST ESTIMATES FOR A HIGH GRADIENT MAGNETIC FILTER BASED 25 MGD CSO/SEWAGE TREATMENT FACILITY

The data generated in this and previous studies of seeded water treatment have provided considerable information useful in the formulation of design and size requirements for larger scale systems. In this section of the report are presented the estimated capital, operation and maintenance-related costs for a proposed integrated wet and dry weather flow treatment plant capable of processing 25 million gallons per day at peak flow. The design of this treatment facility has been upgraded considerably from the one outlined in the earlier report (EPA-600/2-77-015), and includes high-quality system components throughout, with reserve capacity and/or spare units as integral parts of the design.

CAPITAL COSTS

Capital costs for the 25 MGD combined wet and dry weather flow treatment plant are summarized by sub-system in Table VII-1. The total estimated capital cost for this seeded water treatment system is just under 5.2 million dollars. Not included in the capital cost estimates are systems for seed recycling and alum recovery. These systems are contemplated for a full-scale facility, but at this time too little process information is available for a determination of what should be included. It is hoped that a demonstration size plant will be able to generate sufficient quantities of seeded sludge, in the near future, for proper evaluation of various process alternatives in the recovery and reuse of the magnetite seed and/or the aluminum sulfate incorporated therein. The cost of land has not been estimated because of its site-specific nature.

Installation costs were based on estimates from equipment suppliers, the Chemical Engineer's Handbook (Perry), and the Richardson Rapid System. Capital costs are represented at an Engineering News Record (ENR) index of 2700. Labor was figured at $13/hour, based on an ENR of March 9, 1978.

No provisions have been made for the equipment and operational costs associated with the disposal of either the dried sludge cakes or the grit removed from the wastewater.

TABLE VII-1 CAPITAL COST ESTIMATES FOR A HIGH GRADIENT MAGNETIC FILTER BASED 25 MGD CSO/SEWAGE TREATMENT FACILITY

Part 1

Subsystem	Estimated Installed Cost
De-gritting and Pre-screening	$ 394,900
Feed Pumping	297,600
Flocculation Train & Chemical Feed	510,500
SALA-HGMF® High Gradient Magnetic Filters	990,000
Backflushing	141,300
Filter Piping and Valving	527,400
Thickening and De-watering	265,600
Disinfection	86,900
Electrical	137,100
Automatic Process Control & Monitoring	258,700
Physical Plant Construction	490,000
Subtotal:	$ 4,100,000
Construction Contingency @ 10%	410,000
Subtotal:	$ 4,510,000
Engineering and Administration @ 15%	677,000
TOTAL ESTIMATED COSTS:	$ 5,187,000

Part 2

A breakdown of the subsystem components on which the above cost estimates were made is given below.

De-gritting and Pre-screening System

- influent flow meter (Parshall flume);
- coarse bar screen;
- rotary wedge wire screens (6);
- entry pipe to plant;
- by-pass piping and valving;
- concrete troughs and pits;
- influent flow distributors;
- conveyor system; and
- grit hopper.

TABLE VII-1, Part 2 (continued)

Feed Pumping System

- variable speed pumps;
- single speed pumps;
- support frames;
- piping for feed flow; and
- sump well.

Flocculation Train and Chemical Feed System

- flocculators (3);
- flash mixers (6);
- static mixers (3);
- alum storage and delivery system;
- polyelectrolyte make-up and delivery system;
- magnetite slurry and delivery system; and
- support structures.

Magnetic Filters

- SALA-HGMF® Series LP Model 214-15-3 (5 units), including:
  - magnets;
  - canisters;
  - matrices;
  - power supplies;
  - indirect cooling systems;
  - instrumentation; and
  - support structures.

Backflush Equipment

- screw compressors (2);
- piping;
- valves (5);
- air receivers (5);
- stands and concrete pads; and
- instrumentation.

Filter Piping and Valving

- filter piping and valves;
- chemical rinse piping, tank and valves;
- air line piping and valves;
- structures for piping; and
- test component.

TABLE VII-1, Part 2 (continued)

Thickening and De-watering Systems

- thickener and rake;
- sludge pumps (2);
- surge tank;
- vacuum belt filters (2);
- conveyor;
- sludge hopper;
- piping for sludge;
- sump pump for thickener overflow (could be designed for gravity flow); and
- overflow piping.

Disinfection System

- hypochlorite storage tank;
- chlorine diffusers;
- metering pumps;
- residual chlorine analyzer and return pumps;
- chlorine piping;
- contact chambers (3); and
- outfall piping.

Electrical System

- motor control centers;
- wiring and conduit;
- transformer and accessories;
- electrical boxes, etc.

Automatic Process Control and Monitoring Systems

- micro-processor controller, including:
  - flow metering;
  - alarms;
  - differential recording; and
  - interface capability;
- sampler;
- analyzers; and
- monitoring system.

Physical Plant Construction

Building of approximately 16,500 ft^2, including:

- piping;
- electrical system;

TABLE VII-1, Part 2 (continued)

- lighting;
- office facilities;
- control room;
- laundry;
- crane;
- etc.

OPERATION AND MAINTENANCE COSTS

Operation and maintenance costs for the 25 MGD facility are estimated in Table VII-2 in dollars per 1000 gallons of water treated using an assumed average dry weather flow of 5.7 MGD and a peak wet weather flow of 25 MGD over the course of a year.

The chemical and electrical costs shown are approximate, current local prices for the Cambridge, Massachusetts area. Operator labor is based on 24 hours/day monitoring of the facility plus an 8 hour shift for routine maintenance. The freight costs for the chlorine are included in the chemical costs; polyelectrolyte freight costs are considered insignificant.

From the table it will be seen that total estimated operating costs for seeded water treatment range from $.18 to $.23 per 1000 gallons of treated water.

No costs have been included for final disposal of sludge and grit, or for sludge treatment chemical conditioning (should the latter prove necessary). The chemical demand and net operation costs could change significantly if seed recycling or alum recovery are incorporated into the flowsheet.

Power consumption for a system running at 5 MGD and at 25 MGD is shown in Table VII-3. The magnetic filters specified for this system are more efficient than those units previously specified, and will therefore require only about 12 percent of total plant energy consumption.

DESIGN CONSIDERATIONS

The treatment plant will include three main flow streams for wastewater purificaiton, although there will be one flow as they enter the facility (pretreatment) and as they leave (chlorination and de-watering). The actual water/suspended solids separation occurs in one of five high gradient magnetic filters (the fifth is considered a spare). The first filter is available to handle normal dry weather flow, estimated in this instance at 5 MGD, and the remaining four filters operating at a maximum flow rate of 125 gpm/ft^2 are available to handle the 25 MGD peak storm flow. When all five filters are activated, the maximum capacity of the system will be 32 MGD, and average annual through put is assumed to be 5.7 MGD. Figure VII-1 is a system design schematic.

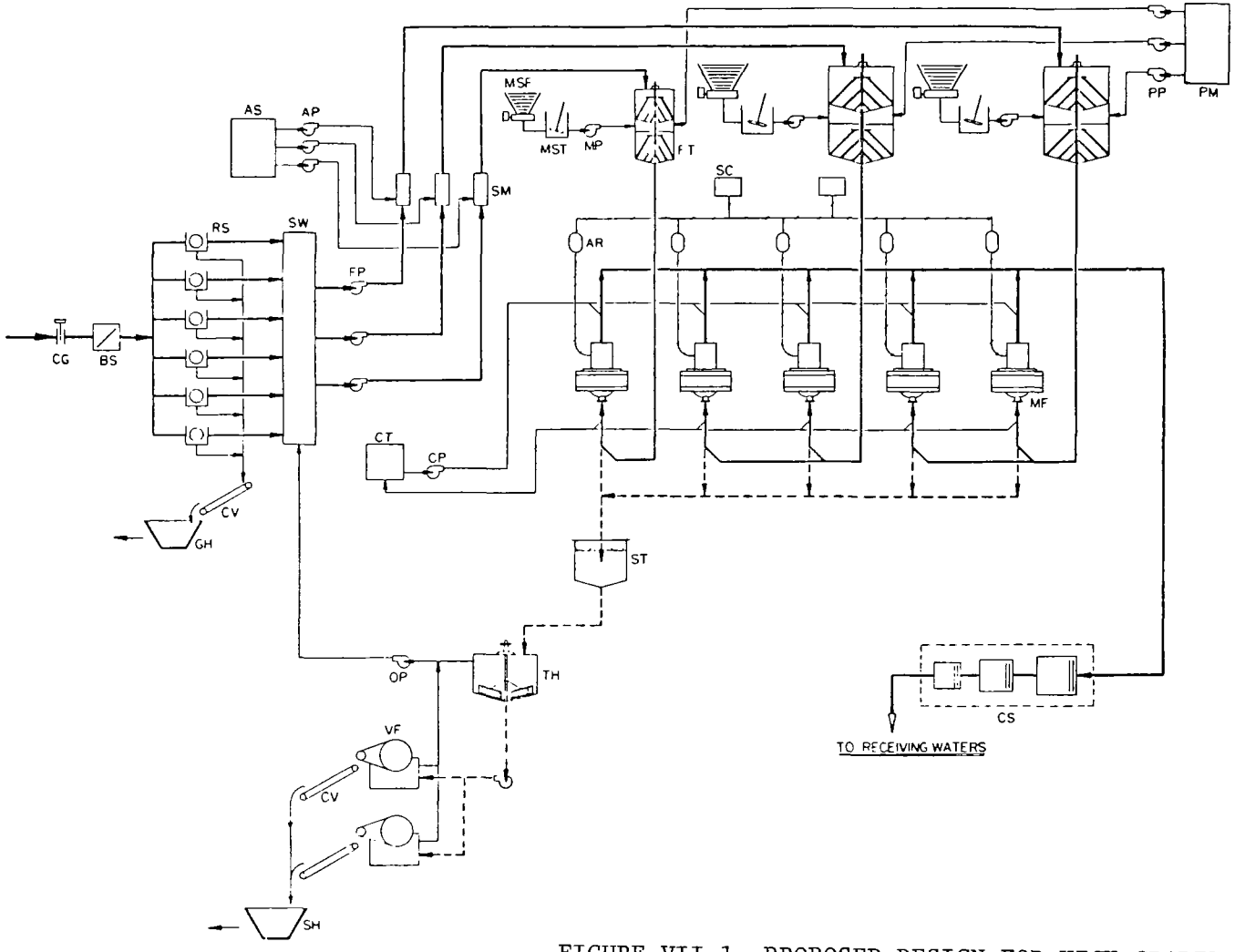


FIGURE VII-1 PROPOSED DESIGN FOR HIGH GRADIENT MAGNETIC FILTER BASED 25 MGD/ SEWAGE TREATMENT FACILITY

KEY TO FIGURE VII-1

No. of Units	Symbol	Description
5	AP	Alum Delivery Pump (2 spare)
1	AS	Alum Storage Tank
5	AR	Air Receiver
1	BS	Bar Screen
1	CG	Control Gate
1	CP	Caustic Rinse Pump
1	CS	Chlorination System
1	CT	Caustic Storage Tank
6	CV	Conveyor
5	FP	Feed Pump (2 spare)
3	FT	Flocculator Tank System
1	CH	Grit Hopper
5	MF	SALA-HGMF® Magnetic Filter
3	MP	Magnetite Delivery Pump
3	MSF	Magnetite Screw Feeder
3	MST	Magnetite Slurry Tank
1	OP	Over-flow Pump
1	PM	Polyelectrolyte Make-up System
5	PP	Polyelectrolyte Delivery Pump (2 spare)
6	RS	Rotary Strainer
2	SC	Screw Compressor
1	SH	Sludge Hopper
3	SM	Static Mixer
2	SP	Sludge Pump (1 spare)
1	ST	Surge Tank
1	SW	Sump Well
1	TH	Thickener
2	VF	Vacuum Filter

TABLE VII-2 OPERATION AND MAINTENANCE COST ESTIMATES FOR A HIGH GRADIENT MAGNETIC FILTER BASED 25 MGD CSO/SEWAGE TREATMENT FACILITY

Item	Costs in $ per 1000 gallons @ 5.7 MGD	@ 25 MGD
Chemicals:		
. Alum (liquid, 50%) @ 100 mg/ℓ $100/dry ton $.110/kg $.27 /gal $.071/ℓ	.042	.042
. Magnetite (commercial grade, -325 mesh) @ 200 mg/ℓ $35/ton $.018/lb $.039/kg	.030	.030
. Polyelectrolyte (Hercofloc 831, anionic) @ 1 mg/ℓ $1.36/lb $3.00/kg	.011	.011
. Chlorine (15% Sodium Hypochlorite, WilChlor 2) @ 2 mg/ℓ $.30/gal $.079/ℓ $.529/kg available Cl_2 (delivered price)	.004	.004
Total Chemical Costs:	.087	.087
Chemical Freight Costs:		
. Alum for 50 mi or 80 km $.05/gal $.013/ℓ	.007	.007
. Magnetite for 200 mi or 322 km $10/ton $.011/kg (estimated)	.008	.008
Total Freight Costs:	.015	.015

TABLE VII-2 (continued)

Item	Costs in $ per 1000 gallons @ 5.7 MGD	@ 25 MGD
Electrical Power @ $.055/kWh	.032	.024
. Magnetic Filter (5) @ 15 kW ea.		
. Other Equipment		
125 kW @ 5 MGD 404 kW @ 25 MGD		
Operator Labor:		
32 man-hours/day @ $15/hr	.039	.039
Maintenance Costs:		
. Mechanical Equipment and Physical Plant (3% of equipment cost)	.042	.008
. Electrical Equipment, Instrumentation, and Piping (2% of equipment cost)	.011	.002
Total Labor and Maintenance Costs:	.092	.049
TOTAL OPERATION AND MAINTENANCE COST PER 1000 GALLONS:	.226	.175

TABLE VII-3 POWER CONSUMPTION FOR A 25 MGD FACILITY

Item	Energy Consumed in kWh @ 5 MGD	@ 25 MGD
De-gritting and Pre-screening	8.2	18.7
Feed Pumping @ 45 ft head	40.0	200.0
Chemical Makeup and Delivery	2.4	6.5
Flocculator Chain Mixing	9.0	39.0
Magnetic Filters	15.0	60.0
Compressors	12.0	45.0
Dewatering System	31.0	42.0
Control Instrumentation and Building Service	12.0	23.0
Miscellaneous	10.0	30.0
TOTAL:	140.0	464.0

TABLE VII-4 ASSUMED PARAMETER VALUES FOR A 25 MGD SYSTEM

Item	Design Value
Magnetic Filters (5 SALA-HGMF® Model 214-15-3)	
. Bore	84 in (214 cm)
. Length	6 in (15 cm)
. Magnetic Field Strength	0-3 kG
. Maximum Flow Rate through Matrix	125 gpm/ft^2 (18 m^3/min) (4800 gpm)
Waste Water Characteristics	
. Maximum Storm Flow	25 MGD (1.1 m^3/sec)
. Nominal Dry Weather Flow	5 MGD (.22 m^3/sec)
. Average Flow over 1 Year	5.7 MGD (.25 m^3/sec)
. Average Influent Suspended Solids	100 mg/ℓ
Backflush Parameters	
. Backflush FLow Flux Rate through Matrix	500 gpm/ft^2 (20.35 m^3/min m^2) (19,300 gpm)
. Backflush Duration	8 sec
. Backflush Volume	2600 gal (10 m^3)
. Maximum Pressure Drop before Backflush	10 psi
. Caustic Rinse Flow Rate through Matrix	20 gpm/ft^2 (.814 m^3/min m^2)
Mixing and Residence Times	
. G Factor for Flash Mixers	300/sec
. G Factor for Flocculator	100/sec
. Reynolds Number for Static Mixers (21 in)	7.5 x 10^5
. Total Mixing Residence Time	5 min
Chemical Dosages	
. Alum Concentration	100 mg/ℓ
. Magnetite Concentration	200 mg/ℓ
. Polyelectrolyte Concentration	1.0 mg/ℓ
. Chlorine Concentration	2 mg/ℓ
. Chemical Storage	6 days at peak flow; 30 days at dry weather flow
Other Parameters	
. Pumping Head for Feed Pumps	45 ft (33 psi)
. Pre-screening size	20 mesh (.84 mm)

Table VII-4 gives the parameter values used in obtaining magnetic filter and operational cost estimates for a 25 MGD facility. These values were chosen on the basis of the experimental data, previous experience in the field, flow requirements, and equipment design limitations.

A combined wet-and dry-weather flow treatment plant has an inherently large reserve capacity which remains unused for a major portion of the year. For the 25 MGD peak flow system in question, it was arbitrarily assumed that in the course of a year there would be 30 storms producing a 25 MGD flow for an average of 10 hours each, or a total of 300 hours of CSO at a 25 MGD through put rate, compared to 8460 hours of dry weather flow at 5 MGD. Although these are assumed values, and may not be representative for a given location, the fact remains that in this type of treatment facility, a large amount of equipment must be regularly maintained for only sporadic use. As a consequence, operation and maintenance costs are relatively high in proportion to the number of gallons treated.

The system shown in Figure VII-1 is similar to the seeded water treatment flowsheets presented in the past (i.e., the Mobile Pilot Plant Trailer design and the 25 MGD system outlined in Figure X-1 of EPA publication EPA-600/2-77-015), with a few design changes. For example, static mixers have been added for initial alum dispersal prior to the large alum residence tank. The floc chain, consisting of an alum residence tank, two flash mixers for polymer and magnetite addition, and a larger flocculator for final residence are sized for a total of 5 minutes mixing time. A detail of this system is shown in Figure VII-2. The pressure head created by the alum mix/flash mix/flocculator tank unit is now designed to be used in place of the filter pump suction head used in previous designs to draw the chemically pretreated water through the magnetic filters. Thus, there is no longer a need for filter pumps in the system.

Another change is with the magnetic filter design which affects the backflush system; each magnetic filter (SALA LP Series) now has its own hydrotank for backflushing incorporated as an integral part of the magnetic filter canister (forward flow) plumbing. In this way, much extra plumbing and valving have been eliminated, as well as the extra control provisions for filling the hydrotanks with filtered water. This latter operation is now accomplished automatically, in a passive manner, with each filter cycle.

Other features have been included in the design to make the system both dependable and foolproof. The design is conservative, and spare pumps assure adequate back-up; the process control system is versatile and completely automatic; and a by-pass system has been included for emergency situations.

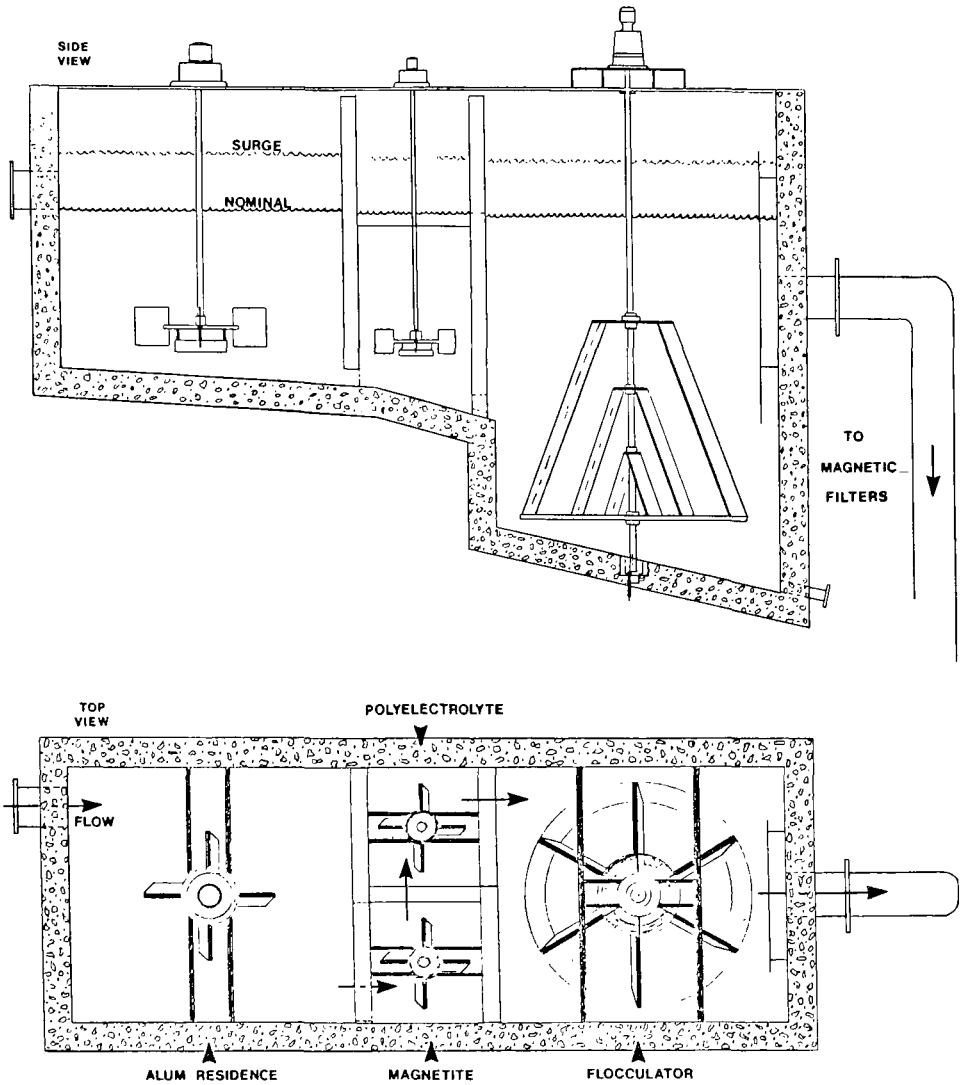


FIGURE VII-2 TOP AND SIDE VIEWS OF ALUM RESIDENCE/FLASH MIX/ FLOCCULATOR RESIDENCE TANK CHAIN FOR THE 25 MGD SEEDED WATER TREATMENT SYSTEM

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GLOSSARY

backflush: A rapid reverse flow of water through the separator matrix with the magnet de-energized following a filtering interval. This serves to purge the accumulated magnetic flocs from the matrix filterbed.

bench test: A test performed manually on an aliquot of sample. More specifically, a waste water sample that is treated with known concentrations of flocculants and seed while being agitated, and is then passed through a gravity feed high gradient magnetic separator, and later analyzed.

canister: The cylindrical copper or stainless steel container holding the magnetic matrix.

combined sewer overflow, or combined storm overflow (CSO): A flow from a sewer receiving both surface run off and municipal sewage, in excess of interceptor capacity, that is discharged into a receiving water.

continuous pilot plant: A small-scale sewage treatment plant set up to cycle automatically and continuously for feasibility studies.

dry weather flow: The flow of municipal sewage during a dry spell in a sewer also able to receive run-off.

first flush: The condition often occuring in storm sewer discharges and combined sewer overflows, in which a disproportionately high pollution load is carried in the first portion of the discharge, or overflow.

flocculation chain (or train): A series of interconnected mixing tanks in which flocculants and magnetic seed are added to the water to be treated by magnetic separation.

high gradient magnetic separator or filter: A solenoid electromagnet containing a filamentary ferromagnetic matrix (proprietary) and encased in a highly efficient steel magnetic flux return frame.

jar test: A standard sewage treatment test in which several aliquots of waste water are taken and treated with various concentrations of flocculants, etc., to determine optimal dosages necessary for effective treatment.

magnetic matrix: The ferromagnetic material (steel wool or expanded metal) which forms the filterbed located within the canister of a high gradient magnetic separator.

matrix loading: The ratio of the weight of solids retained in the magnetic matrix to the weight of the fibers that comprise the matrix.

pilot plant cycle: A series of automatically timed and executed continuous cycles including reset, magnet on delay, filter, magnet off delay, flush, and dump.

seed recycle: The recovery and reuse of the magnetic powder (seed) used in seeded water treatment from the end-product sludge.

sludge: A semi-solid end product of the magnetic separation process consisting of waste solids, magnetic seed and flocculants.

static mixer: A compact device used for chemical dispersion which works by repeated division and rejointure of the flow.

surge flow: A rapid increase in incoming volume of waste water to a treatment or detention facility.

wet weather flow: A waste water containing both storm run-off and raw sewage, resulting from the combining of storm waters with normal dry weather flow.

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16. ABSTRACT

Seeded water treatment using a SALA high gradient magnetic separator pilot plant system was conducted on CSO and raw sewage at SALA Magnetics in Cambridge, MA and at on-site locations in the Boston area. These tests further built upon the data base collected under the first phase of this contract (see EPA Publication 600/2-77-015) with special emphasis on specific design and operational parameters, long term durability and maintenance problems, and system adaptability to integrated wet and dry weather flow conditions. The on-site results reported, although not equaling those obtained on uniform batch samples in house, were nevertheless good and proved that HGMF magnetic filters are effective on fresh CSO and raw sewage and that the magnetic filtration treatment system is easily adaptable to the dynamic solids loading and flow rate conditions typically associated with storm water and integrated wet and dry treatment systems.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Magnetic separators, Flocculators, Sewage treatment, Combined sewers, Water treatment, Filtration	Combined storm overflow, SALA-HGMS magnetic separator, Seeded water treatment, High gradient magnetic field, Continuous pilot plant	13B 13H

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