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EPA-600/2-77-053a
May 1977

Environmental Protection Technology Series

HANDLING AND DISPOSAL OF SLUDGES FROM COMBINED SEWER OVERFLOW TREATMENT
Phase I - Characterization

Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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HANDLING AND DISPOSAL OF SLUDGES FROM COMBINED SEWER OVERFLOW TREATMENT

Phase I - Characterization

by

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Contract No. 68-03-0242

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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 the 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 prevention, treatment, and management of wastewater and solid and hazardous waste 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.

This report discusses the results of a characterization and treatment feasibility test program for the handling and disposal of the residual sludges from combined sewer overflow treatment systems.

Francis T. Mayo, Director
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ABSTRACT

This report summarizes the results of a characterization and treatment test program undertaken to develop optimum means of handling and disposal of residual sludges from combined sewer overflow (CSO) treatment systems. Desk top engineering reviews were also conducted to gather, analyze and evaluate pertinent information relating to pump/bleedback of the treatment residuals to the dry-weather sludge handling/treatment and disposal facilities.

The results indicate that the volumes and characteristics of the residuals produced from CSO treatment vary widely. For the residuals evaluated in this study, the volumes ranged from less than 1% to 6% of the raw volume treated and contained 0.12% to 11% suspended solids. The volatile content of these sludges varied between 25% and 63% with biological treatment residuals showing the highest volatile content and fuel values. The heavy metal and pesticide concentrations of the various sludges were observed to be significant and are presented.

It was concluded that the pump/bleedback of CSO treatment residuals may not be practical for an entire city because of the possibility of hydraulic and/or solids overloading of the dry-weather treatment facilities and other adverse effects. However, controlled pump/bleedback on a selective basis may be feasible. For low solids content residuals (storage, screen backwash, waste activated sludge, etc.), gravity or flotation thickening were concluded to be the optimum steps for the removal of the major water portion while centrifugation and vacuum filtration were concluded to be the optimum dewatering techniques for the high solids content residuals (settled storage treatment sludge, flotation scum and other thickened sludges) prior to their ultimate disposal by incineration or landfill. As a result of the findings and conclusions of this initial study, the USEPA is now involved in a followup study to:

1. Evaluate on a pilot scale basis the process treatment systems of thickening followed by centrifugation or vacuum filtration for handling and disposing of CSO treatment sludges, as well as stabilization methods such as anaerobic digestion.

2. Develop capital and operating costs for the above mentioned treatment systems.

3. Evaluate alternative methods for ultimate disposal of storm generated residuals and assess the potential impacts of such handling and disposal.

This report covers a period from March, 1973 to February, 1975 and was submitted in partial fulfillment of Contract No. 68-03-0242 by the Environmental Sciences Division of Envirex Inc., under the sponsorship of the U.S. Environmental Protection Agency.

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ACKNOWLEDGEMENTS

This investigation was carried out by the Environmental Sciences Division of Envirex Inc. Many people contributed to the success and timely completion of this project. Messrs. Richard Wullschleger, Ernest Bollinger and Mahendra Gupta participated in the bench scale treatment feasibility work. The laboratory analyses were conducted by various personnel of Envirex's process laboratory under the supervision of Richard Wullschleger. The evaluation of the collected data was conducted by a team of engineering personnel led by Mahendra Gupta, Project Manager, and Anthony Geinopolos, Project Director. Other members of the engineering evaluation team were Steve Vanderah, Ernest Bollinger, Charles Hansen, and Michael Clark.

The various CSO treatment facilities operators, engineers, supervisors, contractors, administrators and regional EPA officers were most helpful in providing the sludge samples, past data and other necessary information throughout the conduct of this study. It is impossible to mention all those who have contributed to the success of this project. However, special mention must be made for the support of the project by the U.S. Environmental Protection Agency and the willing assistance and helpful advice of the Project Officer, Mr. Anthony Tafuri and Mr. Richard Field, Chief, Storm and Combined Sewer Section, EPA, Edison, New Jersey.

SECTION I

FINDINGS AND CONCLUSIONS

1. Raw CSO Sludge Characteristics

   a. The sludge volumes produced from the treatment of combined sewer overflows varied from less than 1% to 6% of the raw flow volume treated.

   b. The solids concentration of the sludge residuals from CSO treatment varied widely, ranging from 0.12% to 11% total suspended solids. The wide range observed is attributed to the CSO treatment method used and treatment plant operation.

   c. The volatile content of the sludge solids varied between 25% and 63% for the sludges obtained from the treatment types investigated. Biological treatment sludges showed the highest volatile solids fraction (about 60%), whereas that for sludges from physical/chemical treatment showed only 25% to 40% volatile fraction.

   d. As might be expected, the biological sludges with higher volatile solids also showed higher fuel values compared to other sludge types. The average fuel value of biological sludges was 3515 cal/gm (6334 BTU/lb) compared to an average of 2032 cal/gm (3662 BTU/lb) for other sludges.

   e. Pesticide and PCB concentrations in the residual sludges investigated were observed to be significant. Generally, the PCB concentrations were higher than those for pp'DDD, pp'DDT and dieldrin. The Cottage Farm (Cambridge, MA) storage treatment sludge generally showed the higher pesticide concentrations in this study. The range of PCB and pesticide values for the various sites investigated were:

PCB	non-detectable to	6570 μg/kg dry solids
pp'DDD	non-detectable to	225 μg/kg dry solids
pp'DDT	non-detectable to	170 μg/kg dry solids
Dieldrin	non-detectable to	192 μg/kg dry solids

   f. Heavy metal (Zn, Pb, Cr, Cu, Hg, and Ni) concentrations in the residual sludges were also significant, and varied widely for the sludges investigated. Cambridge, MA sludge again showed generally higher heavy metal concentration of the sludges investigated. The range of heavy metal concentrations for the various sites investigated were:

Zinc	697-7154	mg/kg dry solids
Lead	164-2448	mg/kg dry solids
Copper	200-2454	mg/kg dry solids
Nickel	83- 995	mg/kg dry solids
Chromium	52-2471	mg/kg dry solids
Mercury	0.01-100.5	mg/kg dry solids

2. Disposal of CSO Sludges by Pump/bleedback to Dry-Weather Treatment Facilities

   a. From the results of a desk-top analysis it does not appear practical in the cases studied to pump/bleedback CSO treatment residuals from an entire city's combined sewers to an existing dry-weather treatment facility because of the possibility of exceeding the hydraulic and/or solids handling capacities of such facilities. Addition of sludge handling facilities or controlled pump/bleedback of CSO treatment residuals from a portion of a city's combined sewer area would be possible.

      In some cases on-site treatment of wet-weather flow sludges may be practical, particularly when the dry-weather treatment facilities are at or near design capacity. However, before any one alternate is decided upon, site-specific analysis should be performed.

   b. In the cases studied, pump/bleedback of CSO treatment residuals may produce only marginal hydraulic overloadings (10-20% or less) of the dry-weather treatment capacity when the pump/bleedback is spread over a period of 24 hours or greater.

      However, the solids loadings (assuming complete transport and no solids settling in the sewer), may increase as much as 300%, when the pump/bleedback is spread over a 24 hour period (for treatment residual concentrations greater than 1% solids). The impact of such discharge will be proportionately less when the pump/bleedback is spread over periods greater than 24 hours.

      Tolerable solids loadings may result from the pump/bleedback of such low solids CSO treatment residuals as centrates, supernatants, and filtrates from auxiliary CSO sludge dewatering treatments as gravity or flotation thickening, centrifugation, and vacuum filtration.

   c. Pump/bleedback of the retained contents of storage treatment basins may produce hydraulic and solids overloadings of 100% or higher of the dry-weather treatment facilities when spread over a 24 hour period.

   d. The overload effect of pump/bleedback of CSO treatment residuals may produce shock loads (hydraulic, solids, toxic heavy metal levels, PCB and pesticides, low volatile solids, etc.) which may adversely affect dry-weather treatment operation and performance (primary, secondary and sludge handling and disposal).

e. Any reduction in the treatment efficiency of the dry-weather facilities due to pump/bleedback, although small in terms of concentration, can add significant pollutant load in terms of mass loading on the receiving water body. Furthermore, even assuming no reduction in treatment efficiency, at least some fraction of the pumped-back/bled-back residuals would be discharged to the receiving water as a carryover in the treated effluent. This is a disadvantage of the pump/bleedback concept that must be considered in its evaluation.

3. Dewatering of CSO Treatment Sludges

a. Retained contents of the storage treatment at the end of an overflow must be concentrated via conventional techniques such as sedimentation, prior to further thickening of the residuals. The supernatant may then be either discharged to the receiving waterbody or dry-weather sewage treatment facilities (if permissible hydraulically).

   Centrifugation was found to be the optimum dewatering process for the on-site treatment of Milwaukee, WI and Cambridge, MA (storage treatment) sludges, based on performance, area and cost considerations.

b. A combination of gravity thickening and centrifugation provided optimum treatment for most CSO sludges evaluated during this study. This combination was most effective for less concentrated combined screen backwash and flotation scum residuals such as for Racine, WI. For more concentrated residuals, such as for flotation scums at Milwaukee and San Francisco, direct centrifugation and vacuum filtration were effective.

c. Basket type centrifuges were indicated to be better suited for dissolved-air flotation sludges (Racine and San Francisco) and biological treatment residuals (Kenosha and New Providence) because of poor scrollability of these sludges.

d. Vacuum filtration in combination with gravity or flotation thickening provided optimum dewatering performance for alum treated dissolved-air flotation (San Francisco) sludge and the biological sludges. However, based on area and cost requirements, the results of gravity or flotation thickening plus centrifugation were comparable to vacuum filtration.

e. No significant differences in dewatering characteristics were apparent for the wet and dry-weather sludge samples obtained from the primary and secondary clarifiers at New Providence, NJ, although the raw sludge residuals were significantly different inherently.

4. Considerations for Ultimate Disposal by Incineration

   a. As previously stated, the fuel values obtained for the CSO treatment sludges investigated varied significantly with biological sludges having the highest values.

   b. The calculated heat requirements for the incineration of the dewatered CSO sludges showed that a significant amount of auxiliary heat would be required to sustain combustion.

SECTION II

RECOMMENDATIONS

1. The treatment processes of thickening followed by centrifugation should be further utilized on a full scale basis to demonstrate the effectiveness of this treatment combination for the handling and disposal of CSO sludges.

2. Develop basic design criteria and operating characteristics of the thickening-centrifugation dewatering system in a form that can be translated into actual practice with minimum delay.

3. Develop capital and operating costs for the demonstrated treatment system.

4. Evaluate, on a nationwide basis, the extent of the wet-weather flow sludge problem with respect to quantities generated, characteristics and facility and cost requirements for handling and disposal of the CSO sludges.

5. Evaluate the "shock load" effect of CSO treatment residuals on dry-weather treatment plant operation and performance.

6. Evaluate alternative methods for ultimate disposal of raw CSO sludges and treated CSO sludges.

7. Investigate the feasibility of land treatment/disposal of raw CSO.

SECTION III

INTRODUCTION

The pollutional contribution of combined sewer overflows is of national importance. The magnitude of the problem is illustrated by the fact that more than 1,300 United States communities serving 25.8 million people have combined sewer systems (1). Sufficient information has been accumulated to confirm that the combined sewer overflow problem is of major importance and is growing worse with increasing urbanization, economic expansion, and water demands (2). Various methods for dealing with combined sewer overflows have been proposed. These methods pertain to the segregation of sewers, enlargement of interceptors and storage and treatment of combined sewer overflows. Among the various treatment methods are the physical, physical-chemical and biological treatment systems. Many of these concepts have been demonstrated or are planned for demonstration by the USEPA (3,4,5). As with most wastewater treatment processes, treatment of combined sewer overflows by the above processes results in residuals, which contain, in the concentrated form, objectionable contaminants present in the raw combined sewer overflows.

Sludge handling and disposal of the residual sludges from combined sewer overflow treatment has been generally neglected, thus far, in favor of the problems associated with the treatment of the combined sewer overflow itself. Optimum handling and disposal of these residuals must be considered an integral part of CSO treatment because it significantly affects the efficiency and cost of the total waste treatment system. Surprisingly, there is little information available in the literature concerning the characteristics, methods of disposal and economics of the sludge and its dispensation. EPA has recognized the need for defining the problems and establishing treatment procedures for handling and disposing of residual sludges from combined sewer overflow treatment. During 1973, USEPA awarded a contract (No. 68-03-0242) to Envirex Inc. to investigate Phase I (Characterization) of a two phase program whose total project objectives for both Phase I and Phase II are:

1. Characterize the residual sludges arising from the treatment (physical, physical-chemical, and biological) of combined sewer overflows (Phase I).

2. Develop and demonstrate a process treatment system for handling and disposing of the sludges arising from treatment of combined sewer overflows (Phase II).

3. Develop capital and operating costs for the treatment systems developed and demonstrated (Phase II).

This report incorporates the results of the characterization and feasibility investigations undertaken in Phase I of the above mentioned project.

The first and most difficult step in the ultimate disposal of sludge is the removal of the water normally associated with the sludges. In general, the less water associated with the sludge solids, the less costly the subsequent steps of ultimate disposal. The various steps leading to the ultimate disposal of the sludges arising from conventional dry-weather treatment are: 1) thickening by sedimentation or flotation, 2) digestion of thickened sludges, 3) dewatering by centrifugation or vacuum filtration and 4) ultimate disposal by incineration and/or landfill. Digestion of the sludge residuals is generally practiced after step one and the digested sludge may or may not be dewatered prior to ultimate disposal. Although information regarding the handling and disposal of sludges arising from combined sewer overflow treatment is lacking, it is indicated that the procedures used for handling conventional waste treatment sludges should be applicable. Therefore, the unit treatment processes of gravity thickening, flotation thickening, centrifugation, vacuum filtration and incineration were evaluated for the handling and disposal of CSO treatment residuals.

The specific objectives of this project were met through the performance of the following work tasks:

1. Desk top reviews evaluating a non-conventional method for handling combined sewer overflow residues by pumping back or bleeding back the residual sludges or stored overflows to the deriving sewerage system.

2. Field surveys conducted at selected EPA combined sewer overflow treatment sites to acquire and evaluate differences in sludge characteristics attributable to treatment process differences. In addition, bench scale investigations were conducted on residual sludges using conventional methods for handling combined sewer overflow residues.

3. Derivation, development, evaluation, and comparison of alternative process flow sheets for the handling and disposal of the sludges arising from the treatment of combined sewer overflows.

Several EPA demonstration projects were contacted for the procurement of the residual samples. Suitable samples were obtained from eight treatment sites in seven cities across the nation. A listing of the sites from which the samples were procured is shown in Table 1. Detailed descriptions of the dry and wet weather treatment facilities listed in Table 1 are presented in Appendix A. The ensuing sections of this report delineate the sampling procedures, test methods, treatability test results, desk top reviews, engineering evaluations and proposed recommendations.

Table 1. LIST OF CSO TREATMENT PROJECTS FROM WHICH SLUDGE SAMPLES WERE PROCURED

Location	Nature of process	Type of treatment	Sampling point
1. Humboldt Ave. Milwaukee, WI	Physical treatment	Storage/settling	Storage tank
2. Cottage Farm Cambridge, MA	Physical treatment	Storage/settling	Storage tank
3. Philadelphia, PA	Physical treatment	Microscreening	Screen backwash
4. Racine, WI	Physical/chemical treatment	Screening/dissolved-air flotation	Combined screen backwash & flotation scum
5. Hawley Road Milwaukee, WI	Physical/chemical treatment	Screening/dissolved-air flotation	Flotation scum
6. Baker Street San Francisco, CA	Physical/chemical treatment	Dissolved-air flotation	Flotation scum
7. Kenosha, WI	Biological treatment	Contact stabilization activated sludge	Stabilization tank
8. New Providence, NJ[a]	Biological treatment	Trickling filtration	Primary clarifier; secondary clarifier

a. Both wet-weather and dry-weather treatment sludge samples were procured.

SECTION IV

SAMPLING, TEST METHODS AND PROCEDURES

SAMPLE COLLECTION

As mentioned previously, sludge samples were collected from eight treatment sites in seven U.S. cities. All samples were collected manually. Only one sample was obtained from each site for characterization and testing. Each of these samples was composited manually from several grab samples collected during the operation of the treatment facility. Most of the feasibility tests were conducted on site except for two sites where samples had to be air freighted to Milwaukee because of scheduling difficulties. These arrangements generally necessitated a sludge aging period of 4 to 36 hours after which the feasibility tests could be started. Laboratory analyses requiring immediate attention, such as BOD_5 and coliforms, were undertaken immediately while samples were refrigerated for other less critical analyses. Separate special samples were also preserved immediately in glass bottles having teflon lined stoppers for pesticides and PCB analyses.

Every effort was made to utilize uniform sampling and testing procedures for various sludge samples; yet certain special handling procedures had to be adopted for individual sludge samples because of their inherent differences. The following details the individual sample collections for the various sites visited.

1. Humboldt Avenue, Milwaukee, WI - This detention-chlorination treatment facility produces the entire contents of the storage basin as the treatment residuals. During overflow periods, the tank contents are mixed with only one of the seven rotary mixers to dispense chlorine and to enable the detention tank to act as a settling basin. After the overflow has subsided, all mixers are activated to resuspend settled solids and the pumpback of the tank contents to the sewer commences. Thus, large volumes of relatively dilute residuals are produced that must be disposed of in a satisfactory manner. A 0.9 cu m (240 gal.) sample of the resuspended contents of the storage tank was collected for the storm event of March 3, 1974.

   It was observed that the collected waste settled very poorly and the supernatant was very turbid. This may have been due to the fact that the tank contents were mixed overnight and any floc present was sheared. The suspended solids concentration of this sample was only 181 mg/l and further concentration of the solids present via sedimentation was deemed necessary prior to undertaking any thickening tests. To facilitate faster settling the waste was treated with 25 mg/l of ferric chloride and flocculated for two minutes. The waste was then allowed to settle for one hour before the supernatant was removed. Approximately two gallons of settled sludge was collected from the original sample. This chemically clarified and settled sludge was utilized in the bench testing and laboratory analyses.

2. Cottage Farm, Cambridge, MA - This detention-chlorination facility produces large volumes of retained residuals which are normally returned to the dry-weather treatment facility. No mixing provisions are available in the detention tank. This necessitates manual hosing down of the residual solids from the bottom of the tank after the supernatant has been pumped out. Two separate samples of this residual sludge were collected on February 20 and March 21, 1974.

3. Philadelphia, PA - This pilot scale demonstration facility utilizes microscreening treatment of combined sewer overflows. No suitable sludge sample could be collected during the contract period. However, a backwash waste sample was obtained manually by flushing Callowhill Street between Edgemore and 6th Streets with fire hydrant water on two occasions (January 30 and 31, 1974). Also, a small backwash sample from an earlier overflow (January 27, 1974) was collected. Comparison of the manually flushed and actual storm samples indicated that there were significant differences in their characteristics. Therefore, it was felt that any results derived from the thickening testing of the collected sample would not truly represent the sludges from microscreening treatment of CSO. Hence any results obtained from bench tests at this site were omitted from this report.

4. Racine, WI - The sludge at this site is generated by a screening/dissolved-air flotation system. Because of the nature of this system, two sludges are generated. The first of these is the backwash from the screening process. The second sludge is the scum produced from the dissolved-air flotation process. At this site residual solids from both sources are piped to a common tank and eventually returned to the sewer when sufficiently low flows are experienced. Since it was not physically possible to obtain separate representative samples of the screen backwash and floated scum at this site (due to the closed pipes carrying the two residuals), a 0.15 cu m (40 gal.) sample of the combined residuals was obtained from the holding tank. Due to the dilute nature of this sample it was deemed necessary to provide further concentration of the solids present via sedimentation prior to undertaking any thickening tests. The collected sample showed good amenability to settling and the residual solids could be concentrated to approximately 12% of the original volume within 30 minutes of sedimentation. However, this reduced volume of recovered sludge was not sufficient to conduct all bench-thickening tests. Therefore, another larger sample was collected from the holding tank from the next storm event during September 1973. To facilitate collection of a large concentrated sample, the combined contents of the holding tank were allowed to settle in the same tank at the treatment site. A 0.08 cu m (20 gal.) sample of the concentrated sludge having a solids content of 2.72% was then drawn off for thickening tests.

5. Hawley Road, Milwaukee, WI - This site also has a screening/dissolved-air flotation pilot demonstration system with a treatment capacity of 18,925 cu m/day (5 mgd). During the storm event of July 21, 1973, only the dissolved-air flotation scum was obtained since the screen backwash system did not require activation. Several grab samples collected manually during the operation of the treatment facility were manually composited to one 0.15 cu m (40 gal.) sample for characterization and thickening tests.

6. Baker Street, San Francisco, CA - The dissolved-air flotation process is used for the treatment of CSO at this site. Flexibility exists to permit recycling of either the treated effluent or raw influent stream for air saturation under pressure. The chemical feed systems are provided for adding alum, polyelectrolyte, caustic and sodium hypochlorite solutions. A 0.15 cu m (40 gal.) grab sample of the floated scum was obtained on February 12, 1974 for characterization and laboratory thickening tests. The treatment facility was operated in the effluent recycle mode of operation using alum, caustic and polyelectrolyte during this storm event.

7. Kenosha, WI - A biological type treatment system using the contact stabilization process (modified conventional activated sludge process) is utilized at this site for the treatment of CSO. The system is designed to treat 75,700 cu m/day (20 mgd) of combined sewer overflow. The clarification and solids handling facilities are shared with the dry-weather treatment plant to obtain optimum use of the equipment. During dry-weather, waste activated sludge is discharged through the stabilization tank to maintain a supply of viable stabilized sludge ready for use at all times. During an overflow, this stabilized sludge is mixed with the raw waste and aerated in the contact tank for a period of 15-30 minutes after which the solids are settled in a final clarifier and returned to the stabilization tank. During a storm event, all solids removed from the raw waste or biologically produced are retained within the system, i.e. in the contact tank, stabilization tank or clarifier.

A 0.15 cu m (40 gal.) sludge sample was obtained from the aerated stabilization tank immediately after the overflow stopped on August 9, 1973. This point of sampling represented the most practical sampling point for obtaining a representative sample of the residual waste solids.

8. New Providence, NJ - This facility is designed for the treatment of domestic wastewater with a high amount of stormwater infiltrate during wet-weather periods. However, because of the biological nature of the treatment system (trickling filtration), the biota is kept alive by continuous operation during dry-weather periods. Due to the dual use of this trickling filter facility, two sludge samples were collected, one during dry-weather and one during wet-weather. Samples of the final clarifier and primary clarifier sludge were collected during both the dry and wet-weather periods.

The primary sludge was sampled from the sludge discharge line from the primary clarifier. About 0.13 cu m (35 gal.) was collected for the dry-weather sample and about 0.08 cu m (20 gal.) was collected for the wet-weather sample. The final clarifier sample was withdrawn from the end of the sludge line, where it mixes with the flow at the head end of the plant. About 0.13 cu m (35 gal.) was collected during the dry-weather period for on-site tests while about 0.08 cu m (20 gal.) was collected during the wet weather event for characterization and bench tests.

ANALYTICAL PROCEDURES

Analytical procedures were conducted in accordace with Standard Methods for the Examination of Water and Wastewater (6) and EPA's Methods for Chemical Analysis of Water and Wastes (7). Details are presented in Appendix B.

SLUDGE THICKENING BENCH TEST PROCEDURES

The bench tests consisted of gravity thickening, dissolved-air flotation thickening, centrifuge dewatering, and vacuum filtration. Appendix B contains detailed descriptions of the sludge thickening bench scale testing procedures. A brief description of these tests is presented below:

1. Gravity Thickening - These tests were conducted in one liter graduated cylinders. The cylinders were filled with sludge to the 1000 ml mark and allowed to settle for at least one hour. During this time readings of the position of the interface were taken and recorded along with the elapsed time. This test was then repeated using a variety of sludge concentrations. Following these tests, various flocculating chemicals were screened to determine the optimum chemical and dosage for floc formation. The chemical was then added to the sludge at the predetermined dosage and another set of settling tests were conducted to define the effects of chemical flocculation. The data derived was then analyzed by a combination of the Coe and Clevenger (8) and Mancini (9) methods to define design parameters for a gravity thickener.

2. Dissolved-Air Flotation Thickening - The basic equipment used in these tests was a graduated cylinder, stopwatch, and pressurized flow source. To conduct the test a predetermined amount of sludge was placed in the graduated cylinder and pressurized flow was introduced into the sludge until the total volume reached 1000 ml. The position of the interface was then recorded along with the time of the reading. This test was conducted with different amounts of sludge so that the optimum recycle rate could be determined. Once determined, a series of tests were conducted to determine the optimum chemical dosage. The test yielding the best estimated scum concentration and rate of rise was then selected.

3. Centrifuge Dewatering - Chemically untreated and/or treated sludge was centrifuged for various times at different "G" (gravitational) forces. The resultant centrate was decanted off, measured, and analyzed for suspended solids. The sludge depth was then measured and penetrability was determined via a glass rod. From the data recorded, cake solids, cake quantity, and optimum spin time and speed were determined.

4. Vacuum Filtration - Aliquots of the sludge with different chemical dosages were filtered through a Whatman filter paper held in a Buchner funnel. The volume of the filtrate and the elapsed time were recorded as the test progressed. The specific cake resistance was then calculated to determine the optimum chemical dosage. The filter paper was replaced with filter cloth. A variety of cloths were screened to determine which cloth would best discharge the cake. This cloth was then applied to the filter leaf and placed in approximately two liters of chemically treated sludge for a specified pickup time. The leaf was rotated out of the sludge and held upside down for the specified drying time. The filtrate was then volumetrically measured and both the filtrate and cake were analyzed for solids. The data was then tabulated to determine the optimum conditions for vacuum filtration.

SECTION V

CHARACTERIZATION OF CSO SLUDGES

The characterization of CSO sludges is presented according to the following groupings based on the type of treatment process utilized at the various sites.

A. Physical Treatment and/or Storage/Settling

1. Milwaukee, WI (storage/settling)
2. Cambridge, MA (storage/settling)
3. Philadelphia, PA (microscreening)

B. Physical/Chemical Treatment

1. Racine, WI (screening/dissolved-air flotation)
2. Milwaukee, WI (screening/dissolved-air flotation)
3. San Francisco, CA (dissolved-air flotation)

C. Biological Treatment

1. Kenosha, WI (contact stabilization)
2. New Providence, NJ (trickling filtration)

A discussion of the volumes produced and the sludge characteristics emanating from these groups is presented in the following sections. The sludge quantity and quality data are based on the laboratory analyses of one grab or manual composite sample from each site. The analyses were performed on the raw samples prior to the conduct of the sludge treatment feasibility tests.

SLUDGE VOLUMES

The sludge volumes produced per storm event at each site and the estimated volumes of sludge that would result from the treatment of the entire combined sewer area for the respective cities are presented in Table 2. The volumes shown represent average values and were derived from the past data obtained at these sites. Estimates of the average residual sludge volumes produced per unit of raw combined sewer overflow treated are also shown in this table for the various treatment types investigated. Comparative available sludge volume data for high rate filtration treatment of CSO are also included from the Cleveland, OH study (10).

Table 2. SLUDGE VOLUMES PRODUCED PER STORM EVENT FOR VARIOUS CSO TREATMENT METHODS

Site	Type of Treatment	Contributing areas, 00 Ac: To Site	Contributing areas, 00 Ac: Entire combined sewer	Contributing areas, 00 Ac: Entire city drainage	Average volume of raw CSO treated per storm[a] 000 gal.	Average residual sludge volume per storm[a] 000 gal.	Volume of residual sludge requiring thickening volume of raw CSO treated %	Projected sludge residual volumes /storm event for entire CSO area 000 gal.	Solids content of the residual sludge %
Humboldt Ave., Milw. WI	Storage/settl'g	5.7	172.8	1500	3900	3900 (34.7)[c]	0.9	118,150 (1050)[c]	0.015 (1.74)[c]
Cambridge, MA	Storage/settl'g	333.3	364.7	2610	8800	1500 (18.0)[c]	0.2	1,640 (19.5)[c]	0.016 (4.4)[c]
Philadelphia, PA	Microscreening	0.11	1600	2286	82.6	3.5	4.2	50,600	0 70
Racine, WI	Screening/ flotation	4.7	7.0	1145	2530	121[d]	4.8	181	0.84[d]
Hawley Road, Milw. WI	Screening/ flotation	4.9	172.8	1500	204.6	1.45[e]	0.7	1,278	3.65[e]
San Francisco, CA	Dissolved-Air flotation	1.68	300	300	303.0	1.82	0.6	325	2.25
Kenosha, WI	Contact stabilization	12.0	13.3	92.2	3500	122.6	3.5	236.5[h]	0.83
New Providence, NJ	Trickling filtration	24.3	b	24.3					
Primary - WW[i]					3060	194.2	6.8[g]	210.2	0.12
Secondary - WW[i]						16.0[f]			2.50
Primary - DW					900	18.0[f]	4.9[g]	44.2	0.38
Secondary-DW						26.2[f]			0.46
Cleveland, OH	High Rate filtration		440	620	10	0.4	4.0		0.01 to 1.0

a. Based on past data from various sites.
b. There are no contributing storm sewers. The system treats sanitary sewage with excessive storm water infiltrate.
c. Reduced volume of concentrated solids achieved by settling of solids in the holding tank. It is assumed that only settled solids will require further handling and thickening and the supernatant can be discharged to the receiving water.
d. Floated scum plus screen backwash water.
e. Floated scum only.
f. Sludge production in gallons produced per day.
g. Combined residuals from primary and secondary clarifiers
h. During an average run only 57.5% of CSO from contributing areas is treated by the wet-weather demonstration system
i. WW = wet-weather; DW = dry-weather

Ac = 0.405 ha; gal. = 0.003785 cu m

As seen in Table 2, the volumes of residual sludges produced from the treatment of CSO vary from 0.2 percent to 6.8 percent of the raw flow treated. Among the various types of CSO treatment residuals evaluated during this study, the storage/settling treatment produced the least amounts of residuals as a percentage of raw CSO flow treated for further thickening when it is assumed that the settled supernatant is discharged to the receiving water. Sludge volumes produced by dissolved-air flotation treatment alone were less than 1% of the raw CSO treated (San Francisco and Hawley Road, Milwaukee), however, the addition of screen backwash water to the flotation sludges increased the residual volume to 4.8% of the raw CSO flow (Racine). The solids content of the flotation sludges dropped from approximately 3% to 0.8% due to the dilution by screen backwash water. Thus, when screening is used with dissolved-air flotation, the screen backwash water can account for nearly 80% or more of the sludge volume. Therefore, it is indicated that any possible sludge handling method for the CSO sludge should include separation of the screen backwash water and the floated sludge. Since the backwash is generally low in solids, it could possibly be bled back to the sewer and treated with the raw flow at the dry-weather treatment facilities, if such added hydraulic and solids loadings can be accommodated. Sludge handling would then be concerned with less than 20% of the volume that is due to the floated sludge, which is about 2-4% solids. This sludge could be thickened by gravity settling or flotation and then further concentrated by centrifugation or vacuum filtration before final disposal.

Because comprehensive rainfall monitoring was conducted as part of the Racine project (11), the sludge production can also be related to the rainfall amounts. It was found that an average rainfall amount of 0.25 cm (0.10 in.) must fall in the combined sewer area before overflow will begin. After overflow does begin, each additional 0.25 cm (0.10 in.) of rainfall will produce an average overflow of 17,922 cu m (4,735,000 gal.) for the subject area having a composite average coefficient of runoff (c) value of 0.65. Using 0.048 cu m (12.7 gal.) of sludge produced per unit volume of CSO treated reveals that every 0.25 cm (0.1 in.) of rainfall after the first 0.25 cm (0.1 in.) will produce 957 cu m (226,000 gal.) of CSO sludge for the Racine study area.

Among the biological types of CSO treatment processes investigated, the contact stabilization at Kenosha, WI produced 3.5% of the raw CSO treated through the system as the residual sludge volume. This percentage was calculated from the data obtained from the Kenosha stormwater project report (12). The report showed that during an average run, 13,248 cu m (3.5 million gal.) of CSO was treated removing 3,977 kg (8,760 lbs) of suspended solids and produced another 663 kg (1,460 lbs) of solids. Using these numbers and an average solids concentration of 1% (the solids concentration of one grab sample obtained during this study was 8,300 mg/l), the residual sludge volume was calculated to be 464 cu m (122,600 gal.) or 3.5% of the raw CSO. Comparatively, the average sludge volume from the dry-weather plant operation at Kenosha is indicated to be approximately 1.1% of the average raw flow treated through the plant (13). (This percentage includes both the primary as well as the waste activated sludge.) On a mass basis, it is indicated that an average of 15,193 kg (33,500 lbs) of solids are produced per day from the primary and secondary facilities. The average dry-weather flow through the plant during this period (1974-75) was 83,280 cu m/day (22 mgd). Using these numbers, the amount of residual solids produced from 13,248 cu m (3.5 million gal.) of dry-weather flow would be 2417 kg (5329 lbs) of solids. Thus, it is indicated that the residual solids produced during dry-weather treatment are approximately 52% of the solids produced during wet-weather treatment at Kenosha, WI. The lower production of solids during dry-weather treatment is expected because of the weaker solids concentration of the influent waste during dry-weather flow. Average influent suspended solids concentration during dry-weather flow varied between 125 and 160 mg/l during 1970 to 1975 compared to a weighted mean average of 332 mg/l during 1972 for the wet-weather treatment.

The residual sludge volume from the primary and secondary clarifiers was calculated to be 6.8% of the raw CSO from the trickling filtration treatment at New Providence, NJ (14,15). The comparative dry-weather residual sludge was estimated to be 4.6% of the influent flow and was again found to be less than the wet-weather sludge production.

In order to compare the sludge volume production from various types of CSO treatment, some data was made available to this study from another EPA pilot demonstration project (10) in which high-rate deep-bed filtration was utilized for the treatment of CSO. It was indicated that an average of 4.0% of raw CSO was produced as residual sludge (backwash wastewater) from this type of treatment. The solids content of this wastewater varied from approximately 10,000 mg/l after 1-2 minutes of backwashing to less than 100 mg/l after approximately 5 minutes of backwashing.

SLUDGE CHARACTERISTICS

The characteristics of the CSO sludges obtained from this study are presented in Tables 3-5. The solids content of the sludge samples varied widely. The holding tanks produced sludges of 1.7%, 4.4% and 11.0% solids after sedimentation; the screening up to 0.7%, dissolved-air flotation 2.25% (San Francisco) and 3.65% (Hawley Road, Milwaukee), screening/dissolved-air flotation 0.84% (Racine), and biological treatment 0.12 to 2.5% for trickling filtration (New Providence) and 0.83% for contact stabilization (Kenosha).

The volatile fraction of the sludge suspended solids varied from 25% to 63%. Biological treatment sludges showed the highest volatile fraction, about 60%, while physical and physical/chemical treatment sludges showed only a 25% to 48% volatile fraction.

The BOD, TOC, DOC (dissolved organic carbon), total phosphorus and TKN (total Kjeldahl nitrogen) concentrations also varied widely. The highest concentrations were found in the sludge sample obtained from Cambridge, MA.

The soluble nitorgen forms, ammonia, nitrites, and nitrates, were low in concentration for all sites except the New Providence secondary sludge which was very high in ammonia concentration.

It may be noted that the suspended solids value for Cambridge, MA shown in Table 3 at 11% solids is significantly higher than the corresponding value

Table 3. CHARACTERISTICS OF CSO SLUDGES FROM PHYSICAL OR STORAGE/SETTLING TYPE TREATMENT

Parameter	Units	Sites		
		Milwaukee[a]	Cambridge[a]	Philadelphia
Total Solids	mg/l	18,900	126,900	8,660
Suspended Solids	mg/l	17,400	110,000	7,000
Total Volatile Solids	mg/l	9,150	57,500	2,520
Volatile Suspended Solids	mg/l	8,425	41,400	1,755
BOD_5	mg/l	2,200	12,000	--
TOC	mg/l	7,250	16,200	1,032
Dissolved Organic Carbon	mg/l	55	949	--
Total Phosphorus (as P)	mg/l	109.1	293.4	11.5
Total Kjeldahl Nitrogen (as N)	mg/l	56	28	46
Ammonia (as N)	mg/l	4.1	3.2	--
NO_2 (as N)	mg/l	0.15	0.4	--
NO_3 (as N)	mg/l	1.7	0.5	--
Density	gm/cm^3	1.015	1.06	1.05
pH	--	6.4	5.7	7.4
Total Coliforms	#/100 ml	--	210,000,000	--
Fecal Coliforms	#/100 ml	--	2,800,000	--
Fuel Value	cal/gm (BTU/lb)	--	2721 (4903)	1971 (3227)
PCB's	µg/kg. dry	47	6,570	ND
pp' DDD	µg/kg. dry	ND	ND	ND
pp' DDT	µg/kg. dry	ND	170	ND
Dieldrin	µg/kg. dry	20	58	ND
Zinc	mg/kg. dry	799	946	1,189
Lead	mg/kg. dry	2,063	1,261	2,448
Copper	mg/kg. dry	201	757	200
Nickel	mg/kg. dry	159	126	289
Chromium	mg/kg. dry	243	260	52
Mercury	mg/kg. dry	2.7	0.01	2.1

ND = None detected.
a = After settling of holding tank contents.

Table 4. CHARACTERISTICS OF CSO SLUDGES FROM PHYSICAL/CHEMICAL TYPE TREATMENT

Parameter	Units	Sites Racine	Milwaukee [a]	San Francisco [a]
Total Solids	mg/l	9,769	42,700	24,000
Suspended Solids	mg/l	8,433	41,900	22,500
Total Volatile Solids	mg/l	3,596	11,350	9,400
Volatile Suspended Solids	mg/l	3,340	10,570	8,850
BOD_5	mg/l	1,100	3,200	1,000
TOC	mg/l	260	6,050	1,600
Dissolved Organic Carbon	mg/l	60	340	67
Total Phosphorus (as P)	mg/l	39.2	149	166
Total Kjeldahl Nitrogen (as N)	mg/l	112	517	375
Ammonia (as N)	mg/l	6.3	12.5	7.5
NO_2 (as N)	mg/l	<0.1	<0.1	0.02
NO_3 (as N)	mg/l	<0.1	<0.1	0.1
Density	gm/cm^3	1.01	1.07	1.014
pH	--	6.9	7.2	5.2
Total Coliforms	#/100 ml	40,000	6,400,000	6,300,000
Fecal Coliforms	#/100 ml	1,400	220,000	17,000
Fuel Value	cal/gm (BTU/lb)	1,961 (3534)	1,359 (2449)	1,950 (3514)
PCB's	µg/kg. dry	603	775	113
pp' DDD	µg/kg. dry	ND	225	29
pp' DDT	µg/kg. dry	ND	TR	96
Dieldrin	µg/kg. dry	24	9	192
Zinc	mg/kg. dry	1,638	855	[illegible]8
Lead	mg/kg. dry	1,023	164	1,583
Copper	mg/kg. dry	481	248	367
Nickel	mg/kg. dry	215	173	<83
Chromium	mg/kg. dry	215	150	1,667
Mercury	mg/kg. dry	2.3	2.1	3.9

ND = None Detected TR = Trace (<0.2 µg/l on wet basis)
a = Floated sludge only

Table 5. CHARACTERISTICS OF CSL SLUDGES FROM BIOLOGICAL TREATMENT

Parameter	Units	Kenosha	New Providence Wet-Weather Sludges: Primary	New Providence Wet-Weather Sludges: Secondary
Total Solids	mg/l	8,527	2,010	25,500
Suspended Solids	mg/l	8,300	1,215	25,070
Total Volatile Solids	mg/l	5,003	1,120	15,500
Volatile Suspended Solids	mg/l	5,225	780	14,770
BOD_5	mg/l	1,700	728	11,200
TOC	mg/l	3,400	700	13,000
Dissolved Organic Carbon	mg/l	29	220	710
Total Phosphorus (as P)	mg/l	194	22	436
Total Kjeldahl Nitrogen (as N)	mg/l	492	65	6
Ammonia (as N)	mg/l	24	9	180
NO_2 (as N)	mg/l	0.055	0.02	0.02
NO_3 (as N)	mg/l	0.065	0.11	0.09
Density	gm/cm^3	--	1.005	1.013
pH	--	7.9	6.9	--
Total Coliforms	#/100 ml	1,200,000	44,000,000	1,300,000,000
Fecal Coliforms	#/100 ml	79,000	3,400,000	1,000,000
Fuel Value	cal./gm. (BTU/lb)	3,446 (6210)	3,585 (6460)	3,583 (6457)
PCB's	µg/kg. dry	767	547	--
pp' DDD	µg/kg. dry	93	ND	--
pp' DDT	µg/kg. dry	TR	ND	--
Dieldrin	µg/kg. dry	88	ND	--
Zinc	mg/kg. dry	7,154	697	1,294
Lead	mg/kg. dry	528	<498	353
Copper	mg/kg. dry	1,454	995	1,020
Nickel	mg/kg. dry	528	995	784
Chromium	mg/kg. dry	1,278	746	2,471
Mercury	mg/kg. dry	2.6	100.5	--

TR = Trace (<0.2 µg/l on wet basis)

Table 5. (continued)
CHARACTERISTICS OF CSO SLUDGES
FROM BIOLOGICAL TREATMENT

Parameter	Units	New Providence Dry-Weather Sludges Primary	Secondary
Total Solids	mg/l	4,168	4,930
Suspended Solids	mg/l	3,840	4,620
Total Volatile Solids	mg/l	3,205	3,638
Volatile Suspended Solids	mg/l	3,200	3,610
BOD_5	mg/l	1,600	2,950
TOC	mg/l	--	--
Dissolved Organic Carbon	mg/l	92	54
Total Phosphorus (as P)	mg/l	40.7	92.7
Total Kjeldahl Nitrogen (as N)	mg/l	214	277
Ammonia (as N)	mg/l	38	25
NO_2 (as N)	mg/l	<0.01	0.019
NO_3 (as N)	mg/l	0.03	0.01
Density	gm/cm^3	1.006	1.005
pH	--	6.7	6.7
Total Coliforms	#/100 ml	20,000,000	8,500,000
Fecal Coliforms	#/100 ml	2,000,000	1,000,000
Fuel Value	cal./gm. (BTU/lb)	4,452 (8022)	--
PCB's	µg/kg. dry	ND	--
pp' DDD	µg/kg. dry	1,750	--
pp' DDT	µg/kg. dry	878	--
Dieldrin	µg/kg. dry	3,000	--
Zinc	mg/kg. dry	1,288	1,744
Lead	mg/kg. dry	240	304
Copper	mg/kg. dry	600	953
Nickel	mg/kg. dry	480	913
Chromium	mg/kg. dry	847	2,049
Mercury	mg/kg. dry	6.2	21.5

for the same site in Table 2 at 4.4%. These two values represent two separate grab samples. The first sample showed a solids value of 4.4%, however, enough sample was not available for detailed analysis. Therefore, a second sample in larger volume was obtained from this site. This sample was analyzed for various constituents and was found to have the significantly higher solids concentration. The lower value was used in Table 2 comparisons because it was judged to be more representative of the residual solids concentrations based on communications with the plant personnel (15).

The sludge densities ranged from 1.005 to 1.0 gm/cm^3 for the various sludges analyzed with an average value of 1.026 gm/cm^3. The storage/settling type sludges had density values of 1.015 gm/cm^3 and 1.06 gm/cm^3 for Milwaukee and Cambridge sites. The physical/chemical treatment sludges had densities ranging between 1.01 to 1.07 gm/cm^3.

The pH of the sludge samples collected ranged from 5.2 to 7.9. The low value of 5.2 was found in San Francisco where alum was being used.

As would be expected with higher volatile solids, the biological sludges also had the greatest fuel values among the sludges evaluated. The biological sludges had an average fuel value of 3,515 cal/gm (6334 BTU/lb) while the other sludges produced an average fuel value of 2,032 cal/gm (3662 BTU/lb). It can also be noted that the fuel value for the primary and secondary sludges for dry as well as wet-weather treatment at New Providence, NJ were quite close, ranging between 3500 to 4500 cal/gm (6307 to 8109 BTU/lb).

As can be seen in Table 5, the various constituents such as suspended solids, volatile suspended solids, BOD_5 and TOC showed significantly higher concentrations in the secondary wet-weather sludge compared to the dry-weather sludge for New Providence. This increase in wet-weather solids may be attributed in some part to the synthesis of dissolved organic matter present in the sewer infiltrate resulting in higher solids from the secondary clarifier. The weaker suspended solids in the primary wet-weather sludge may be a result of the dilution of the influent sewage solids by the infiltrate.

The results of the PCB and pesticide analyses are summarized in Table 6. Among the PCB's and pesticides analyzed for the various sludges, the PCB's were generally of the highest concentrations. The Cambridge sludge showed the highest concentrations of PCB's and pp'DDT while the Milwaukee (Hawley Road) sludge had the highest concentration of pp'DDD and the San Francisco sludge had the highest concentration of dieldrin. The significantly higher PCB value at Cambridge may have been a result of pollutant buildup in combined sewers and incomplete flushing of the tank residuals at the end of previous storm events.

Table 6. AVERAGE PCB AND PESTICIDE CONCENTRATIONS IN CSO SLUDGES

Parameter	Average (µg/kg dry)	Range	Site of highest concentration
PCB	407[a]	ND-6570	Cambridge
pp'DDD	43	ND-225	Milwaukee
pp'DDT	44	ND-170	Cambridge
Dieldrin	49	ND-192	San Francisco

a. Represents the average PCB value without Cambridge data. When Cambridge PCB value is used, the average PCB value becomes 1347 µg/kg dry solids, which is significantly higher than all other sludge sample values.

ND = none detected.

The heavy metals concentrations analyzed for various sludges are summarized in Table 7. Zinc was usually found to be the heavy metal of the highest concentration with the concentration of lead also being high. The secondary wet-weather sludge from New Providence and the sludge from Kenosha were both found to be high in heavy metal concentration. At New Providence, increased heavy metal loadings may be a result of the leaching of these metals in the groundwater infiltrate. Comparing the average heavy metal values obtained during this study for wet-weather sludges with the 33 dry-weather plant sludge average (17), it is seen that the dry-weather values are significantly higher than the wet-weather values. The higher heavy metal values in dry-weather sludges may be a result of accumulations of these pollutants in sludge blankets over a longer period compared to shorter wet-weather treatment durations.

Table 7. AVERAGE HEAVY METAL CONCENTRATIONS IN CSO SLUDGES

Parameter	(mg/kg dry)	Range	Site of highest concentration	Average 33 dry-weather plant sludges[b], mg/kg dry
Zinc	1,700	697-7154	Kenosha	4,210
Lead	1,100	164-2448	Philadelphia	2,750
Copper	636	200-1454	Kenosha	1,590
Nickel	372	83- 995	New Providence	680
Chromium	787	52-2471	New Providence	1,860
Mercury	2.2	0.01-100.5	New Providence	10

a. Represents average mercury concentration without New Providence data. When this data is used, the average mercury value becomes 14.5 mg/kg dry solids.

b. See Reference 17.

SECTION VI

BENCH-SCALE THICKENING TESTS AND EVALUATIONS

The results of the bench-scale dewatering tests on the sludge samples procured from the various CSO treatment facilities mentioned earlier are discussed for each site in the three subsections below. Along with the technical feasibility evaluations, economic analyses of the dewatering techniques were also developed for each site. A complete listing of the cost data and the assumptions made to develop these data are presented in Appendix C. Cost data represent the latest available, December, 1974 prices for capital equipment and updated published cost data (18,19) to December 1974 prices. Since the CSO treatment systems at Philadelphia, Milwaukee, (Hawley Road), and San Francisco were pilot scale studies and did not treat the entire overflow from the sewer outfall drainage area, these sites were scaled up to the entire flow for the respective technical and economic evaluations that follow.

A. PHYSICAL TREATMENT AND/OR STORAGE/SETTLING

Three samples of the treatment residuals were obtained under this category of CSO treatment. Two of these samples were procured from storage treatment sites in Milwaukee, WI, and Cambridge, MA. The third sample was the backwash waste from the pilot microscreening unit in Philadelphia, PA. The detained contents (CSO) from storage basins were very dilute compared to conventional sludges. For disposal, these residuals can either be pumped or bled back to the dry-weather sewage treatment facilities or dewatered on-site. A discussion of the pump/bleedback concept of such residuals is presented in Section VII of this report. For on-site treatment, it is imperative that such residuals be concentrated via conventional techniques prior to their thickening treatment. Therefore, for the sludge treatability studies herein, only the clarified sludge residuals were evaluated. As mentioned earlier, in Section IV, because of the special handling required for the procurement of these three sludge samples, only limited amounts of residuals were available for the dewatering tests. Accordingly, only gravity, flotation and centrifugation thickening tests were conducted on these samples.

Milwaukee, WI, and Cambridge, MA

Figures 1 and 2 show the treatment schematics of the bench-scale dewatering techniques investigated at Milwaukee and Cambridge, respectively. The Milwaukee CSO sample was first treated with 25 mg/l ferric chloride and

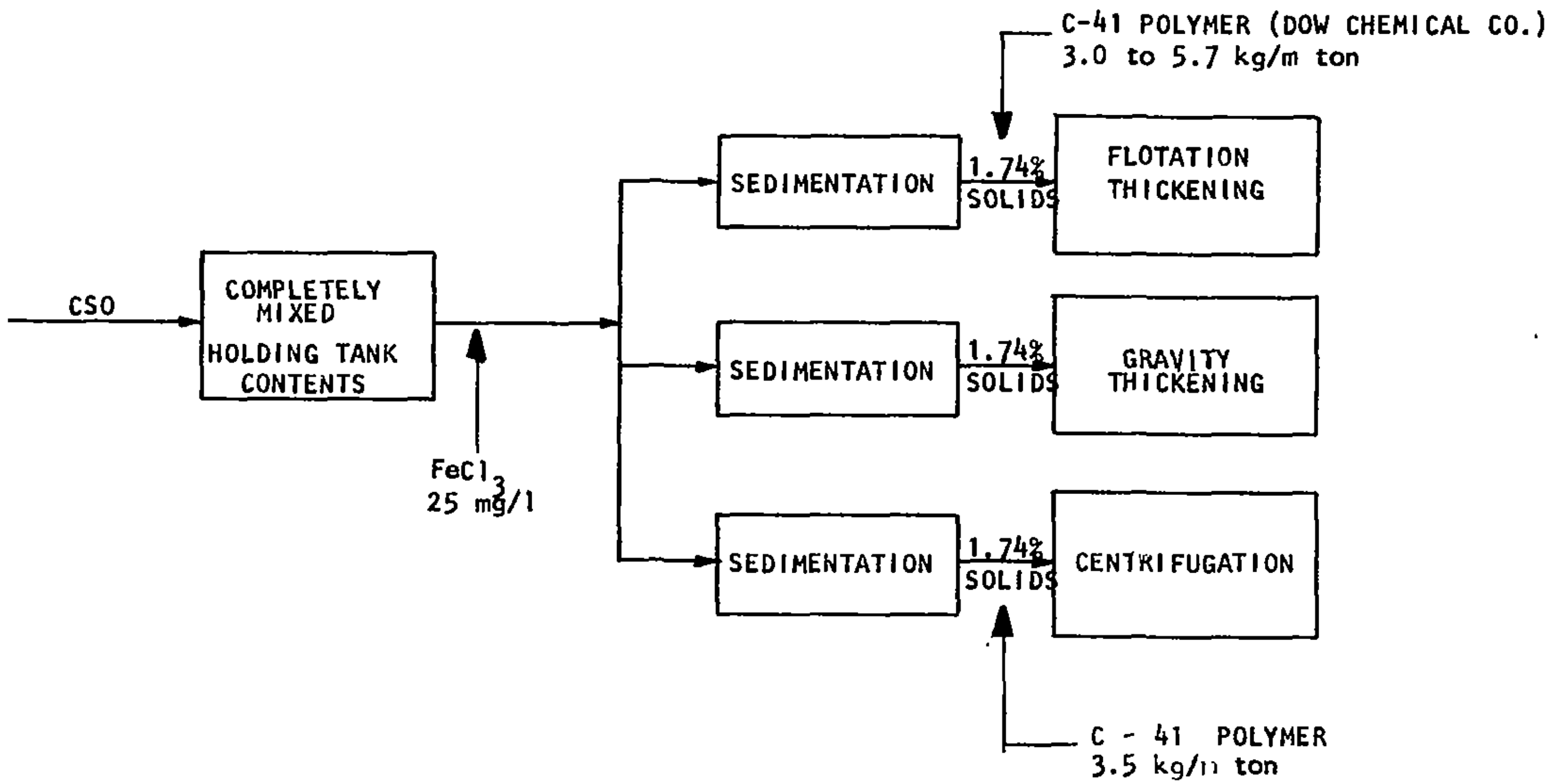


Figure I. Humboldt Avenue, Milwaukee, WI - bench scale dewatering tests

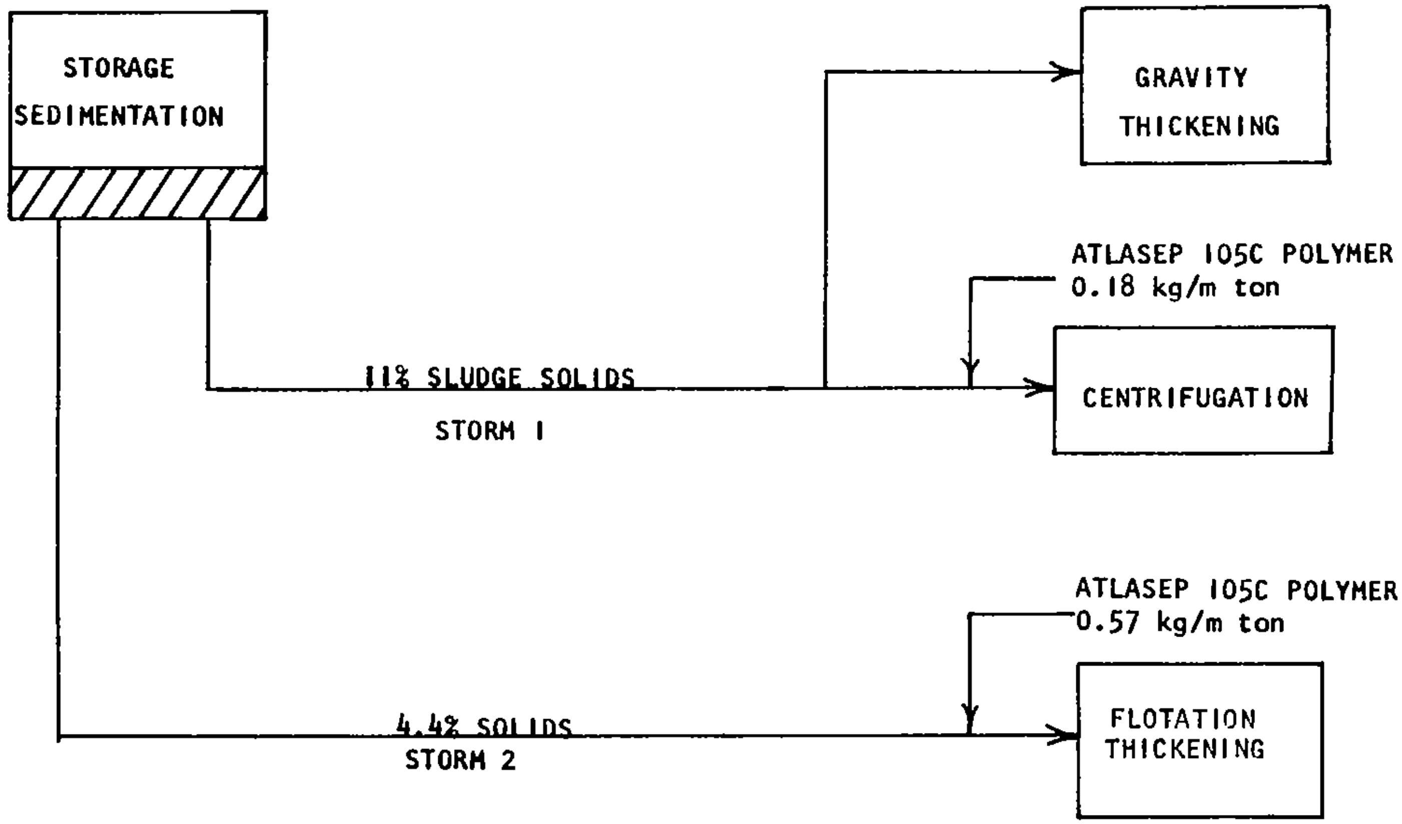


Figure 2. Cambridge, MA - Bench scale dewatering tests

settled in the laboratory prior to the thickening tests as shown in Figure 1. The Cambridge CSO was settled in the detention tank itself and two separate samples were used for the thickening tests as shown in Figure 2. Bench-scale tests consisted of gravity, flotation, and centrifugation thickening.

The average quantities of sludge requiring dewatering treatment for the two sites were calculated to be approximately 131 cu m (34,700 gal.) and 68 cu m (18,000 gal.) on a per storm event basis (Table 2). The chemical clarification of Milwaukee (Humboldt Avenue) tank contents produced a residual with 1.74% solids while the sedimented residue samples obtained from Cambridge showed 4.4% and 11% solids for two separate samples. The flux concentration curves (see Appendix B for details of curve construction) for the gravity thickening tests for Milwaukee and Cambridge samples are shown in Figures 3 and 4. From these curves, it can be seen that for Milwaukee, the sludge could be concentrated to 6% solids at an allowable mass loading rate of approximately 45 kg/sq m/day (9 lbs/sq ft/day). The corresponding concentration level achieved for the Cambridge sludge was 14% solids with the more concentrated raw sample at 160 kg/sq m/day (32 lbs/sq ft/day) without any chemicals. The results of the flotation thickening tests for the two sites are shown in Figures 5 through 8. It was found essential to use flocculating chemicals (cationic polyelectrolytes such as Atlasep 105C and Dow C-41) to aid flotation. Optimum flotation thickening results were achieved at recycle rates between 300 and 600% and polyelectrolyte dosages between 1 and 3 kg/m ton (2 to 6 lbs/ton). Scum solids concentrations of 11 to 14% for Milwaukee and 6 to 8% for Cambridge sample (with the 4.4% solids raw sample) at the above mentioned optimum chemical dosages and recycle rates were achieved. The results of the centrifuge tests for the two storage tank residuals are presented in Tables 8 and 9. Again optimum results were achieved with the aid of the cationic polyelectrolyte, Dow C-41. Optimum solids recoveries were achieved at gravitational force between 700 and 1,000 G and spin time between 60 and 120 seconds. Cake solids between 30 and 35% could easily be achieved for both sludges under optimum conditions.

A summary of the estimated area and cost requirements of various dewatering techniques under optimum treatment conditions for the two storage/settling type treatment sites is shown in Table 10. The total annual costs shown in this table include the amortized capital costs, operating costs and the cost of hauling the ultimate treatment residuals to a landfill area. It is also assumed that the dewatered supernatant liquid can be discharged to the dry-weather treatment facilities. Additional details of the cost estimates are presented in Appendix C. For comparison, vacuum filtration treatment costs are also included based on engineering judgment and filter performance for other sludges evaluated in this study. Examination of Table 10 shows that centrifugation was the optimum dewatering process based on performance, area and cost requirements for both the storage treatment sites evaluated in this study.

Philadelphia, PA

As mentioned earlier, the backwash wastewaters produced from the micro-

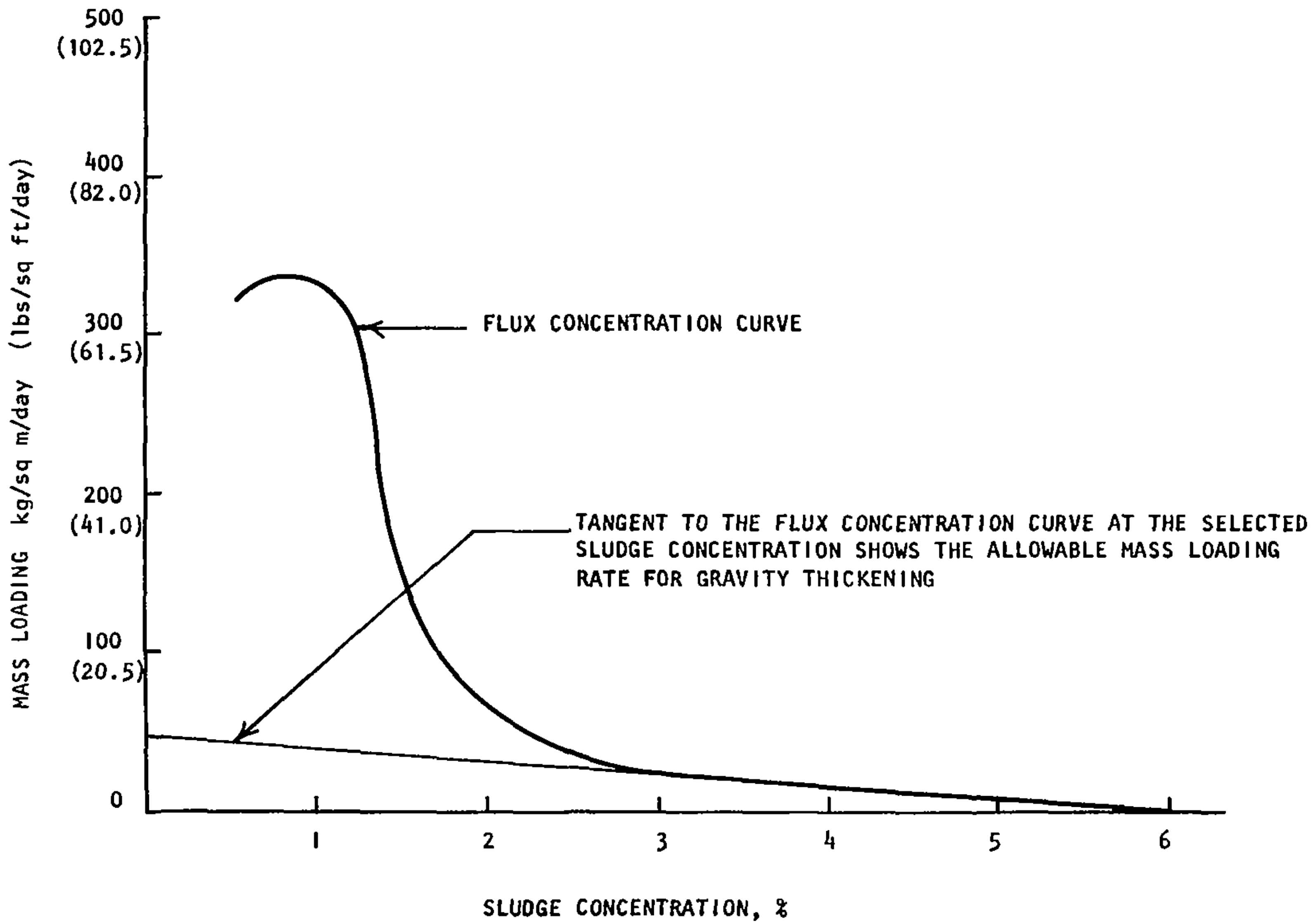


Figure 3. Flux concentration curve for Milwaukee (Humboldt Ave.) (storage/settling) sludge

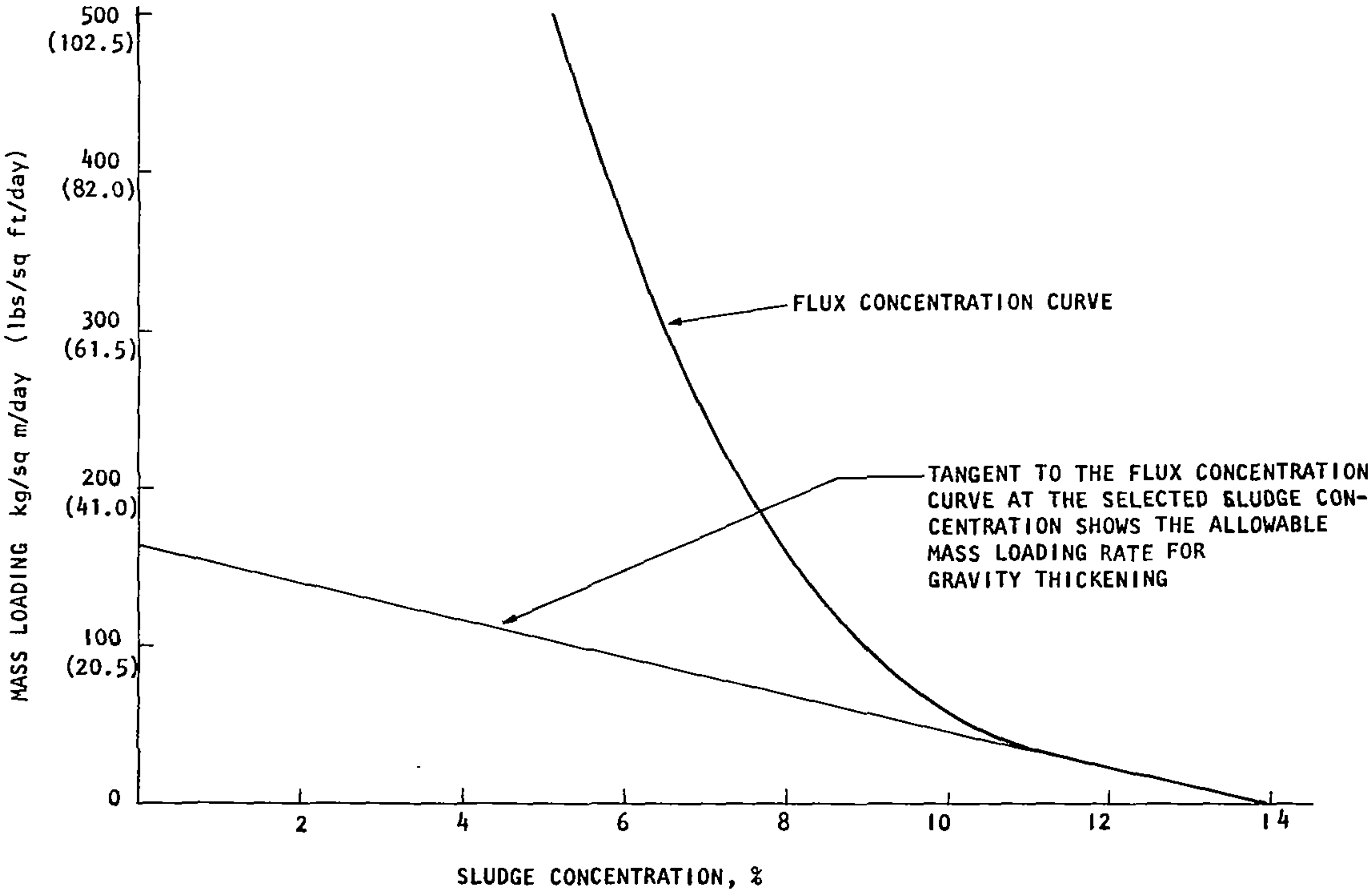


Figure 4. Flux concentration curve for Cambridge (storage/settling) sludge

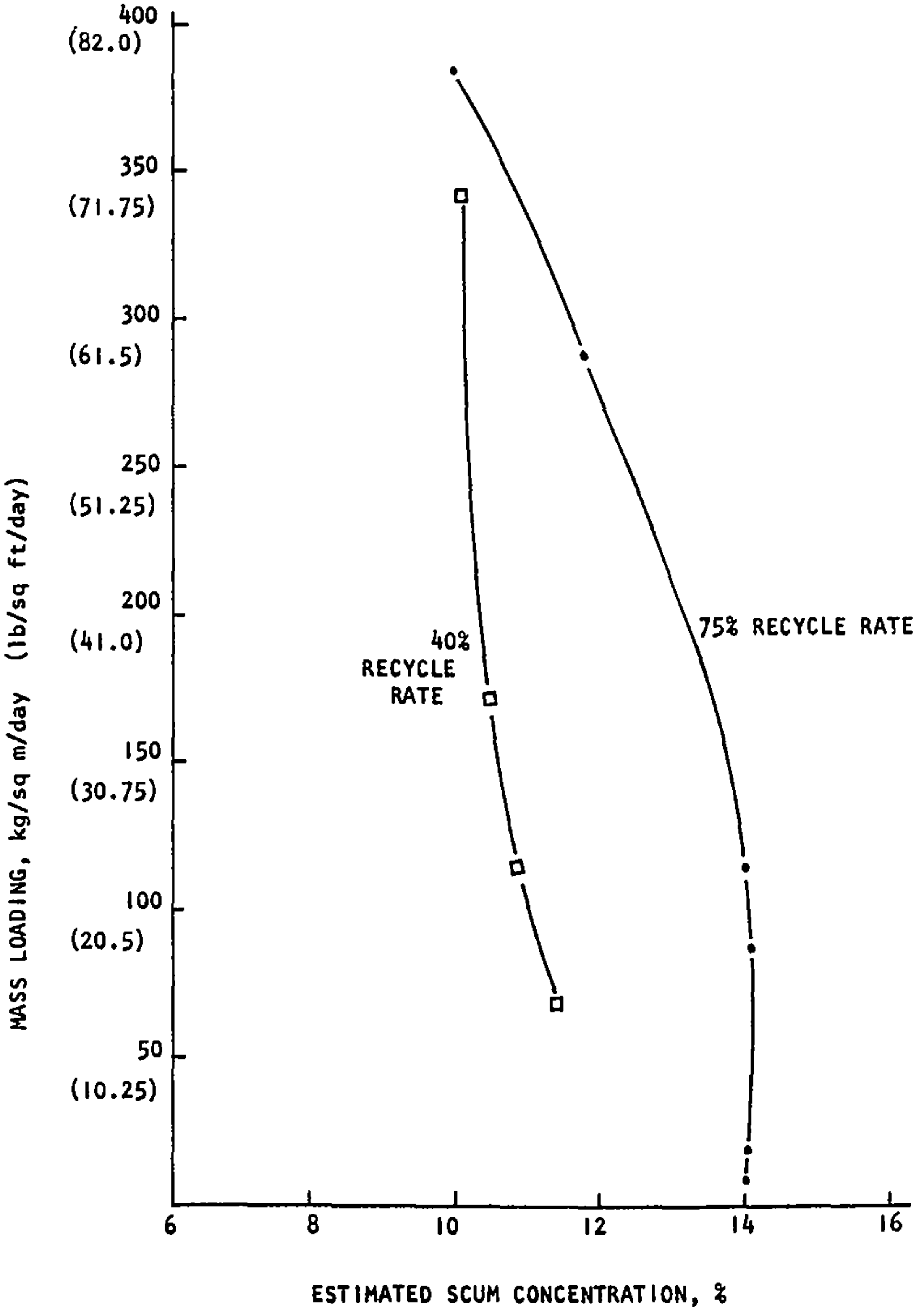


Figure 5. Flotation thickening results for Milwaukee (Humboldt Ave.) WI, storage/settling sludge - without chemicals

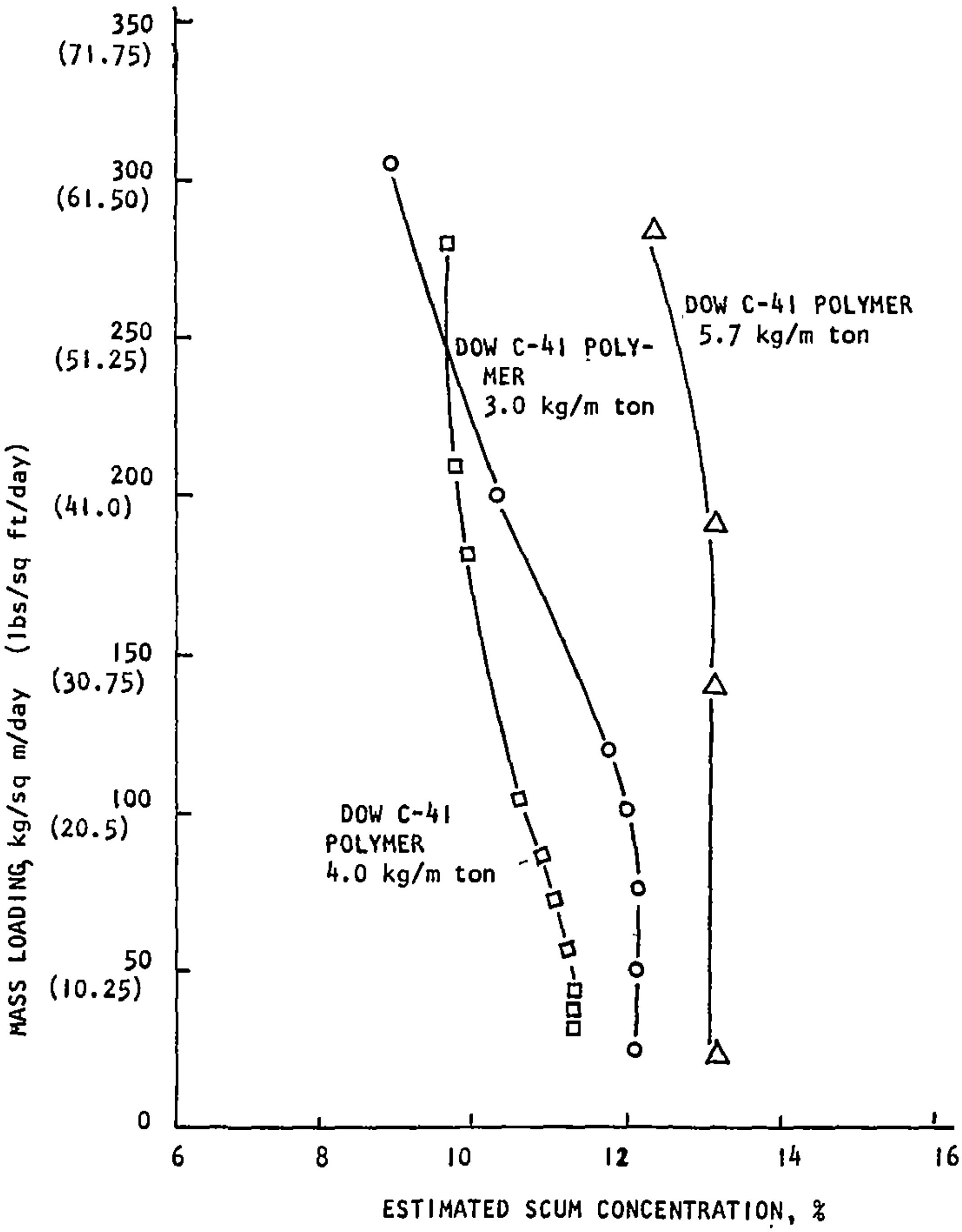


Figure 6. Flotation thickening results for Milwaukee, WI (Humboldt Avenue) storage/settling sludge-with chemicals (All tests at 290% recycle rate)

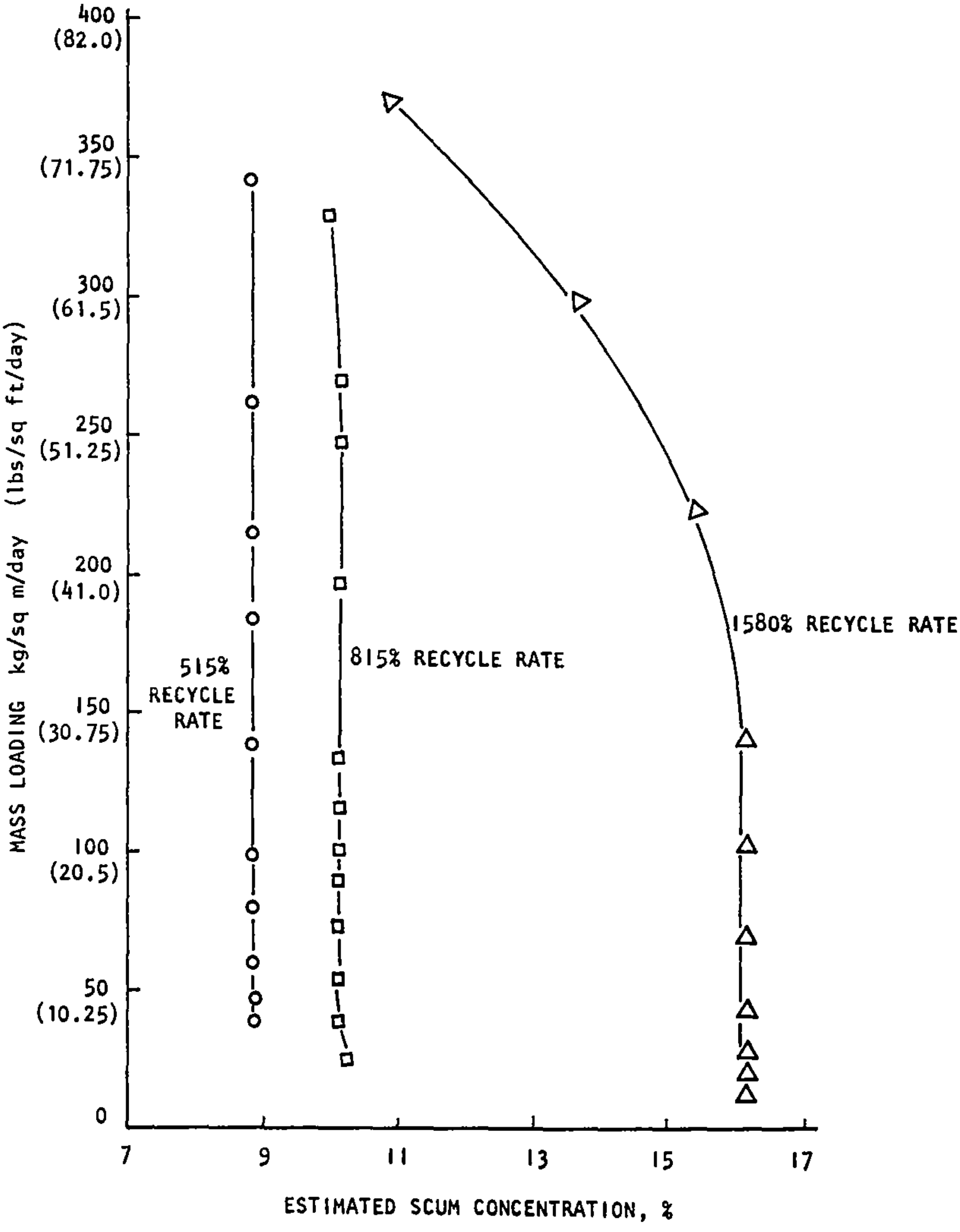


Figure 7. Flotation thickening results for Cambridge, MA storage/settling sludge-without chemicals

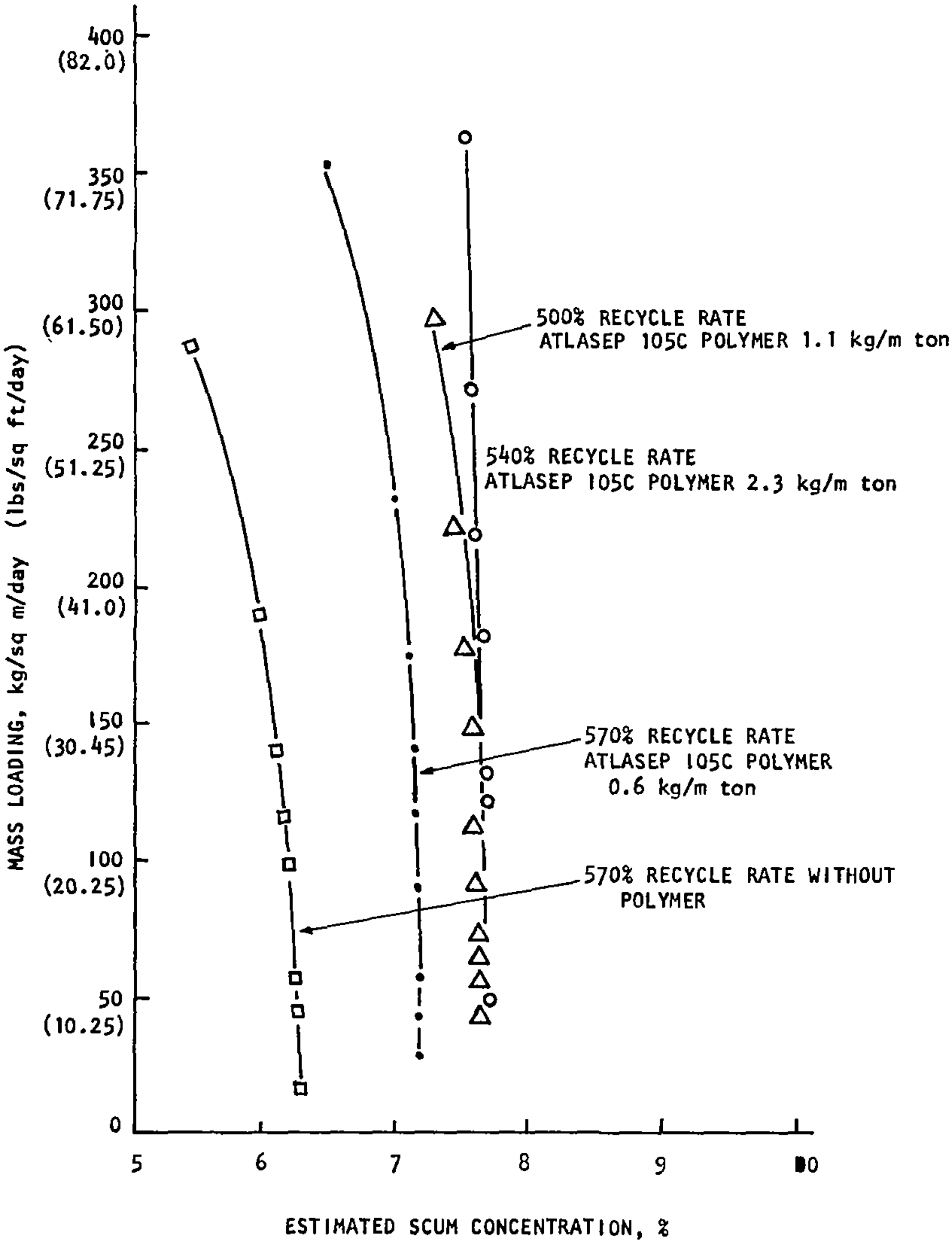


Figure 8. Flotation thickening results for Cambridge, MA storage/settling sludge - with chemicals

Table 8. CENTRIFUGE TESTING RESULTS FOR MILWAUKEE, WI, HUMBOLDT AVENUE, STORAGE/SETTLING SLUDGE

Test No.	Applied G force, G's	Time, sec	Feed solids, mg/l	Chemical	Dosage, kg/m ton	Centrate solids, mg/l	Centrate volume, ml	Penetration, cm	Sludge depth, cm	Cake solids, %	Penetration, %	Recovery, %	Corrected recovery, %
1	1,000	120	17,400	none	none	238	67	0.75	1.45	16.1	50	98.6	91.9
2	1,000	90	17,400	none	none	228	70	0.8	1.4	25.8	42	98.6	90.4
3	1,000	60	17,400	none	none	288	69	0.85	1.5	21.4	44	98.3	90.5
4	1,000	30	17,400	none	none	524	68	1.1	1.6	18.1	31	96.9	86.1
5	700	120	17,400	none	none	190	67	0.8	1.6	16.1	30	98.9	92.2
6	700	90	17,400	none	none	230	68	0.95	1.6	18.4	41	98.6	90.1
7	700	60	17,400	none	none	324	69	1.0	1.45	21.4	31	96.3	87.4
8	700	30	17,400	none	none	570	68	1.45	1.45	18.1	0	96.7	0[a]
9	400	120	17,400	none	none	326	69	1.55	1.55	21.4	0	98.1	0[a]
10	400	90	17,400	none	none	401	69	1.65	1.65	21.3	0	97.6	0[a]
11	400	60	17,400	none	none	605	66	1.75	1.75	14.1	0	96.5	0[a]
12	400	30	17,400	none	none	3,200	64	1.9	1.9	10.0	0	81.6	0[a]
13	1,000	120	17,400	C-41	3.4	119	71	0.4	1.4	32.4	71	99.3	95.9
14	1,000	90	17,400	C-41	3.4	119	72	0.4	1.35	43.2	70	99.3	95.8
15	1,000	60	17,400	C-41	3.4	107	71	0.45	1.6	32.4	72	99.3	96.0
16	1,000	30	17,400	C-41	3.4	121	70	1.6	1.6	25.9	0	99.3	0[a]
17	800	120	17,400	C-41	3.4	84	71	0.6	1.6	32.5	63	99.5	95.0
18	800	90	17,400	C-41	3.4	114	71	0.4	1.3	32.4	69	99.3	95.6
19	800	60	17,400	C-41	3.4	84	74	0.45	1.4	13.0	67	99.3	95.5
20	800	30	17,400	C-41	3.4	89	73	1.3	1.3	64.9	0	99.4	0[a]
21	600	120	17,400	C-41	3.4	90	74	0.5	1.4	13.0	64	99.4	95.0
22	600	90	17,400	C-41	3.4	151	71	0.65	1.5	32.4	57	99.1	93.6
23	600	60	17,400	C-41	3.4	155	71	0.65	1.6	32.3	60	99.1	94.1
24	600	30	17,400	C-41	3.4	134	69	0.9	1.55	21.6	0	99.2	0[a]
25	400	120	17,400	C-41	3.4	106	69	0.65	1.6	21.6	59	99.3	94.1
26	400	90	17,400	C-41	3.4	120	69	0.7	1.65	21.6	57	99.3	93.8
27	400	60	17,400	C-41	3.4	128	69	1.6	1.6	21.6	0	99.2	0[a]
28	400	30	17,400	C-41	3.4	129	68	1.8	1.8	18.5	0	99.2	0[a]

a. Indicates full penetration of the test rod through the thickened sludge and hence poor performance under the corresponding test conditions. See Appendix B for procedure.

Table 9. CENTRIFUGE TESTING RESULTS FOR CAMBRIDGE, MA, STORAGE/SETTLING SLUDGE

Test No.	Applied G Force, G's	Spin time, sec	Feed solids, mg/l	Chemical, Atlasep	Dosage, kg/m ton	Centrate solids, mg/l	Centrate volume, ml	Penetration, cm	Sludge depth, cm	Cake solids, %	Penetration, %	Recovery, %	Corrected recovery %
1	1,000	120	110,000	none	none	912	42	1.0	3.8	24.9	74	91.7	88
2	1,000	90	110,000	none	none	987	43	1.0	3.75	25.6	73	91.0	86
3	1,000	60	110,000	none	none	975	43	1.15	3.6	25.6	68	91.1	87
4	1,000	30	110,000	none	none	2,183	46	0.35	3.3	28.1	89	80.2	79
5	800	120	110,000	none	none	766	48	0.45	3.25	30.4	86	93.0	91
6	800	90	110,000	none	none	812	47	0.35	3.5	29.3	90	92.6	91
7	800	60	110,000	none	none	1,949	46	0.45	3.35	28.1	87	82.3	81
8	800	30	110,000	none	none	2,733	45	0.40	3.45	27.1	88	75 2	74
9	600	120	110,000	none	none	1,249	43	0.6	3.05	25.6	85	88.6	86
10	600	90	110,000	none	none	1,616	45	0 7	3.6	27.2	81	85.3	83
11	600	60	110,000	none	none	1,433	47	0.7	3.55	29.2	80	87.0	84
12	600	30	110,000	none	none	3,000	46	0.75	3.6	28.0	79	72.7	70
13	400	120	110,000	none	none	1,566	42	0.8	3.85	24.8	79	85.8	83
14	400	90	110,000	none	none	1,383	39	0.65	4.2	22.8	86	87.4	85
15	400	60	110,000	none	none	1,683	40	0.95	4.2	23.4	76	84.7	81
16	400	30	110,000	none	none	3,066	41	1.3	4.5	23.9	71	72.1	70
1	1,000	120	110,000	105C	0.18	515	49	0.55	3.2	31.6	83	95.3	93
2	1,000	90	110,000	105C	0.18	585	50	0.4	3.25	32.9	88	94.7	93
3	1,000	60	110,000	105C	0.18	810	49	0.45	3.4	31.6	87	92.6	91
4	1,000	30	110,000	105C	0.18	910	46	0.55	3.55	28.3	84	91.7	89
5	800	120	110,000	105C	0.18	580	47	0.3	3.4	29.4	91	94.7	93
6	800	90	110,000	105C	0.18	610	51	0.4	3.45	34.2	88	94.4	92
7	800	60	110,000	105C	0.18	735	49	0.55	3.35	31.6	84	93.3	91
8	600	30	110,000	105C	0.18	845	48	0.55	3.55	30.4	84	92.3	90
9	600	120	110,000	105C	0.18	780	44	0.55	3 6	26.5	85	92.9	90
10	600	90	110,000	105C	0 18	720	44	0.45	4.05	26.5	89	93.4	91
11	600	60	110,000	105C	0.18	735	46	0.5	3.65	28.3	86	93.3	91
12	600	30	110,000	105C	0.18	965	43	0.65	3.9	25.6	83	91.2	89
13	400	120	110,000	105C	0.18	830	47	0.5	3.8	29.3	87	92.4	90
14	400	90	110,000	105C	0.18	670	43	0.55	4.15	25.7	87	93.9	91
15	400	60	110,000	105C	0.18	855	37	0.85	4.7	21.6	62	92.2	90
16	400	30	110,000	105C	0.18	1,290	34	1.0	4.5	20.0	78	88.3	86

Table 10. SUMMARY OF AREA AND COST REQUIREMENTS FOR STORAGE/SETTLING TREATMENT RESIDUALS UNDER OPTIMUM TREATMENT CONDITIONS

Site	Humboldt Avenue				Cambridge			
	Sludge solids, %	Area		Total annual cost,[a] $/yr	Sludge solids, %	Area		Total annual cost[a], $/yr
		sq ft	(sq m)			sq ft	(sq m)	
Gravity thickening[b]	6	710	(66)	57,600	14	1260	(117)	37,900
Flotation thickening[b]	14	452	(42)	39,600	7	365	(34)	72,300
Centrifugation[b]	32	32	(3)	21,300	34	32	(3)	22,700
Vacuum filtration[b]	30[c]	140	(13)	26,700	30[c]	140	(13)	31,000

[a] Capital costs amortized for 20 year equipment life and 10% interest rate. For details of cost estimates, see Appendix C.

[b] All tests conducted after concentration of storage tank contents with sedimentation

[c] Comparative data based on assumptions of 95% solids recovery and yield of 15 kg/sq m/hr (3 lbs/sq ft/hr).

All costs based on December, 1974 prices.

screening treatment of CSO are quite dilute in nature and pre-concentration of these wastes is necessary prior to any dewatering. Because of the many difficulties experienced in collecting a suitable sludge sample from this site, a synthetic waste sample was produced for bench-scale dewatering tests by flushing the site drainage area with fire hydrant water. It was hoped that the waste sample produced would be similar to the actual screen backwash waste. However, only an extremely limited amount of concentrated sludge sample could be generated by the hydrant flushing and the data obtained was highly questionable. It was felt that any conclusions derived from such data would not be meaningful and may be misleading. Therefore, it was decided to omit the data from the treatment feasibility tests for this site. However, evaluations were conducted on the pump/bleedback concept for this wastewater, and are presented in Section VII of this report.

B. PHYSICAL/CHEMICAL TREATMENT

Three samples of residuals were obtained under this category of CSO treatment. Two of these samples were procured from screening/dissolved-air flotation treatment facilities in Milwaukee and Racine, WI. The third sample was obtained from the dissolved-air flotation treatment facility in San Francisco, CA.

Racine, WI

Two separate samples of the combined screen backwash and flotation scum from the sludge holding tank were obtained in Racine. A schematic of the various dewatering tests conducted on these samples is shown in Figure 9. The average quantity of the residuals (both floated scum and screen backwash) requiring handling and/or treatment on a per storm basis for the Racine facility is estimated to be 458 cu m (121,000 gal.) at a suspended solids concentration of 8,430 mg/l (Table 2). The flux concentration curve for the gravity thickening tests for Racine sludge is shown in Figure 10. The sludge settled extremely well with and without chemicals. Using the Coe and Clevenger (8) and Mancini (9) method of gravity thickening analysis, underflow concentrations greater than 15% solids could be expected at extremely high solid loading rates in excess of 2,000 kg/sq m/day (400 lbs/sq ft/day).

The results of the flotation thickening tests are shown in Figures 11 and 12. Addition of 0.2 kg/m ton (0.4 lbs/ton), of Atlasep IAI polymer helped to produce better flotation thickening results. Solids concentrations of up to 8% could be estimated for the thickened scum. However, due to the dilute nature of the sludge, when a sample was gravity thickened first to about 7% solids and then flotation thickened, solids concentrations of 15 to 19% could be achieved. Optimum recycle rates were between 300 and 400% and mass loading rates of 200-250 kg/sq m/day (40-50 lbs/sq ft/day) could be successfully utilized.

The results of the centrifuge tests for Racine sludge are presented in Table 11. Several samples were tested for centrifugation at various feed solid levels shown in the table. Generally, the tests showed amenability of the

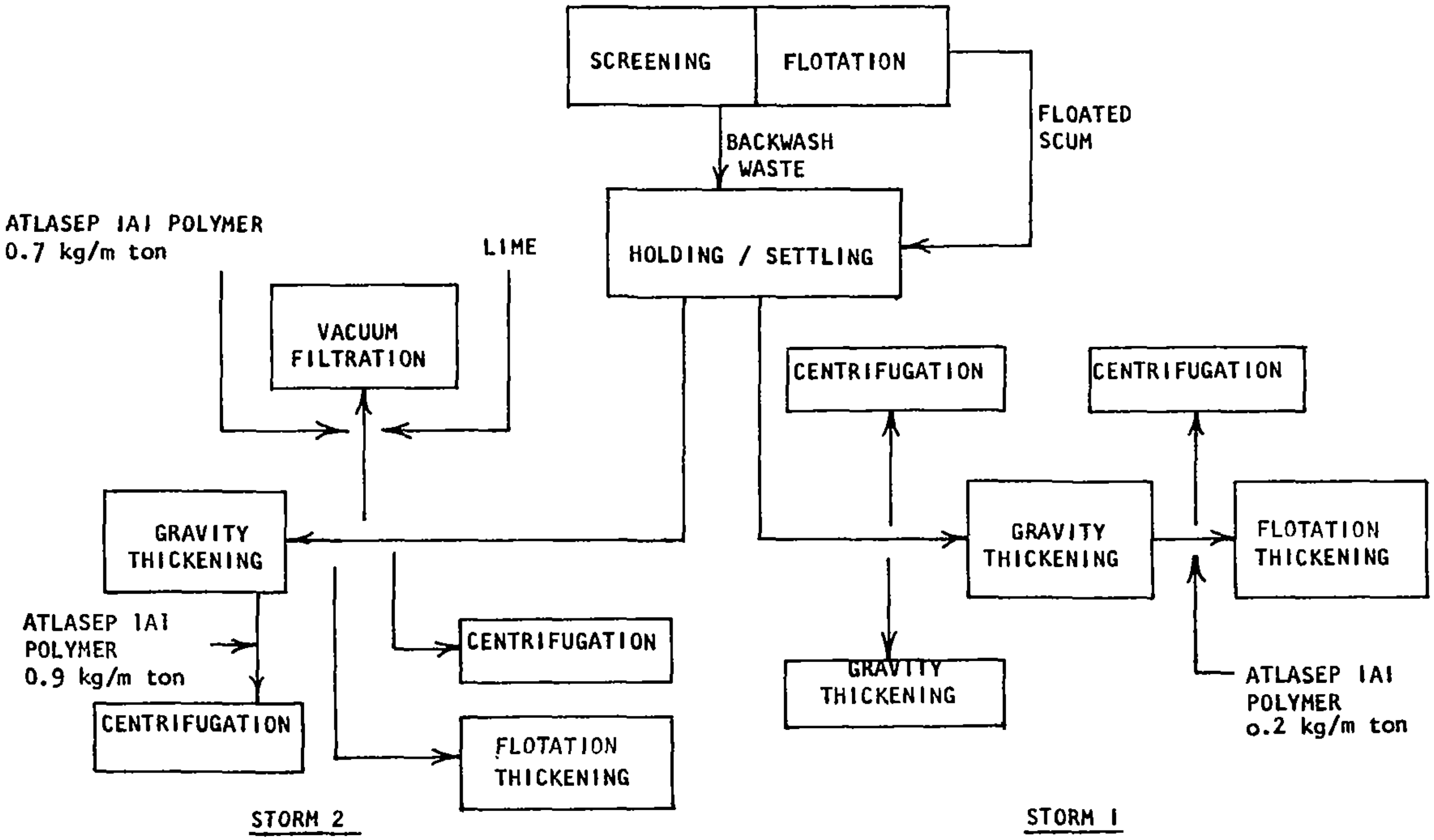


Figure 9. Racine, WI - Bench scale dewatering tests

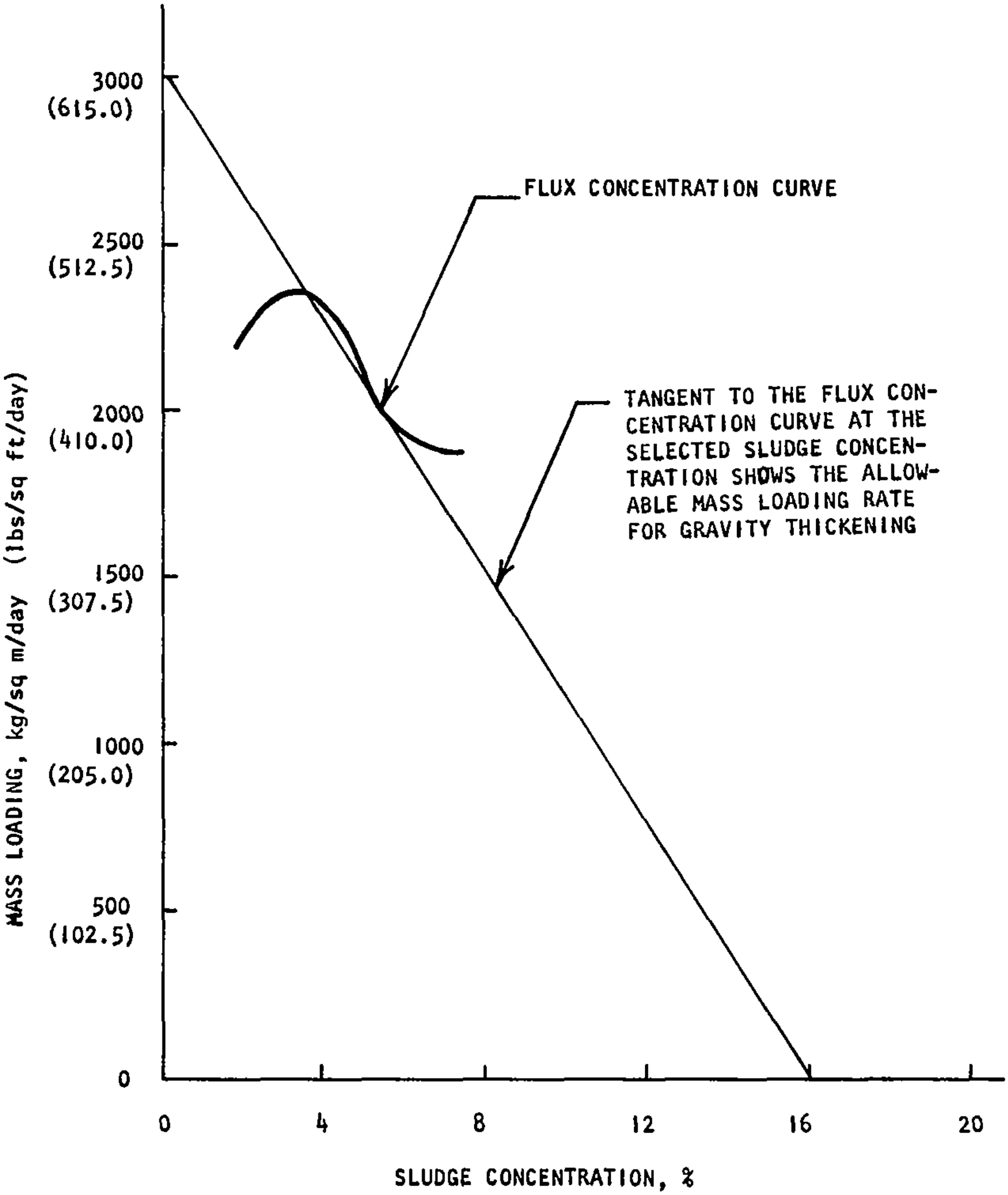


Figure 10. Flux concentration curve for Racine, WI, screening/ dissolved-air flotation sludge - without chemicals

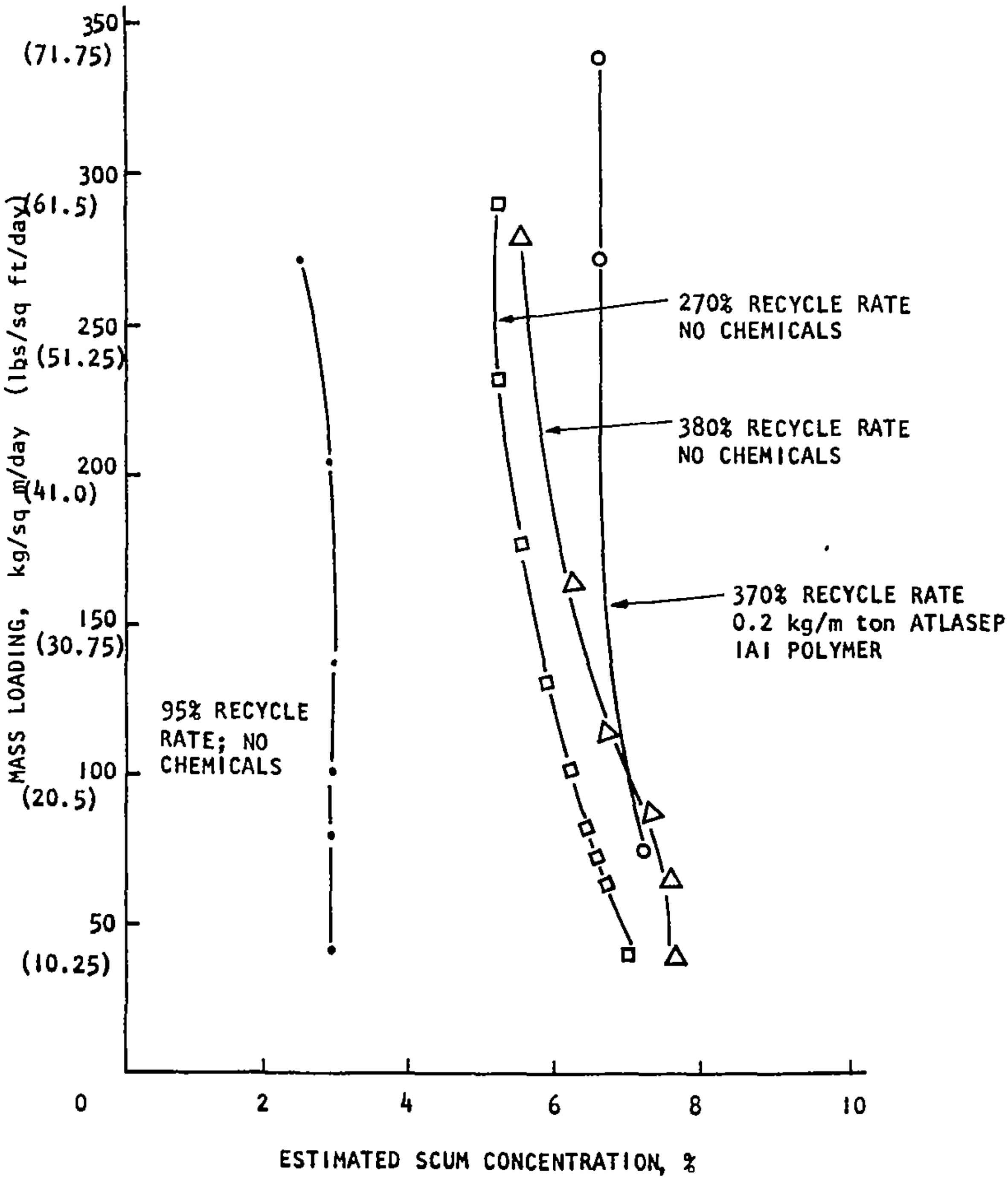


Figure 11. Flotation thickening results for Racine, WI, screening/dissolved-air flotation sludge

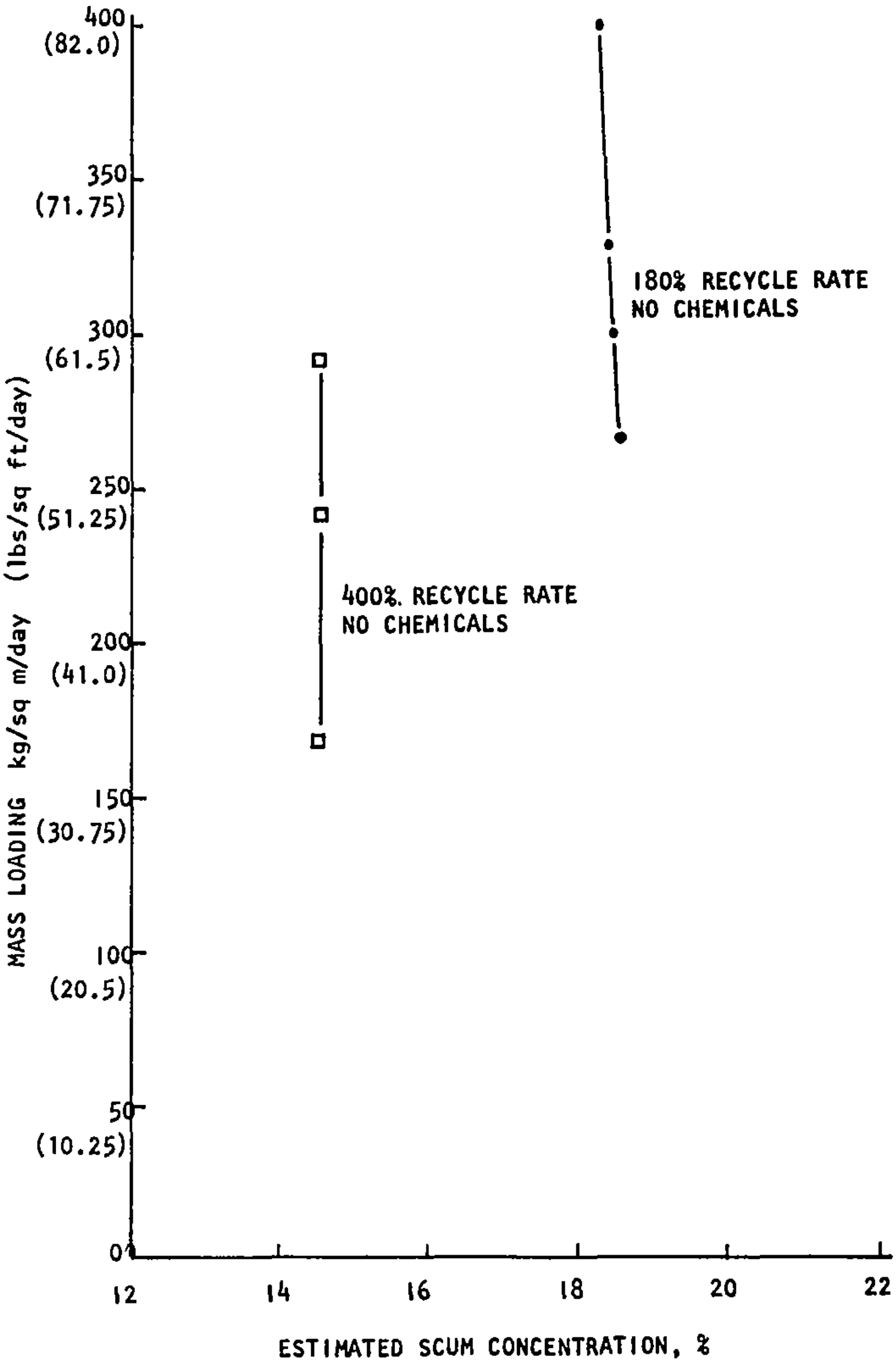


Figure 12. Flotation thickening results for Racine, WI, screening/dissolved-air flotation sludge after pre-gravity thickening to 6.9% solids

Table 11. CENTRIFUGE TESTING RESULTS FOR RACINE, WI, SCREENING/DISSOLVED-AIR FLOTATION SLUDGE

Test No.	Applied G force, "G's"	Spin time, sec	Feed solids, mg/l	Chemical	Dosage, kg/m ton	Centrate solids, mg/l	Centrate volume, ml	Penetration, cm	Sludge depth, cm	Cake solids, %	Penetration, %	Recovery, %	Corrected recovery, %
1	400	60	8,433	none	none	305	71.5	1.3	1.3	17.4	0	96.4	0[a]
2	400	90	8,433	none	none	328	72.3	1.2	1.2	22.5	0	96.1	0[a]
3	400	120	8,433	none	none	167	72.8	1.2	1.2	28.2	0	98.0	0[a]
4	750	60	8,433	none	none	118	73.0	1.0	1.0	31.2	0	98.6	0[a]
5	750	90	8,433	none	none	90	72.8	1.15	1.15	28.4	0	98.9	0[a]
6	750	120	8,433	none	none	90	71.8	1.1	1.1	19.6	0	98.9	0[a]
7	1,000	60	8,433	none	none	104	71.5	1.2	1.2	17.8	0	98.8	0[a]
8	1,000	90	8,433	none	none	79	72.0	0.5	1.1	20.9	60	99.1	93
9	1,000	120	8,433	none	none	79	71.8	1.05	1.05	19.6	0	99.1	0[a]
10	400	60	75,400	none	none	1,038	52.3	1.05	2.7	24.7	61	98.6	94
11	400	90	75,400	none	none	870	54.8	0.98	2.8	27.8	65	98.8	95
12	400	120	75,400	none	none	850	55.5	1.05	2.7	28.8	61	98.9	94
13	750	60	75,400	none	none	850	56.2	0.80	2.65	29.8	70	98.9	95
14	750	90	75,400	none	none	900	58.0	0.60	2.5	32.9	71	98.8	96
15	750	120	75,400	none	none	755	55.0	0.60	2.75	28.1	78	99.0	97
16	1,000	60	75,400	none	none	1,210	53.8	0.78	2.75	26.4	72	98.4	95
17	1,000	90	75,400	none	none	905	52.0	0.50	2.8	24.4	82	98.8	97
18	1,000	120	75,400	none	none	785	56.5	0.48	2.5	30.3	80	99.0	97
19	400	60	75,400	905-N	0.59	2,710	55.0	0.65	2.75	27.5	76	96.4	94
20	750	60	75,400	905-N	0.59	640	56.0	0.45	2.5	29.6	82	99.2	97
21	1,000	60	75,400	905-N	0.59	425	56.8	0.40	2.55	30.9	84	99.4	98
22	400	120	75,400	905-N	0.59	640	53.5	0.55	2.7	26.1	80	99.2	97
23	750	120	75,400	905-N	0.59	634	54.5	0.4	2.65	27.4	85	99.2	98
24	1,000	120	75,400	905-N	0.59	560	55.0	0.25	2.6	28.1	90	99.2	98
25	400	60	27,200	none	none	6,100	62.0	1.25	2.15	12.8	39	77.6	71
26	750	60	27,200	none	none	3,170	62.0	1.4	2.15	14.2	35	88.3	80
27	1,000	60	27,200	none	none	2,090	61.0	1.05	2.25	13.7	53	99.5	87
28	400	60	27,200	1-A-1	0.98	332	56.0	2.4	2.75	10.6	13	98.8	84
29	750	60	27,200	1-A-1	0.98	317	58.5	1.25	2.35	12.5	47	98.8	92
30	1,000	60	27,200	1-A-1	0.98	285	61.0	0.8	2.25	14.4	64	99.0	95
31	400	120	27,200	none	none	2,200	59.8	1.2	2.3	12.6	48	91.9	85
32	750	120	27,200	none	none	405	59.0	1.3	2.25	12.6	40	98.5	90
33	1,000	120	27,200	none	none	298	60.5	1.3	2.2	13.9	41	98.9	90
34	400	120	27,200	1-A-1	0.98	252	59.0	1.4	2.3	12.7	40	99.1	90
35	750	120	27,200	1-A-1	0.98	222	61.8	1.0	2.2	15.4	55	99.2	93
36	1,000	120	27,200	1-A-1	0.98	206	62.2	0.55	2.05	15.8	73	99.2	96
37	400	60	32,000	1-A-1	0.93	339	49.5	1.35	3.4	9.3	60	98.9	94
38	750	60	32,200	1-A-1	0.93	248	51.5	0.55	3.15	10.2	83	99.2	97
39	1,000	60	32,000	1-A-1	0.93	276	55.0	0.65	2.85	11.9	77	99.1	97
40	400	120	32,000	1-A-1	0.93	313	53.5	0.6	3.0	11.1	80	99.0	97
41	750	120	32,000	1-A-1	0.93	276	55.5	0.5	2.7	12.2	82	99.1	97
42	1,000	120	32,000	1-A-1	0.93	244	56.0	0.5	2.7	12.6	81	99.2	97

a. Denotes poor scrollability of the thickened sludge. See Appendix B for procedure.

sludge to centrifugation. Addition of chemical flocculants aided centrifugation but did not provide very significant improvement in the results. Sludge samples without prior gravity thickening showed high cake solids (20-30%) but the scrollability of this sludge was found to be poor, indicating that a basket type centrifuge would be required for direct sludge centrifugation as opposed to a scroll type centrifuge. However, when the raw sludge was gravity thickened prior to centrifugation, cake solids as high as 30 to 35% could be achieved for a scroll type centrifuge. Optimum solids recoveries were achieved at gravitational forces between 600 and 1,000 G and spin time between 60 and 120 seconds.

Vacuum filtration test results for Racine sludge are presented in Table 12. Buchner Funnel tests indicated that lime at a dosage of 147 kg/m ton (294 lbs/ton) in conjunction with anionic polyelectrolyte, Atlasep IAI, at a dosage of 0.7 kg/m ton (1.4 lbs/ton) provided optimum results for vacuum filtration on sedimented sludge samples with a feed solids concentration of approximately 3%. Optimum cake solids (20 to 25%) with good cake discharge characteristics were observed with either a 4/1 satin multifilament or a 7/1 satin monofilament cloth. Optimum yield rates were between 14 to 18 kg/sq m/hr (2.9 to 3.7 lbs/sq ft/hr) at a submergence of 37.5%. It was also observed that sludge may be free draining and therefore amenable to dewatering via gravity draining. In this regard, one liter of sludge treated with 1.1 kg/m ton (2.2 lbs/ton) IAI was poured on to an open weave filter cloth (1/1 plain weave, saran, monofilament 30x25 threads per inch). After gravity drain of several seconds the cloth was wrapped around the dewatered sludge to form a ball. The sludge ball was then compressed by hand to further dewater the sludge. The filtrate volume was 910 ml. Cake solids were 24.6% and filtrate suspended solids were 405 mg/l. No problem was encountered with discharge from the cloth media. This indicates that a gravity drain-compression or filter press type dewatering may be applicable for such CSO sludges.

Milwaukee, WI (Hawley Road)

A sludge sample of the floated scum without any screen backwash water was obtained from the Hawley Road treatment facility for bench-scale tests. A schematic of the various bench-scale dewatering tests conducted on this sample is shown in Figure 13. Hawley Road is only a small demonstration treatment facility and treats less than 4% of the CSO at its outfall location. Based on published data (20) it is indicated that the flotation scum volumes requiring handling and/or treatment would be approximately 0.7% of the raw CSO volume treated and are comparable to the corresponding residual sludge volumes for Racine and San Francisco flotation scum volumes as discussed in Section V. The flux concentration curves for the gravity thickening tests for this sludge are shown in Figures 14 and 15. The sludge was found to be amenable to gravity thickening and underflow solids concentrations of 8 to 10% could be achieved. Addition of flocculating chemicals aided in the gravity thickening by providing improved mass loading rates (from 200 to 300 kg/day/sq m (40 to 60 lbs/sq ft/day) @10% solids) as shown in the flux curves. Optimum chemical was found to be a cationic polyelectrolyte, Dow C-41, at a dosage of 4 to 5 kg/m ton (8 to 10 lbs/ton).

Table 12. VACUUM FILTRATION TESTING RESULTS FOR RACINE, WI, SCREENING/DISSOLVED-AIR FLOTATION SLUDGE

Feed Solids Concentration - 27,200 mg/l

Chemical dosage, kg/m ton: Al	Chemical dosage, kg/m ton: CaO	Cycle time, min	Pickup time, sec	Dry time, sec	Submergence, %	Yield, $kg/hr/m^2$	Loading, kg/m^2	Cake solids, %	Filtrate solids, mg/l	Filtrate volume, ml	Type of cloth	Cake Discharge characteristics
1.1	0	4	90	100	37.5	--	--	--	--	910	2 X 2 twill multi-filament olefin	No cake
1.1	0	2	45	45	37.5	--	--	--	--	540	2 X 2 twill multi-filament olefin	No cake
1.1	0	1.3	30	30	37.5	--	--	--	--	820	2 X 1 twill saran monofilament	No cake
0	0	2	45	45	37.5	7.09	0.24	20.8	8,550	170	2 X 1 twill saran monofilament	Good thin
0.49	0	2	45	45	37.5	--	--	--	--	345	2 X 1 twill saran monofilament	No cake
0.49	0	2	45	45	37.5	8.38	0.28	18.0	405	250	4 X 1 satin nylon multifilament	Fair
0.49	0	4	90	100	37.5	3.55	0.24	25.0	187	365	4 X 1 satin nylon multifilament	Fair
0.49	110	2	45	45	37.5	18.4	0.61	21.5	74	260	4 X 1 satin nylon multifilament	Excellent
0.49	110	1.3	30	30	37.5	26.7	0.59	18.5	13	220	4 X 1 satin nylon multifilament	Excellent
0.49	110	4	90	100	37.5	16.8	1.12	21.2	6	370	4 X 1 satin nylon multifilament	Excellent
0.74	147	3	65	75	37.5	11.2	0.56	49.0	25	250	4 X 1 satin nylon multifilament	Excellent
0.74	147	4	90	100	37.5	14.2	0.94	23.9	16	325	4 X 1 satin nylon multifilament	Excellent
0.74	147	6	100	130	37.5	14.8	1.48	21.4	11	380	Satin polypropylene	Excellent
0.74	147	3	65	75	37.5	17.0	0.85	23.2	1,400	460	Satin polypropylene	Excellent
0.74	147	4	90	100	37.5	21.0	1.40	21.6	2,090	480	Satin polypropylene	No cake
1.1	0	3	90	100	37.5							

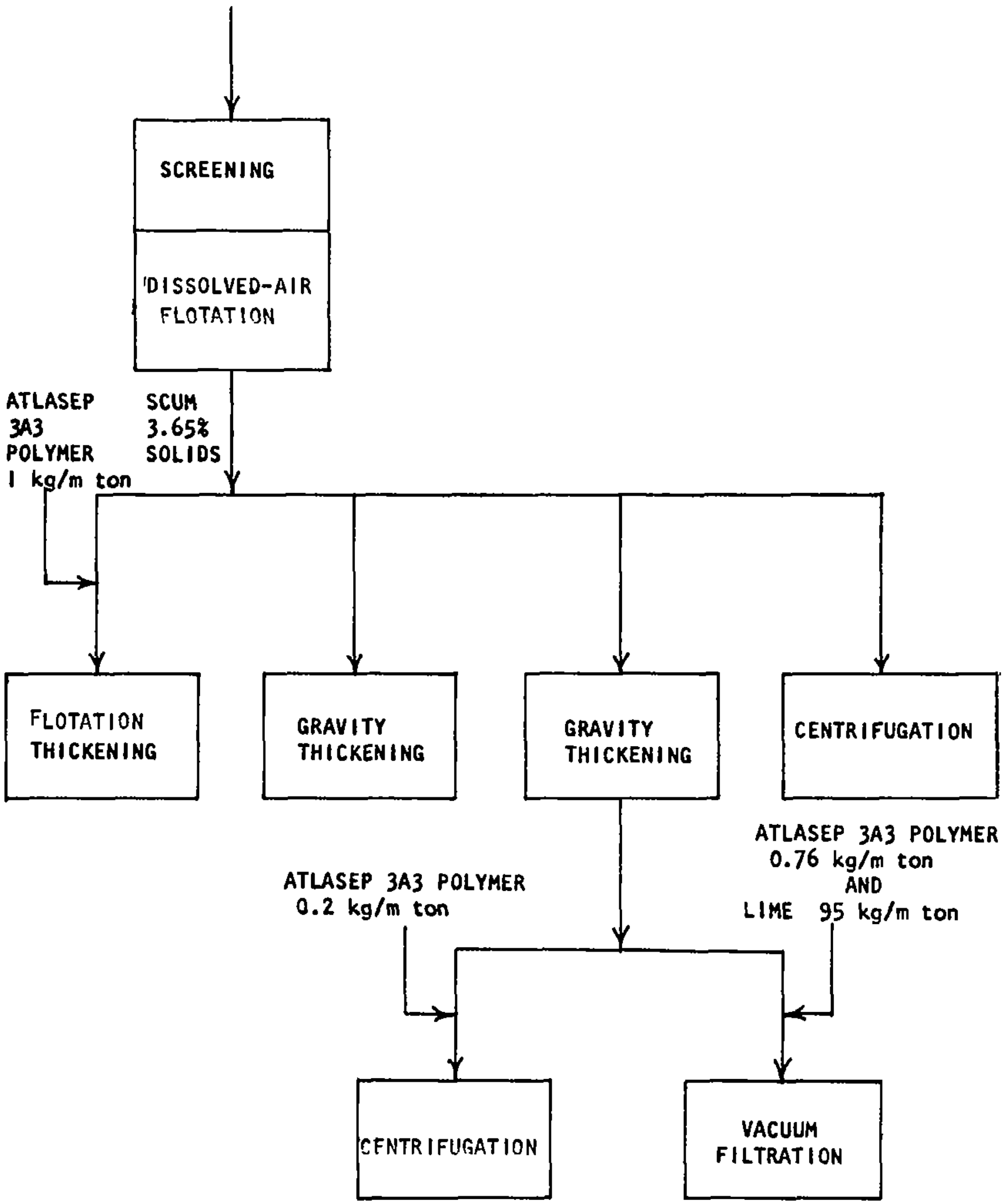


Figure 13. Milwaukee, WI (Hawley Road) - bench scale dewatering tests

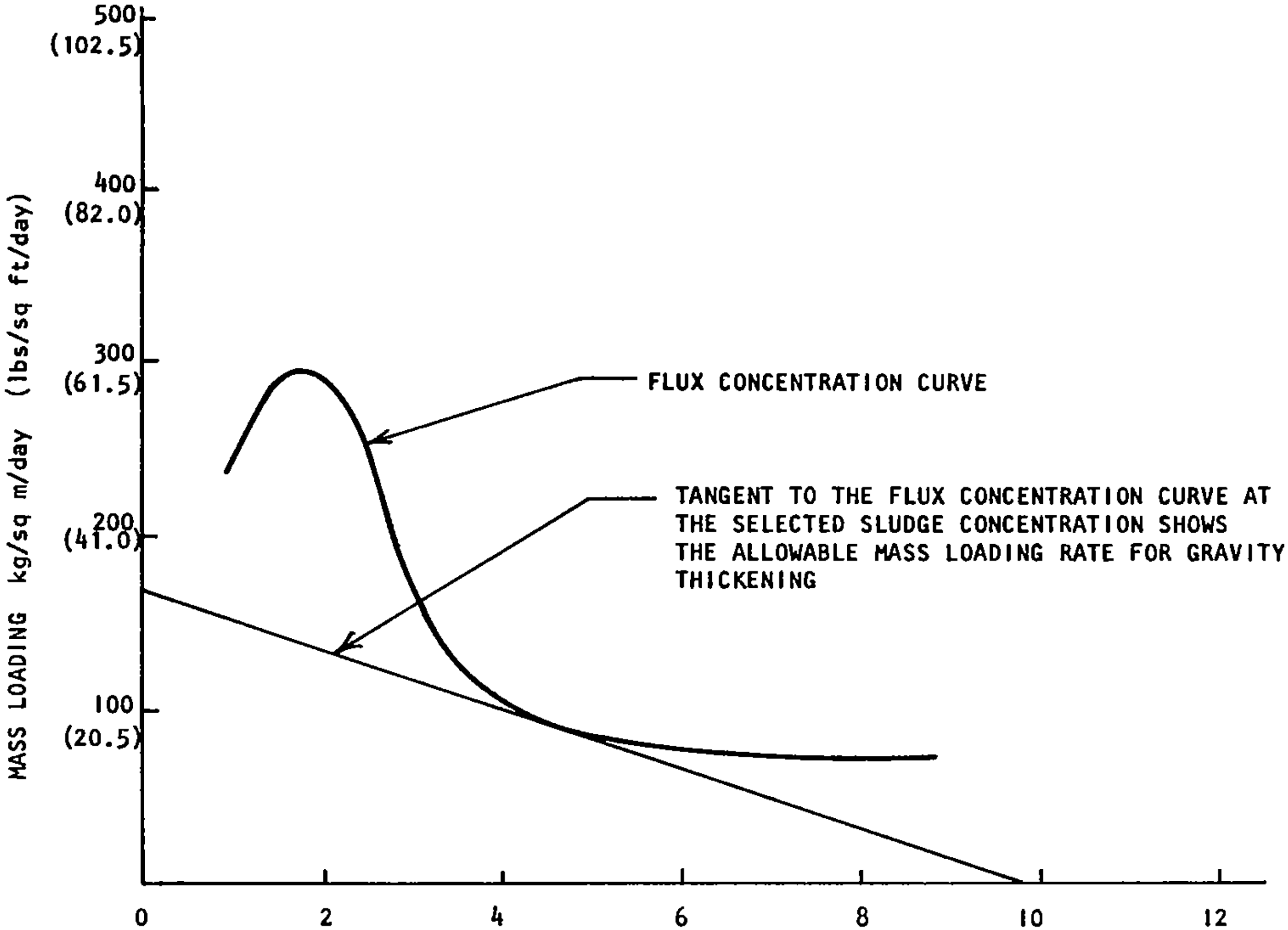


Figure 14. Flux concentration curve for Milwaukee, WI (Hawley Road), dissolved-air flotation sludge, without chemicals

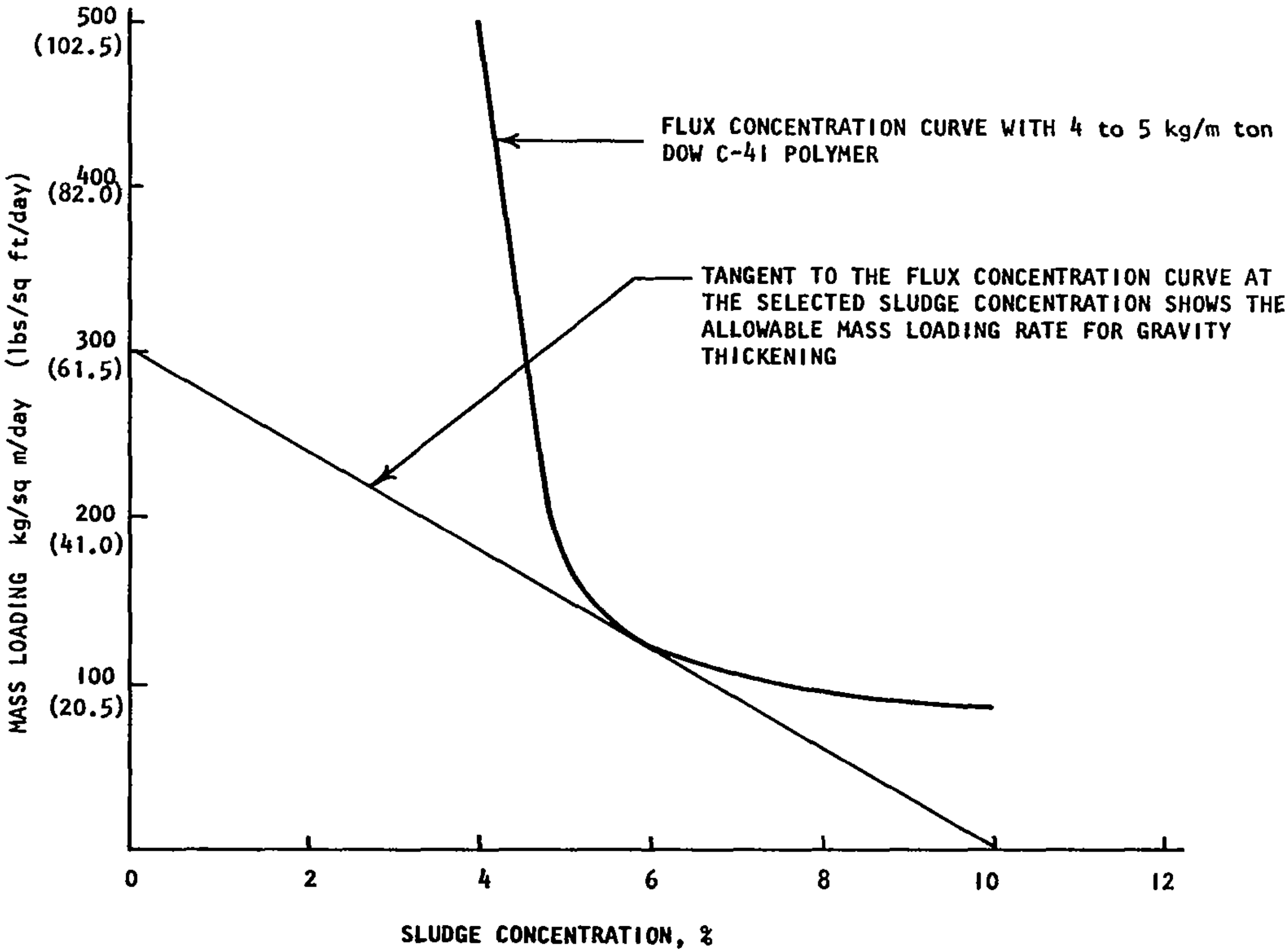


Figure 15. Flux concentration curve for Milwaukee, WI, (Hawley Road) dissolved-air flotation sludge with chemicals

The results of flotation thickening tests are shown in Figure 16. Without the aid of any chemicals, scum concentrations of up to 15% could be expected at a solids loading rate of approximately 75 kg/sq m/day (15 lbs/sq ft/day). However, use of an anionic polyelectrolyte, Atlasep 3A3, provided a scum concentration of 10-11% at significantly higher loading rates of the order of 250-350 kg/sq m/day (50-70 lbs/sq ft/day). Optimum recycle rates ranged between 350 and 400%.

Centrifugation test results are shown in Table 13. Again, prior gravity thickening and chemical addition (0.2 kg/m ton, Atlasep 3A3) helped to provide improved cake solids. Raw scum yielded a cake solids concentration in the range of 19 to 23% while chemically treated and sedimented sludge (feed concentration 9-10% solids) yielded cake solids of approximately 22 to 30% upon centrifugation. Optimum solids recoveries were achieved at gravitational forces between 700 and 1,000 G and spin time between 60 and 120 seconds.

Vacuum filtration tests on this sludge were conducted on gravity thickened samples having a feed solids concentration of 10.3%. The test results are shown in Table 14. Buchner Funnel tests showed that a chemical combination of lime (95 kg/m ton) and Atlasep 3A3 (0.8 kg/m ton) provided optimum test results. Cake solids of up to 30% were achieved under optimum chemical conditions. Optimum yield rates of 50 kg/sq m/hr (10 lbs/sq ft/hr) were achieved at 37.5% submergence.

San Francisco, CA

A treatment schematic of the various bench scale tests conducted on the San Francisco sludge sample is shown in Figure 17. The grab sample obtained for bench tests had a suspended solids concentration of 2.25% as compared to the flotation scum sample for Hawley Road at 3.65% solids. The flux concentration curve for the gravity thickening tests for this sludge is shown in Figure 18. The results showed generally poor settling characteristics. Chemical coagulants were necessary for any meaningful gravity thickening results. Even with the aid of chemical coagulants (up to 12 kg/m ton of Atlasep 105C, a cationic polyelectrolyte), the sludge was thickeded only to a level of 2 to 3% solids at low mass loading rates of 50 to 70 kg/sq m/day (10-14 lbs/sq ft/day). At significantly reduced loading rates of the order of 10 to 20 kg/sq m/day (2 or 4 lbs/sq ft/day), thickening up to 4% solids may be possible. It was indicated that such poor performance for gravity thickening may be due to the alum treatment of CSO utilized at this treatment facility.

The results of flotation thickening tests are shown in Figures 19 and 20. Scum concentrations of up to 5 to 6% solid could be achieved at mass loading rates between 50 to 100 kg/sq m/day (10-20 lbs/sq ft/day) and recycle rates between 350 and 450%. With the aid of Atlasep 105C (0.4 to 0.5 kg/m ton dosage), maximum concentration of only 7.5% solids was possible at similar mass loadings and recycle rates. (It should be noted that the Atlasep 105C polymer used here has since been discontinued for production by the manufacturer but any equivalent polymer should provide comparable performance). Centrifuge test data for the

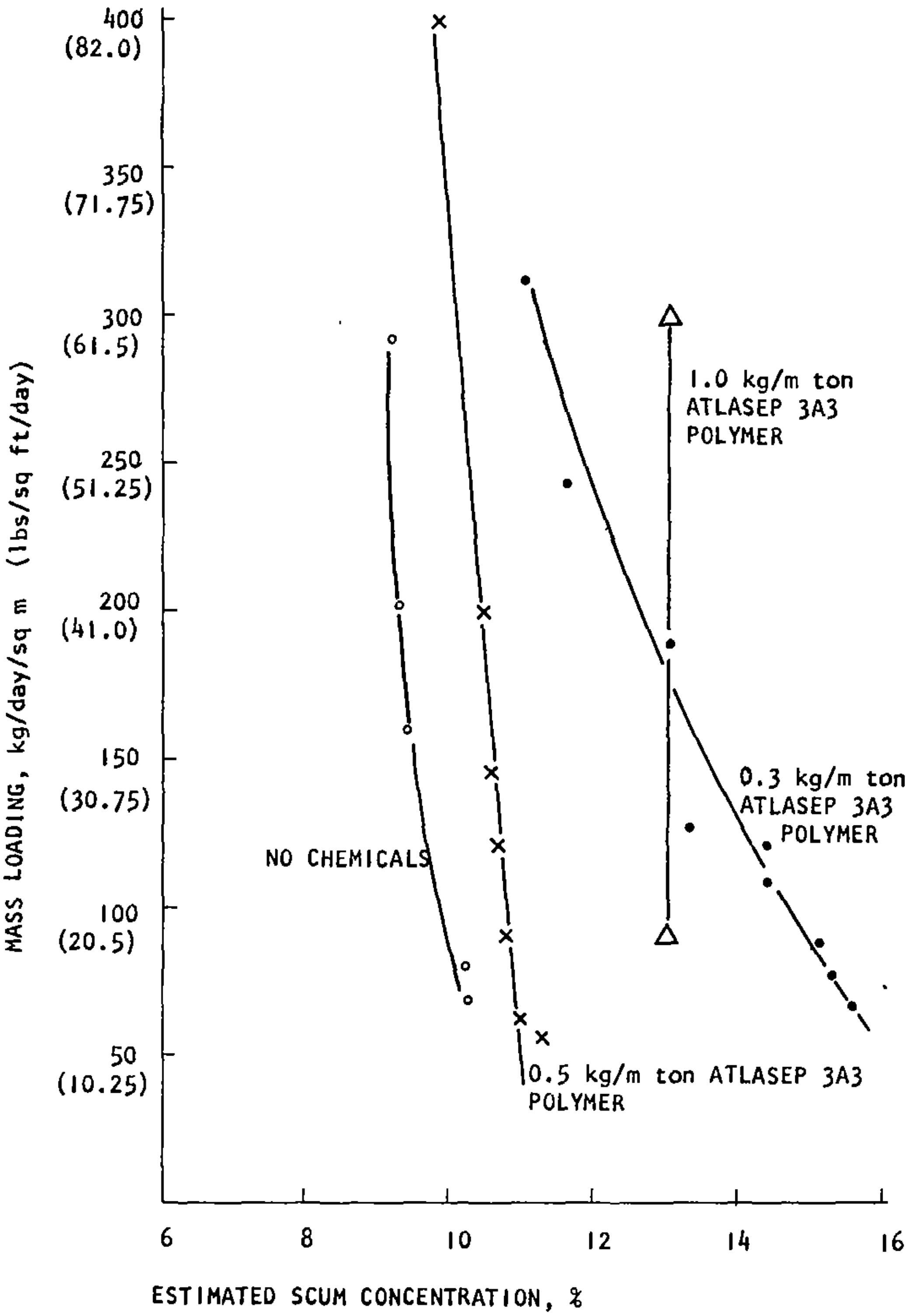


Figure 16. Flotation thickening results for Milwaukee, WI, Hawley Road., dissolved-air flotation sludge (all tests at 390% recycle rate for thickening)

Table 13. CENTRIFUGE TESTING RESULTS FOR MILWAUKEE, WI, HAWLEY ROAD, DISSOLVED-AIR FLOTATION SLUDGE

Test No.	Applied G force, "G's"	Spin time, sec	Feed solids, mg/l	Chemical	Dosage, kg/m ton	Centrate solids, mg/l	Centrate volume, ml	Penetration, cm	Sludge depth, cm	Cake solids, %	Penetration, %	Recovery, %	Corrected recovery, %
1	400	30	36,540	none	none	5,475	59.5	2.1	2.1	15.6	0	85.0	0.0[a]
2	400	60	36,540	none	none	300	59.3	2.1	2.1	17.4	0	99.4	0.0[a]
3	400	90	36,540	none	none	210	62.3	1.6	1.9	21.4	14	99.5	81.7
4	400	120	36,540	none	none	208	62.9	1.4	2.1	21.1	34	99.5	89.6
5	700	30	36,540	none	none	776	58.8	2.2	2.3	16.9	4	97.8	70.9
6	700	60	36,540	none	none	96	61.0	1.4	2.4	19.6	41	99.7	91.2
7	700	90	36,540	none	none	171	60.8	1.3	1.9	19.2	34	99.6	89.4
8	700	120	36,540	none	none	161	62.5	1.1	1.7	21.9	31	99.6	88.6
9	1,000	30	36,540	none	none	204	58.8	2.0	2.3	16.9	14	99.5	81.7
10	1,000	60	36,540	none	none	142	62.0	1.3	1.9	21.1	31	99.7	88.7
11	1,000	90	36,540	none	none	153	63.0	1.1	2.0	22.8	44	99.7	91.3
12	1,000	120	36,540	none	none	134	63.3	1.0	1.7	23.4	45	99.7	92.0
13	700	30	99,200	Atlasep 3A3	0.20	865	42.0	3.2	3.9	22.4	18	99.1	83.5
14	700	75	99,200	Atlasep 3A3	0.20	332	48.0	1.7	3.3	27.5	54	99.7	93.8
15	700	120	99,200	Atlasep 3A3	0.20	298	50.5	1.3	3.3	30.3	61	99.7	94.9
16	1,000	30	99,200	Atlasep 3A3	0.20	1,770	45.0	2.8	3.9	24.5	30	98.2	87.1
17	1,000	75	99,2000	Atlasep 3A3	0.20	424	48.0	1.8	3.4	27.5	46	99.6	92.2
18	1,000	120	99,2000	Atlasep 3A3	0.20	465	50.0	1.6	3.2	29.7	50	99.5	92.8

a. Denotes poor scrollability of thickened sludge. See Appendix B for procedure.

Table 14. VACUUM FILTRATION TESTING RESULTS MILWAUKEE, WI, HAWLEY ROAD, DISSOLVED-AIR FLOTATION SLUDGE

Feed solids concentration 10.3%

Chemical dosage, kg/m ton		Cycle time, min	Pickup time, sec	Dry time, sec	Submergence, %	Yield, kg/hr/m^2	Loading, kg/m^2	Cake solids, %	Filtrate solids, mg/l	Filtrate volume, ml	Type of cloth	Cake Discharge characteristics
3A3	CaO											
0.76	95	5	75	150	25	37.1	3.08	35.7	232	235	2x2 twill olefin multifilament	Excellent
0.76	95	4	90	100	37.5	50.8	3.38	30.4	463	197	2x2 twill olefin multifilament	Excellent
0.36	95	4	90	100	37.5	50.2	3.34	31.1	3,591	200	2x1 plain polypropylene monofilament	Excellent
0.38	95	4	90	100	37.5	49.[illegible]	3.33	31.7	--	--	2x2 twill olefin multifilament	Excellent

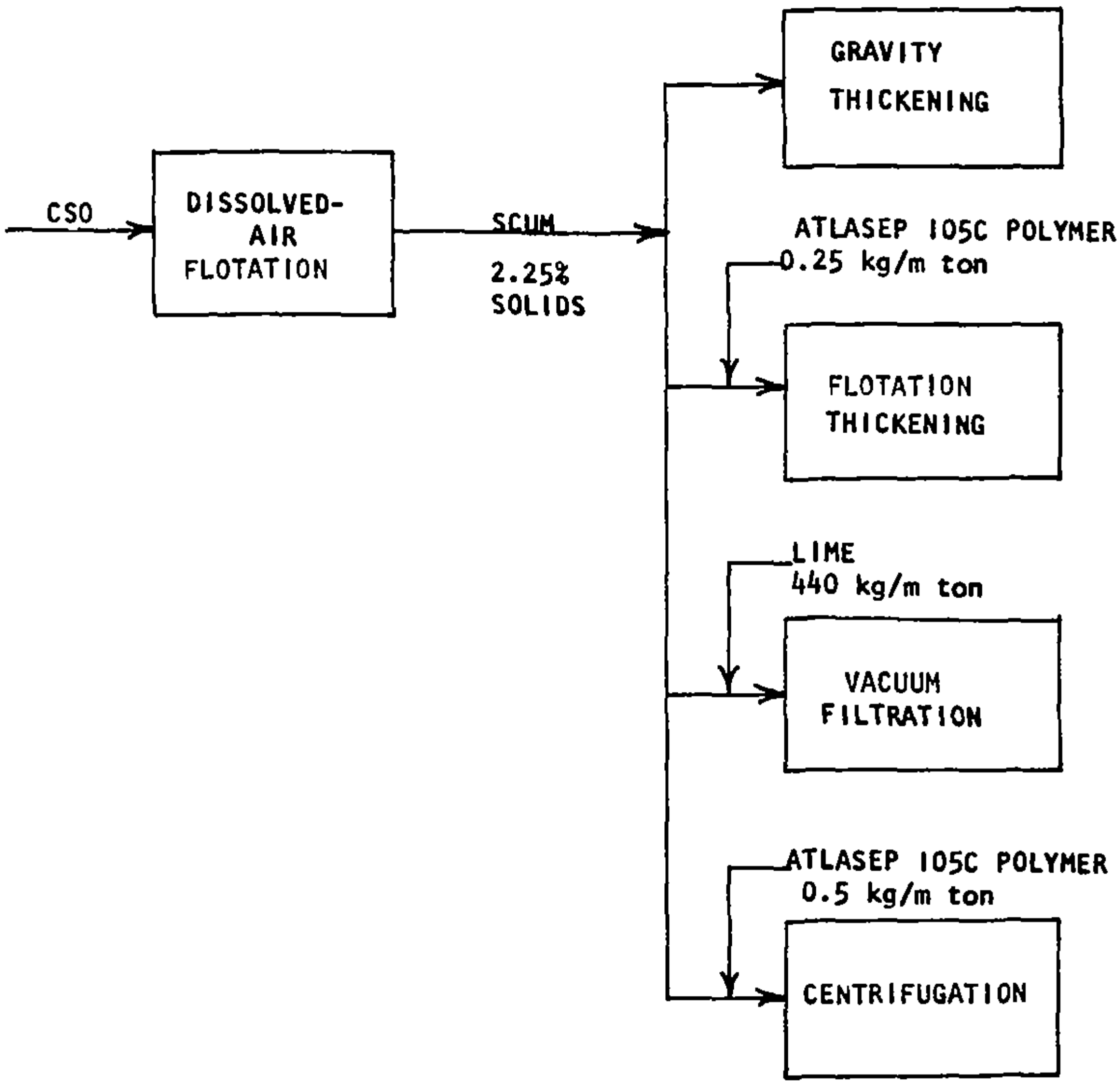


Figure 17. San Francisco, CA, - bench scale dewatering tests

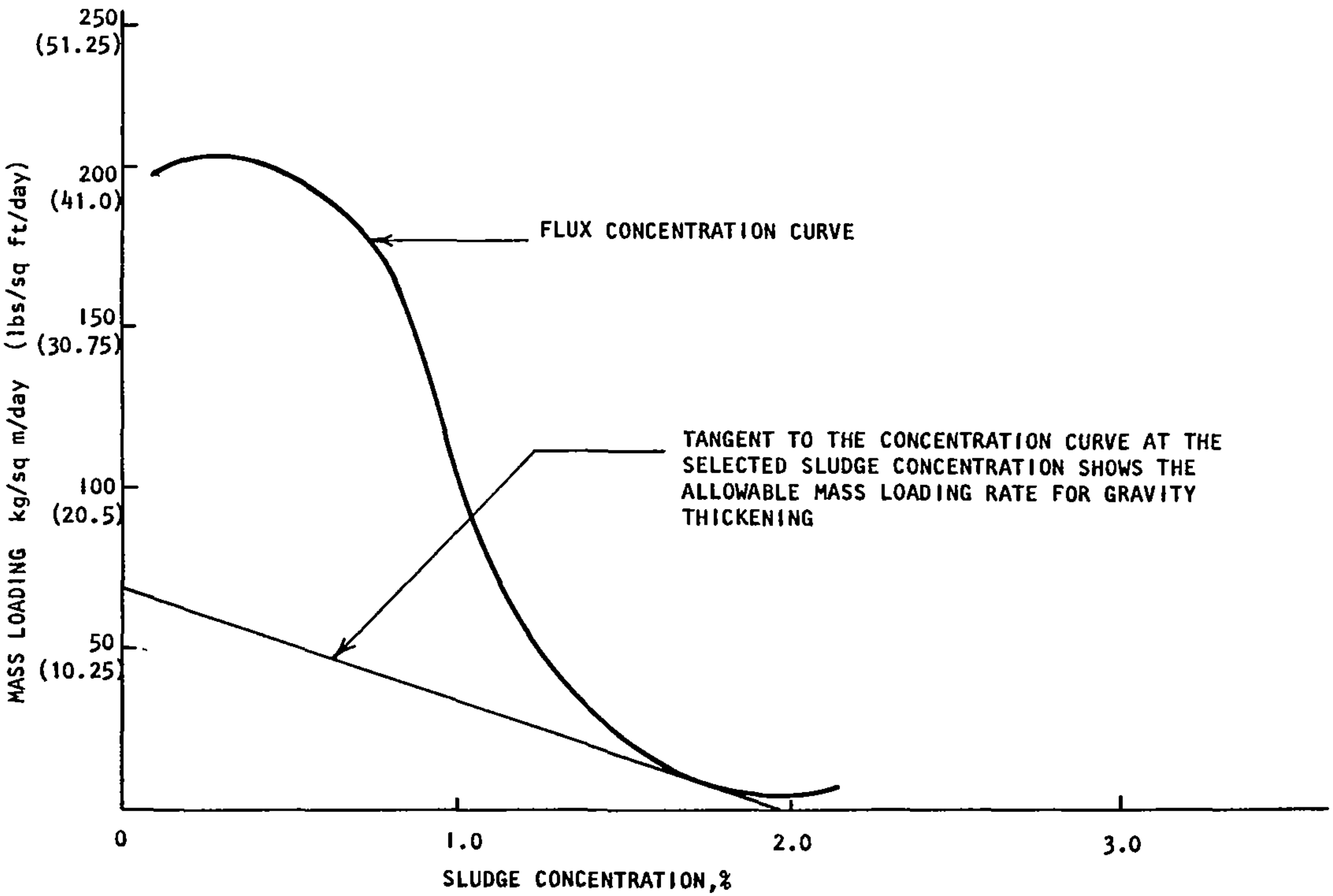


Figure 18. Flux concentration curve for San Francisco, CA, dissolved-air flotation sludge (with chemicals)

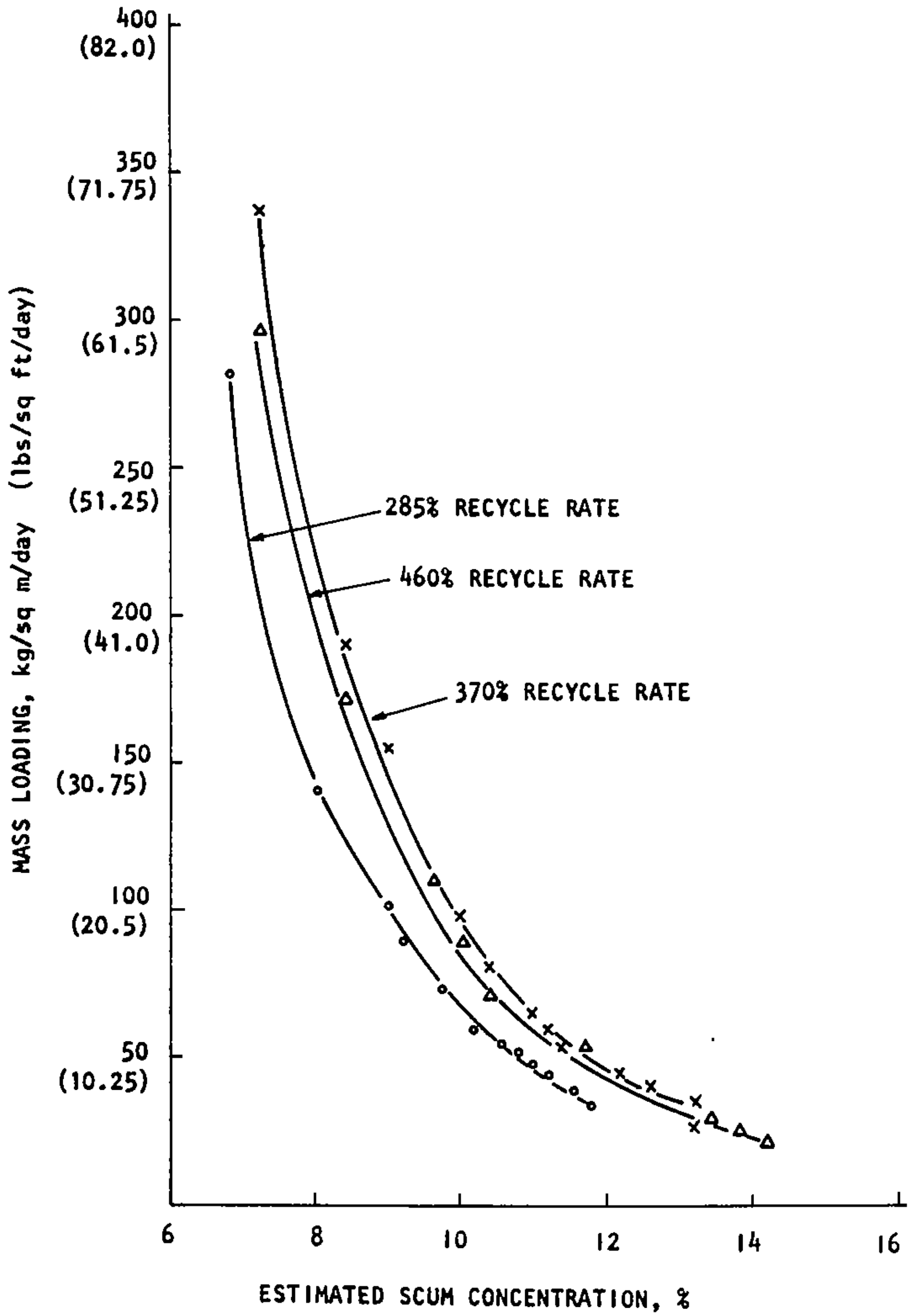


Figure 19. Flotation thickening results for San Francisco, CA dissolved-air flotation sludge - without chemicals

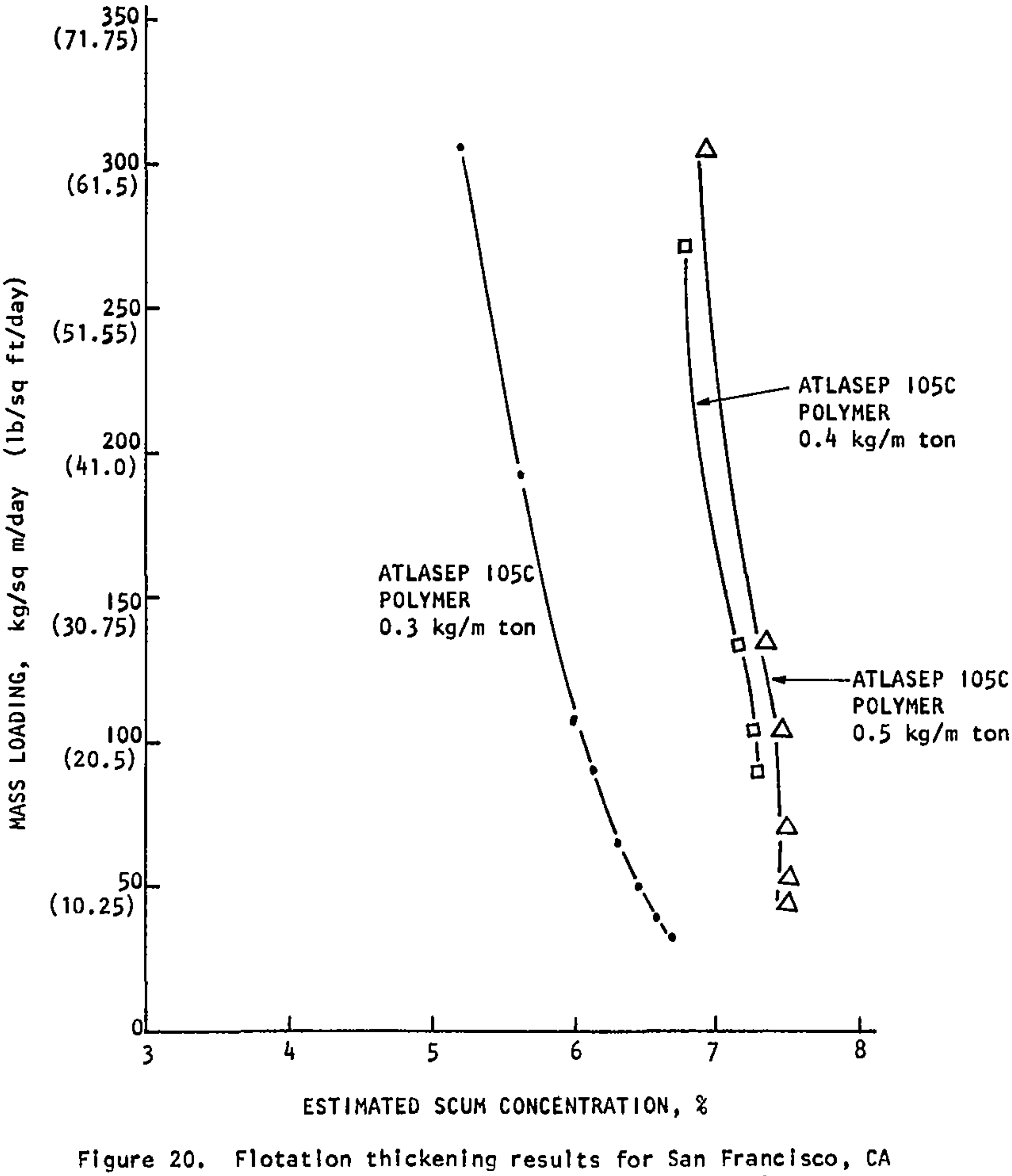


Figure 20. Flotation thickening results for San Francisco, CA dissolved-air flotation sludge - with chemicals (all tests at 370% recycle rate for thickening)

San Francisco sample is presented in Table 15. Without chemical treatment, the sludge showed poor scrollability characteristics and could be concentrated only to about 7-8% solids. However, concentrations up to 11% solids were achieved when chemical treatment with Atlasep 105C (0.5 kg/m ton) was utilized. It was indicated that the chemically treated sludge could be treated with both the scroll and basket type centrifuges. Marked improvement in the centrate clarity was also achieved with chemical clarification.

The results of the vacuum filtration tests are shown in Table 16. Buchner Funnel tests indicated that best filtration results were obtained with large dosages of lime (350 to 450 kg/m ton) instead of the cationic polyelectrolyte, Atlasep 105C that had shown optimum results for other dewatering techniques. A 3 x 1 twill weave filter media provided the best cake discharge characteristics with lime treatment. The loading and yield rates shown in Table 16 are based on dry weight of sludge solids. Cake solids of approximately 18% for a yield of 15 to 20 kg/sq m/hr (3 to 4 lbs/sq ft/hr) were achieved for the thickened sludge.

Treatment Costs for Physical/Chemical CSO Sludges

A summary of the estimated area and cost requirements of various dewatering techniques under optimum treatment conditions for Physical/Chemical CSO sludges is shown in Table 17. As mentioned earlier for storage treatment the total costs shown include the amortization of capital costs and the hauling cost of the ultimate treatment residuals from the site along with other operating costs such as labor, chemical, maintenance, power, etc. Details of these cost estimates and the assumptions made to arrive at them are presented in Appendix C. It is evident that generally centrifugation alone or in combination with gravity thickening are the optimum dewatering steps based on performance, area and cost requirements. For Racine and San Francisco, basket type centrifuges were considered for cost calculations based on the results of the feasibility tests. It is interesting to note that the total cost of gravity or flotation thickening is significantly more than centrifugation or vacuum filtration even when the latter are in combination with the former. The reason for such a difference stems from the hauling cost of the ultimate treatment residuals, which are significantly larger in volume for gravity thickening and flotation thickening compared to the residual volumes after centrifugation or vacuum filtration. For San Francisco, the cost results of centrifugation and vacuum filtration are close; while vacuum filtration edges out centrifugation in thickened solids performance. This may be due to the nature of the raw sludge because of the use of alum treatment at San Francisco, compared to ferric chloride treatment at Racine and Milwaukee (Hawley Road).

C. BIOLOGICAL TREATMENT

Sludge samples from two sites using biological treatment were procured. Both these sites are operated during wet-weather as well as dry-weather. A wet-weather sludge sample was procured from Kenosha, WI where the contact stabilization activated sludge process is utilized. Four sludge samples were procured

Table 15. CENTRIFUGE TESTING RESULTS FOR SAN FRANCISCO, CA, DISSOLVED-AIR FLOTATION SLUDGE

No.	Applied G force, "G's"	Spin time, sec	Feed solids, %	Chemical	Dosage, kg/m ton	Centrate solids, mg/l	Centrate volume, ml	Penetration, cm	Sludge depth, cm	Cake solids, %	Penetration, %	Recovery, %	Corrected recovery, %
1	400	30	2.25	none	none	--	--	--	--	--	0	--	0[a]
6	600	60	2.25	none	none	6,925	59.5	3	3	8.2	0	69.2	0[a]
7	800	60	2.25	none	none	4,825	58.0	2.8	2.8	8.3	0	78.5	0[a]
8	1,000	60	2.25	none	none	3,260	57.8	2.7	2.7	8.3	0	85.7	0[a]
10	600	90	2.25	none	none	3,690	55.5	3.0	3.0	7.6	0	83.6	0[a]
11	800	90	2.25	none	none	2,260	56.0	2.8	2.8	8.2	0	89.9	0[a]
12	1,000	90	2.25	none	none	1,500	56.5	2.68	2.68	8.7	0	93.3	0[a]
13	400	120	2.25	none	none	1,460	56.5	2.73	2.73	8.7	0	93.7	0[a]
14	600	120	2.25	none	none	2,275	55.0	2.73	2.73	7.8	0	89.8	0[a]
15	800	120	2.25	none	none	1,350	56.0	2.63	2.63	8.5	0	94.0	0[a]
16	1,000	120	2.25	none	none	1,025	57.5	2.6	2.6	9.3	0	95.4	0[a]
17	400	30	2.25	105C	0.53	89	53.0	3.05	3.05	7.6	0	99.6	0[a]
18	700	30	2.25	105C	0.53	51	54.8	2.85	2.85	8.3	0	99.7	0[a]
19	1,000	30	2.25	105C	0.53	72	55.8	2.63	2.63	8.8	0	99.6	0[a]
20	400	60	2.25	105C	0.53	67	55.0	2.8	2.8	8.4	0	99.7	0[a]
21	700	60	2.25	105C	0.53	98	58.2	1.3	2.53	10.0	48	99.5	92.4
22	1,000	60	2.25	105C	0.53	66	58.3	1.3	2.38	10.1	43	99.7	91.6
23	400	90	2.25	105C	0.52	80	55.2	2.75	2.75	8.5	0	99.6	0[a]
24	700	90	2.25	105C	0.52	73	58.8	0.85	2.5	10.4	64	99.6	95.2
25	1,000	90	2.25	105C	0.53	56	59.2	1.5	2.35	10.6	35	99.7	89.8
26	400	120	2.25	105C	0.53	82	59.0	1.1	2.63	10.5	58	99.6	94.3
27	700	120	2.25	105C	0.53	132	59.8	0.8	2.53	11.0	68	99.4	95.6
28	1,000	120	2.25	105C	0.53	33	59.8	1.2	2.35	11.1	48	99.8	92.7

a. Denotes poor scrollability of thickened sludge. See Appendix B for procedure.

Table 16. VACUUM FILTRATION TESTING RESULTS FOR SAN FRANCISCO, CA, DISSOLVED-AIR FLOTATION SLUDGE

Feed solids concentration: 2.25%

Chemical	Dosage, kg/m ton	Cycle time, min	Pickup time, sec	Dry time, sec	Submergence, %	Yield, kg/hr/m^2	Loading, kg/m^2	Cake solids, %	Filtrate solids, mg/l	Filtrate volume, mg/l	Type of cloth	Cake Discharge characteristics
105-C	0.66	5	75	150	25	--	--	No Cake	147	580	3X1 twill	Poor
105-C	0.66	8	175	195	37.5	--	--	23.3	62	530	3X1 twill	Poor
CaO	356	7.8	170	190	37.5	--	--	24.7	77	255	3X1 twill	Good
CaO	444	8	170	190	37.5	11.4	1.48	18.2	123	680	3X1 twill	Very Good
CaO	444	5	110	122	37.5	14.7	1.23	18.0	134	520	3X1 twill	Very Good
CaO	444	3	65	73	37.5	19.3	0.96	18.1	110	405	3X1 twill	Very Good
CaO	444	2	44	48	37.5	21	0.70	18 4	146	300	3X1 twill	Very Good
CaO	444	3	44	92	25	13.5	0.67	18.7	108	310	3Y1 twill	Very Good

Table 17. SUMMARY OF AREA AND COST REQUIREMENTS FOR PHYSICAL/CHEMICAL SLUDGES UNDER OPTIMUM TREATMENT CONDITIONS

Site	Racine				Hawley Road				San Francisco			
	Sludge solids, %	Area sq ft	Area (sq m)	Total annual cost[a], $/yr	Sludge solids, %	Area sq ft	Area (sq m)	Total annual cost[a], $/yr	Sludge solids, %	Area sq ft	Area (sq m)	Total annual cost[a], $/yr
Gravity thickening	10	172	(16)	54,800	10	312	(29)	71,500	4	1,959	(182)	45,000
Flotation thickening	13[b]	1,400	(130)	63,800	13	797	(74)	69,200	6	172	(16)	40,500
Centrifugation	20	194	(18)	56,900	23	21.5	(2)	39,800	11	32	(3)	24,600
	33[b]	205	(19)	32,400	30[b]	345	(32)	38,100				
Vacuum filtration	23[b]	323	(30)	44,100	36[b]	452	(42)	41,300	18	129	(12)	23,900

a. Capital costs amortized for 20 year equipment life and 10% interest rate. For details of cost estimates, See Appendix C.

b. These tests conducted on gravity thickened sludge.

All costs based on December, 1974 prices.

from the primary and secondary clarifiers at New Providence, NJ where trickling filtration treatment is utilized during both the wet and dry-weather treatment periods.

Kenosha, WI

A treatment schematic of the bench scale dewatering techniques investigated at Kenosha is shown in Figure 21. The average quantity of sludge requiring handling and/or treatment on a per storm basis was estimated to be 464 cu m (122,600 gal.) at a suspended solids concentration of 0.8 to 1.0% solids. These values are based on published data (12) and analytical results obtained during this study. The flux concentration curves for the gravity thickening tests are shown in Figures 22 and 23. These curves represent the test data without chemicals and with chemicals respectively. As can be seen from these curves, this sludge showed poor amenability to gravity thickening both with and without chemical aids. Sludge concentrations of less than 2% solids could be achieved at low solids loadings 10-20 kg/sq m/day (2-4 lbs/sq ft/day). Such performance of a biological sludge is similar to gravity thickening performance of conventional dry-weather biological sludges.

The flotation thickening test results are shown in Figures 24 and 25. Optimum recycle rate was found to be approximately 200%. Chemical dosage tests were conducted using Dow C-31, a cationic polyelectrolyte and Atlasep 3A3, an anionic polyelectrolyte based on chemical screening tests. The cationic polymer, C-31, produced optimum results and concentrations of 4 to 5% solids could be achieved at mass loading rates of 50-100 kg/sq m/day (10-20 lbs/sq ft/day).

Data on the centrifugation tests for the Kenosha sludge sample is shown in Table 18. Bench test procedure for a scroll type centrifuge indicated poor scrollability as evidenced by the zero resistance to penetration of the centrifuged sludge in all tests. Chemical aids did not provide any improvement in test results both in terms of cake solids, centrate clarity or scrollability of the centrifuged sludge. Therefore, it was concluded that scroll type centrifuge would not be applicable to the biological sludge at Kenosha. However, a basket type centrifuge is expected to produce positive results as evidenced by the cake solids up to 9% for centrifuged sludge (test no. 8) under optimum test conditions of 1000G and 120 seconds detention time. A combination of flotation thickening and centrifugation did not provide any improvement in the test results for a scroll type centrifuge.

The results of vacuum filtration tests are shown in Table 19. Because of the dilute nature of the raw sludge, all filtration tests were conducted after flotation thickening of the raw sludge to a level of 3.1% solids. Chemical dosage screening tests on a Buchner Funnel showed that a chemical combination of 160 kg/m ton (220 lbs/ton) ferric chloride and 128 kg/m ton/ (256 lbs/ton) lime provided optimum filtration results of the various filter media investigated, best cake discharge characteristics were obtained with the 4/1 satin nylon multifilament cloth. Cake solids of up to 15% for a yield of approximately 18 kg/sq m/hr (3.6 lbs/sq ft/hr) were achieved under optimum test conditions.

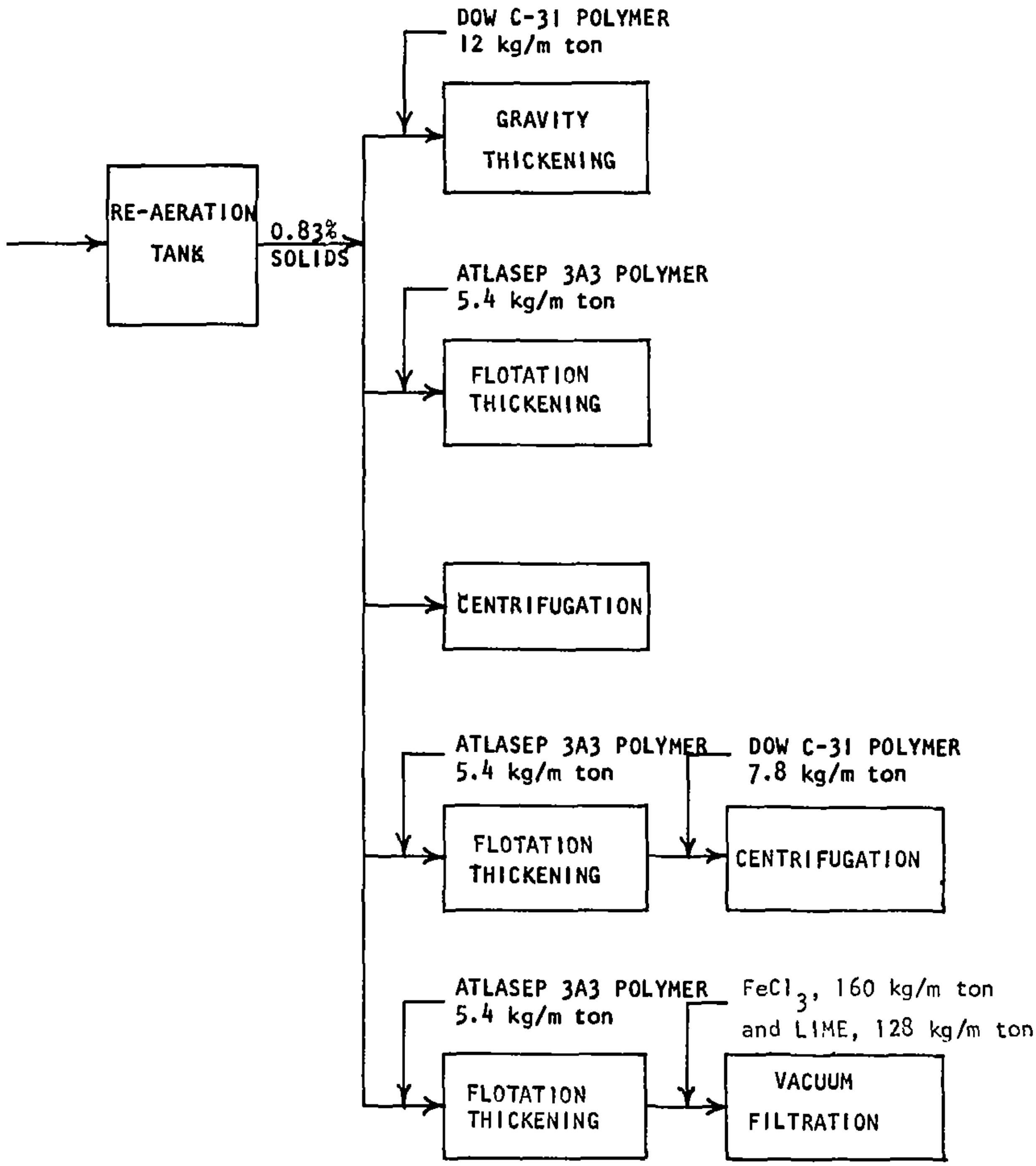


Figure 21. Kenosha, WI - Bench-Scale Dewatering Tests

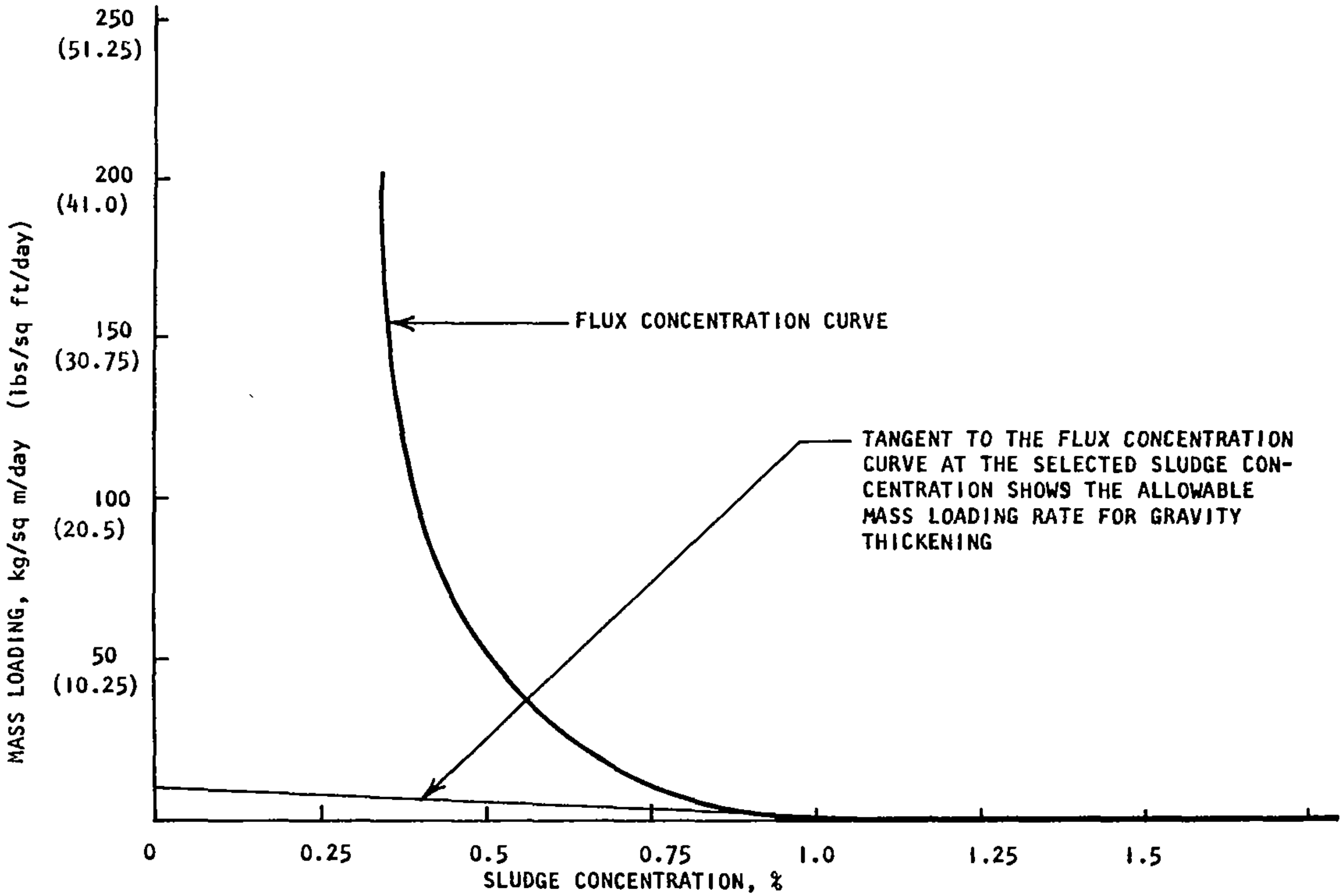


Figure 22. Flux concentration curve for Kenosha, WI, contact stabilization sludge (without chemicals)

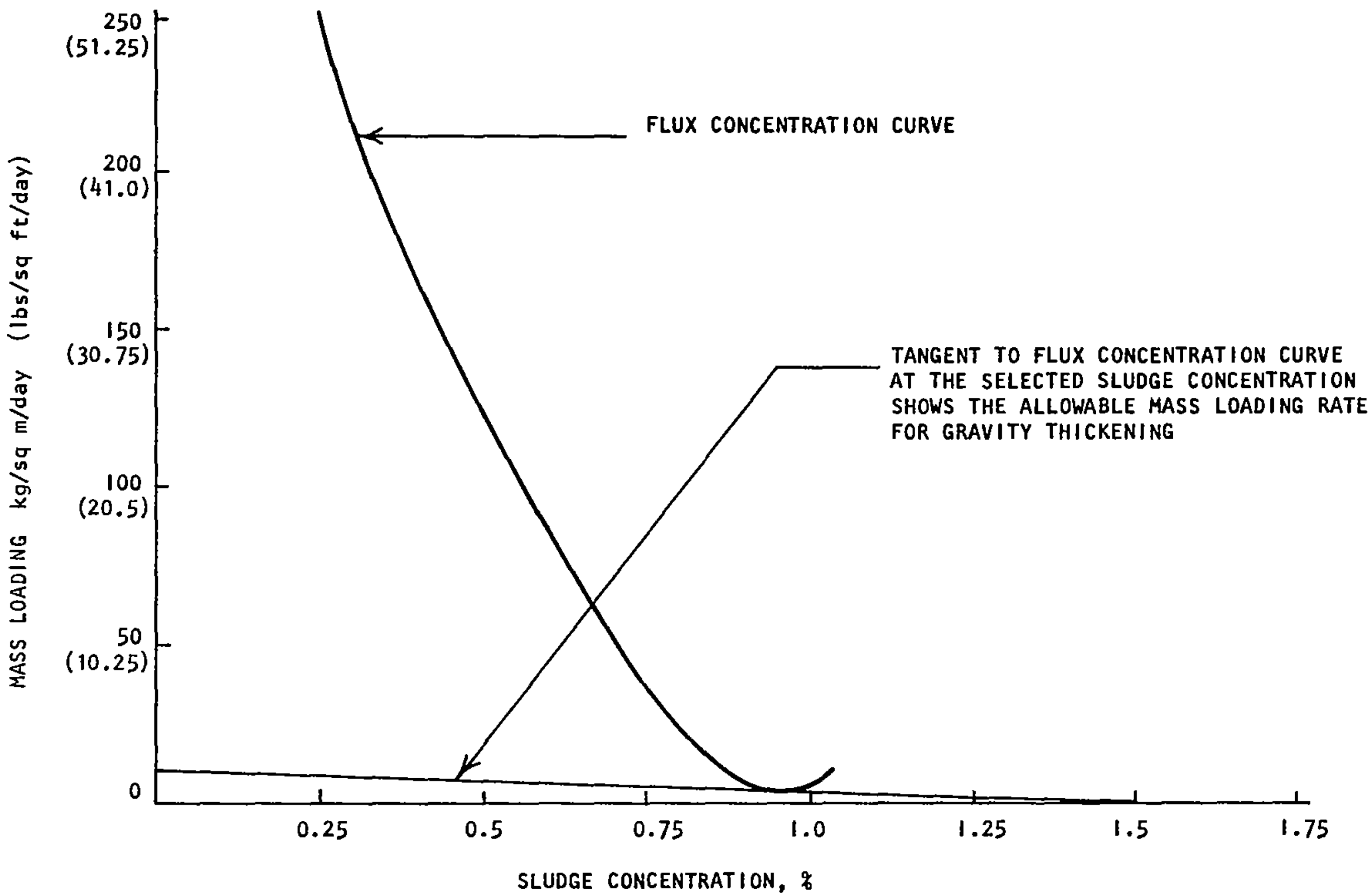


Figure 23. Flux concentration curve for Kenosha, WI, contact stabilization sludge (with DOW C-31 polymer, 11-12 kg/m ton)

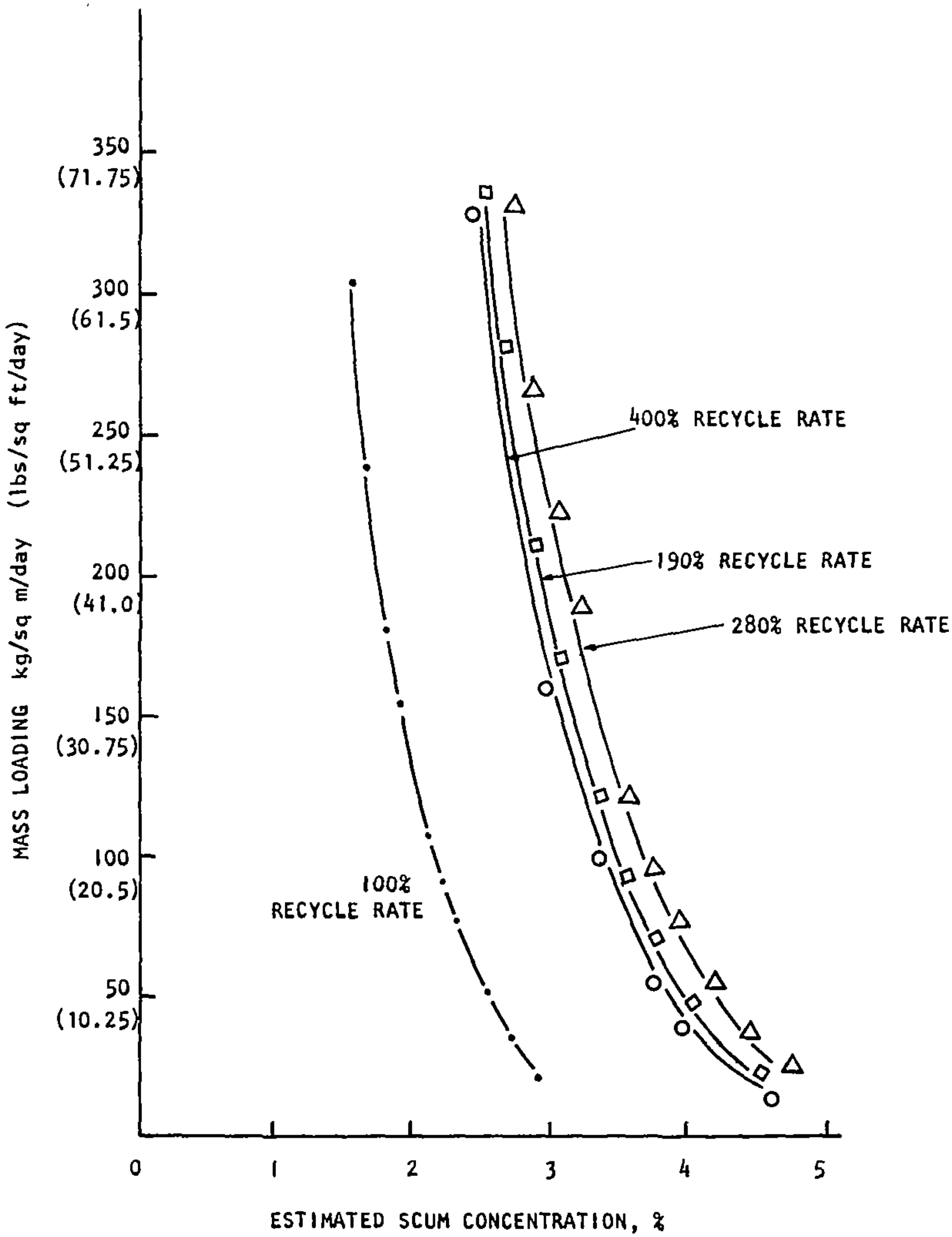


Figure 24. Flotation thickening test results for Kenosha, WI, contact stabilization sludge (without chemicals)

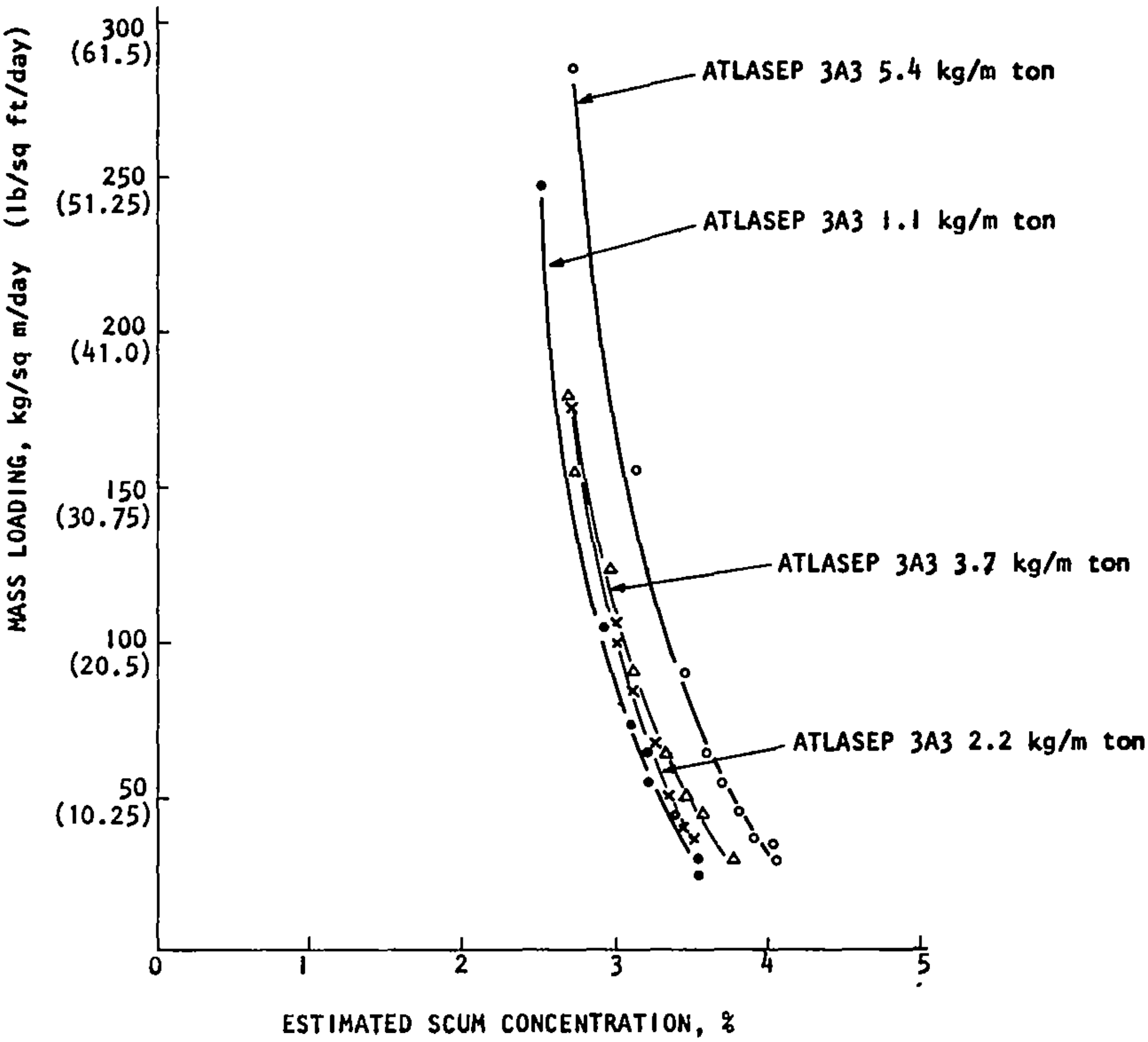


Figure 25. Flotation thickening test results for Kenosha, WI, contact stabilization sludge (with Atlasep 3A3 polymer at 190% recycle rate)

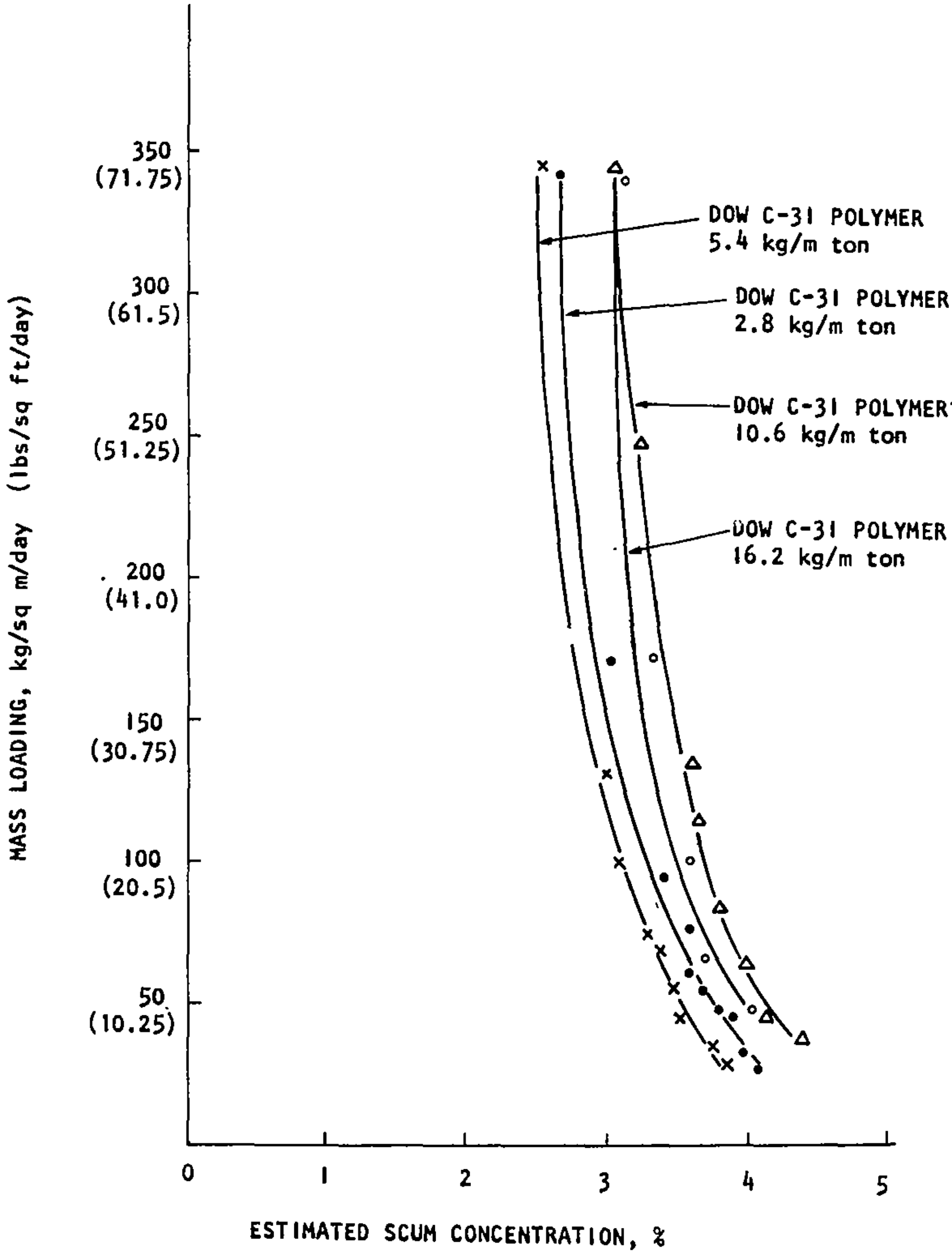


Figure 25 (contd.) Flotation thickening test results for Kenosha, WI contact stabilization sludge (with DOW C-31 polymer at 190% recycle rate)

Table 19. VACUUM FILTRATION TESTING RESULTS FOR KENOSHA, WI, CONTACT STABILIZATION SLUDGE

Feed solids concentration: 3.1%

Chemical dosage, kg/m ton: $FeCl_3$	Chemical dosage, kg/m ton: CaO	Cycle time, min	Pickup time, sec	Dry time, sec	Submergence, %	Yield, kg/hr/m^2	Loading, kg/m^2	Cake solids, %	Filtrate solids, mg/l	Filtrate volume, ml	Type of cloth	Cake Discharge characteristics
60	128	4	60	120	25	14.3	0.98	14.9	3,850	310	2x2 twill olefin multifilament	Poor
60	128	3	45	90	25	18.0	0.88	15.16	1,560	220	2x2 twill olefin multifilament	Poor
60	128	4	60	120	25	15.8	1.07	14.89	88	428	Napped 1x5 olefin spun staple	Poor
60	128	4	60	120	25	15.6	1.02	13.94	60	460	Napped 1x5 olefin spun staple	Poor
60	128	3	45	90	25	18.0	0.88	15.16	82	360	Napped 1x5 olefin spun staple	Poor
60	128	4	60	120	25	13.1	0.88	16.55	92	290	1x4 satin nylon multifilament	Good
60	128	3	45	90	25	18.2	0.93	14.28	45	235	1x4 satin nylon multifilament	Excellent
60	128	4	90	120	25	17.1	1.12	13.33	--	295	1x4 satin nylon multifilament	Good
60	128	3	65	75	37.5	19.8	0.98	11.89	--	270	1x4 satin nylon multifilament	Good
60	128	4	60	120	25	14.2	0.93	13.95	10	240	1x4 satin nylon multifilament	Excellent
60	128	3	45	90	25	11.2	0.93	13.09	--	200	1x4 satin nylon multifilament	Good
60	128	3	45	90	25	17.6	0.88	15.36	--	210	1x4 satin nylon multifilament	Good

Table 18. CENTRIFUGE TESTING RESULTS FOR KENOSHA, WI, CONTACT STABILIZATION SLUDGE

Test No.	Applied G force, "G's"	Spin time, sec	Feed solids, mg/l	Chemical	Dosage, kg/m ton	Centrate solids, mg/l	Centrate volume, ml	Penetration, cm	Sludge depth, cm	Cake solids, %	Penetration, %	Recovery, %	Corrected recovery, %
1	400	60	8,413	none	none	--	--	7.8	7.8	--	0	--	0[a]
2	750	60	8,413	none	none	--	68.3	2.2	2.2	--	0	--	0
3	1,000	60	8,413	none	none	--	64.0	1.9	1.9	--	0	--	0
4	1,000	90	8,413	none	none	134	64.0	7.9	7.9	5.6	0	98.4	0
5	750	90	8,413	none	none	132	62.5	1.9	1.9	5.2	0	98.4	0
6	400	120	8,413	none	none	--	70.8	9.75	9.75	--	0	--	0
7	750	120	8,413	none	none	140	63.0	1.84	1.84	5.7	0	98.3	0
8	1,000	120	8,413	none	none	54	64.0	1.75	1.75	8.9	0	99.3	0
9	1,000	120	8,413	C31	12.05	96	68.0	1.5	1.5	8.0	0	98.8	0
10	750	120	8,413	C31	12.05	79	67.2	1.65	1.65	2.1	0	99.0	0
11	750	120	8,413	C31	7.81	90	44.5	3.84	3.84	6.1	0	98.9	0
12	400	120	8,413	C31	12.05	77	64.8	1.9	1.9	5.6	0	99.1	0
13	400	60	25,850	none	none	--	--	8.5	8.5	--	0	--	0
14	750	60	25,850	none	none	--	61.5	7.25	7.25	--	0	--	0
15	1,000	60	25,850	none	none	--	67.5	6.5	6.5	--	0	--	0
16	1,000	90	25,850	none	none	12,900	52.5	5.68	5.68	6.2	0	49.6	0
17	750	90	28,850	none	none	14,725	57.2	5.97	5.97	6.0	0	42.5	0
18	400	120	25,850	none	none	--	60.5	4.9	4.9	--	0	--	0
19	750	120	25,850	none	none	12,195	53.5	6.78	6.78	6.0	0	52.4	0
20	1,000	120	25,850	none	none	7,790	49.0	4.4	4.4	6.0	0	69.6	0
21	1,000	120	25,850	C31	7.81	107	45.8	3.73	3.73	6.6	0	99.6	0
22	400	120	25,850	C31	7.81	7,350	44.5	7.02	7.02	5.2	0	71.3	0
23	400	120	25,850	C31	7.81	206	40.0	7.65	7.65	5.5	0	99.2	0
24	1,000	120	25,850	C31	11.72	160	41.5	7.5	7.5	5.8	0	99.4	0

a. Denotes poor scrollability of the thickened sludge. See Appendix B for procedure.

Table 19. VACUUM FILTRATION TESTING RESULTS FOR KENOSHA, WI, CONTACT STABILIZATION SLUDGE

Feed solids concentration: 3.1%

Chemical dosage, kg/m ton: $FeCl_3$	Chemical dosage, kg/m ton: CaO	Cycle time, min	Pickup time, sec	Dry time, sec	Submergence, %	Yield, $kg/hr/m^2$	Loading, kg/m^2	Cake solids, %	Filtrate solids, mg/l	Filtrate volume, ml	Type of cloth	Cake Discharge characteristics
60	128	4	60	120	25	14.3	0.98	14.9	3,850	310	2x2 twill olefin multifilament	Poor
60	128	3	45	90	25	18.0	0.88	15.16	1,560	220	2x2 twill olefin multifilament	Poor
60	128	4	60	120	25	15.8	1.07	14.89	88	428	Napped 1x5 olefin spun staple	Poor
60	128	4	60	120	25	15.6	1.02	13.94	60	460	Napped 1x5 olefin spun staple	Poor
60	128	3	45	90	25	18.0	0.88	15.16	82	360	Napped 1x5 olefin spun staple	Poor
60	128	4	60	120	25	13.1	0.88	16.55	92	290	1x4 satin nylon multifilament	Good
60	128	3	45	90	25	18.2	0.93	14.28	45	235	1x4 satin nylon multifilament	Excellent
60	128	4	90	120	25	17.1	1.12	13.33	--	295	1x4 satin nylon multifilament	Good
60	128	3	65	75	37.5	19.8	0.98	11.89	--	270	1x4 satin nylon multifilament	Good
60	128	4	60	120	25	14.2	0.93	13.95	10	240	1x4 satin nylon multifilament	Excellent
60	128	3	45	90	25	11.2	0.93	13.09	--	200	1x4 satin nylon multifilament	Good
60	128	3	45	90	25	17.6	0.88	15.36	--	210	1x4 satin nylon multifilament	Good

New Providence, NJ

This treatment facility utilizes trickling filters for the treatment of dry-weather flow as well as large quantities of polluted water during wet-weather periods generated by infiltration to the sewer system. Dewatering tests were conducted on separate sludge samples from the primary and secondary clarifier during both the wet and dry-weather periods.

Wet-Weather Sludge Samples - A schematic of the dewatering techniques investigated on wet-weather samples is shown in Figure 26. The total quantity of the primary sludge during wet-weather is 735 cu m (194,200 gal.) per storm event based on mass balance for a measured sludge concentration of 0.12% solids. However, this low solid strength for a primary sludge probably stems from the unique clarifier operation situation at New Providence whereby a fixed amount of sludge produced per day is sent out for separate treatment and therefore, sludge blanket and strength do not build up in a conventional manner. If this underflow is compared to a conventional situation, assuming 4% solids (21,22), approximately 22 cu m (5,800 gal.) of sludge would be produced. The quantity of sludge produced from secondary clarifier was estimated at approximately 62 cu m (16,380 gal.) per storm event. The measured solids concentration of the secondary sludge sample procured was 2.5%.

The flux concentration curves for the gravity thickening tests for the primary and secondary samples are shown in Figures 27 through 30. The dilute primary sludge sample showed amenability to gravity thickening. With the help of flocculating chemicals (lime and anionic polymer), up to 8% solids could be expected at mass loading rates of 500 kg/sq m/day (100 lbs/sq ft/day). Without chemical aids, the results were significantly poorer. Comparitively, the secondary sludge showed poor amenability to gravity thickening as solids concentrations of only 2 to 3% were achieved with or without chemical aids at low loading rates of less than 20 kg/sq m/day (4 lbs/sq ft/day).

The flotation thickening test results are shown in Figures 31 through 33. For primary sludge, again chemicals aided in superior performance and solids concentrations similar to gravity thickening (up to 8%) were achieved at mass loading rates of the order of 250 kg/sq m/day (50 lbs/sq ft/day). The optimum recycle rates were generally less than 160%. For secondary clarifier sludge, the flotation thickening performance was significantly better than gravity thickening as solid concentrations up to 5% without chemicals and up to 6% with chemicals were achieved. With chemical aids (lime and Magnifloc anionic polyelectrolyte 837-A), these concentrations were achieved at significantly higher loading rates of 250 to 350 kg/sq m/day (50 to 10 lbs/sq ft/day) compared to lower loading rates of less than 50 kg/sq m/day (10 lbs/sq ft/day) without chemicals. The optimum recycle rates were between 250 and 300%.

The results of centrifugation tests for the primary and secondary sludge samples are shown in Tables 20 and 21 respectively. The results show poor amenability to centrifugation for the primary sludge sample. Cake

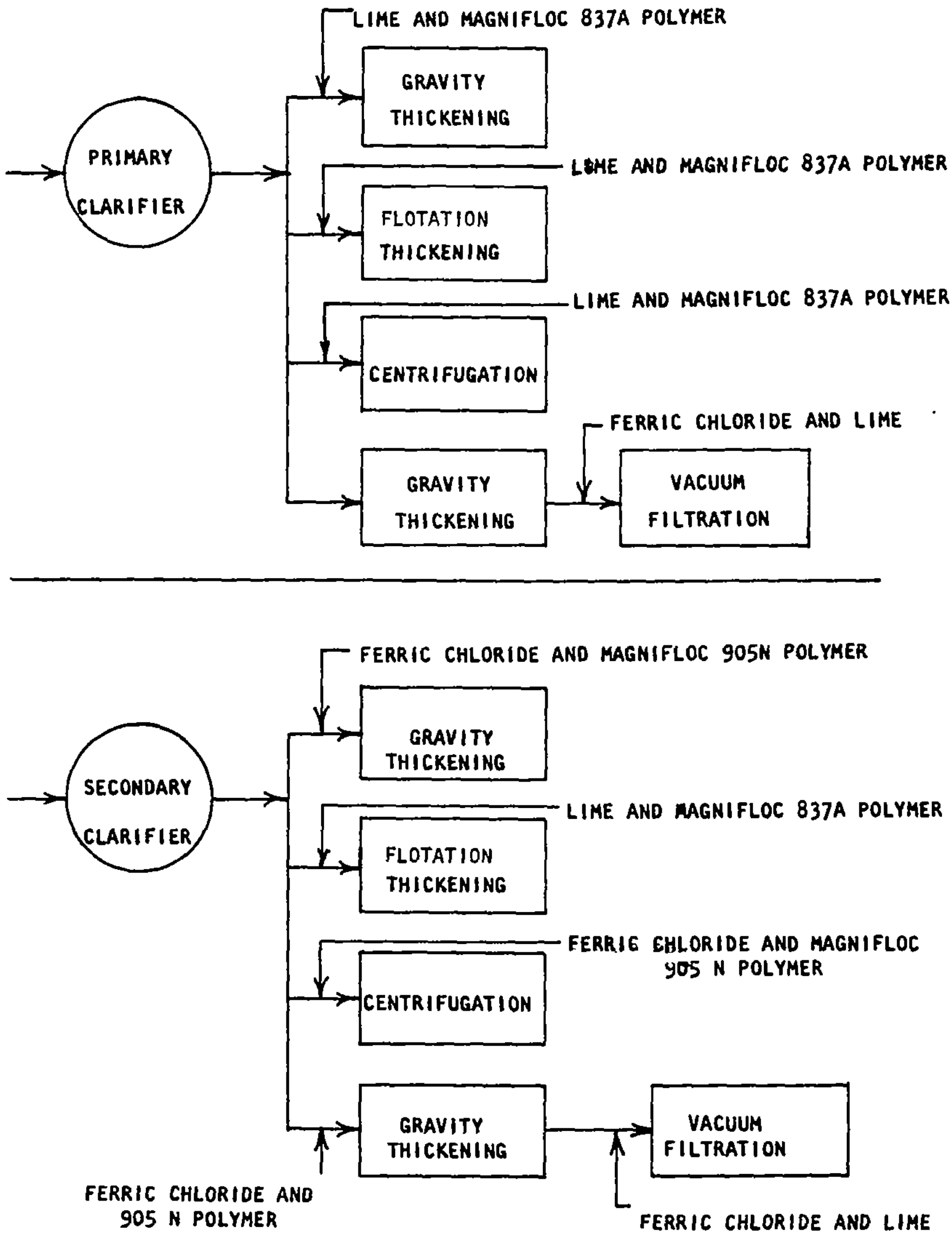


Figure 26. New Providence, NJ - bench scale dewatering tests (wet-weather)

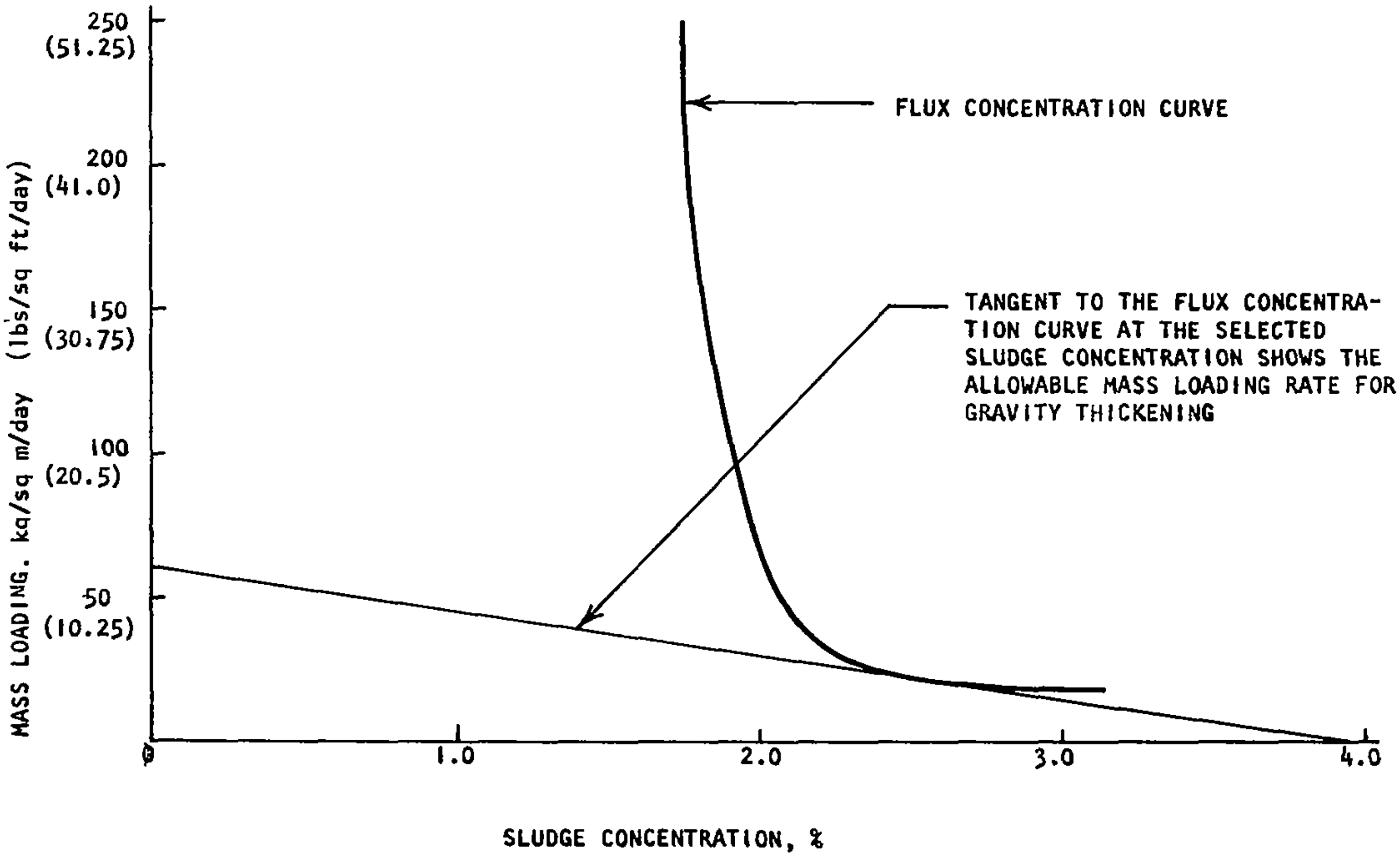


Figure 27. Flux concentration curve for New Providence, NJ, wet-weather trickling filtration primary sludge (without chemicals)

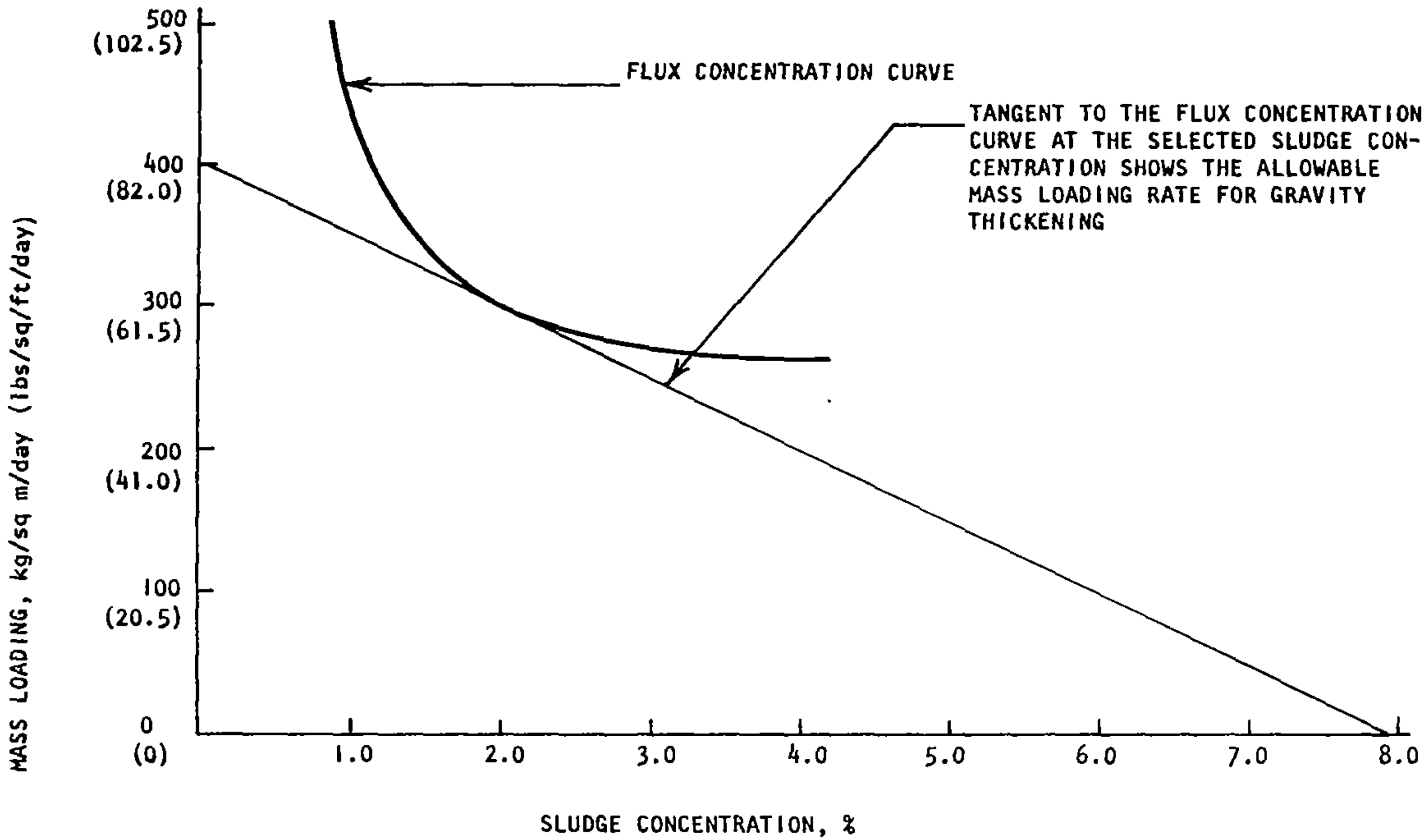


Figure 28. Flux concentration curve for New Providence, NJ, wet-weather trickling filtration primary sludge with chemicals (333 kg/m ton of lime and 5.0 kg/m ton of magnifloc 837A polymer)

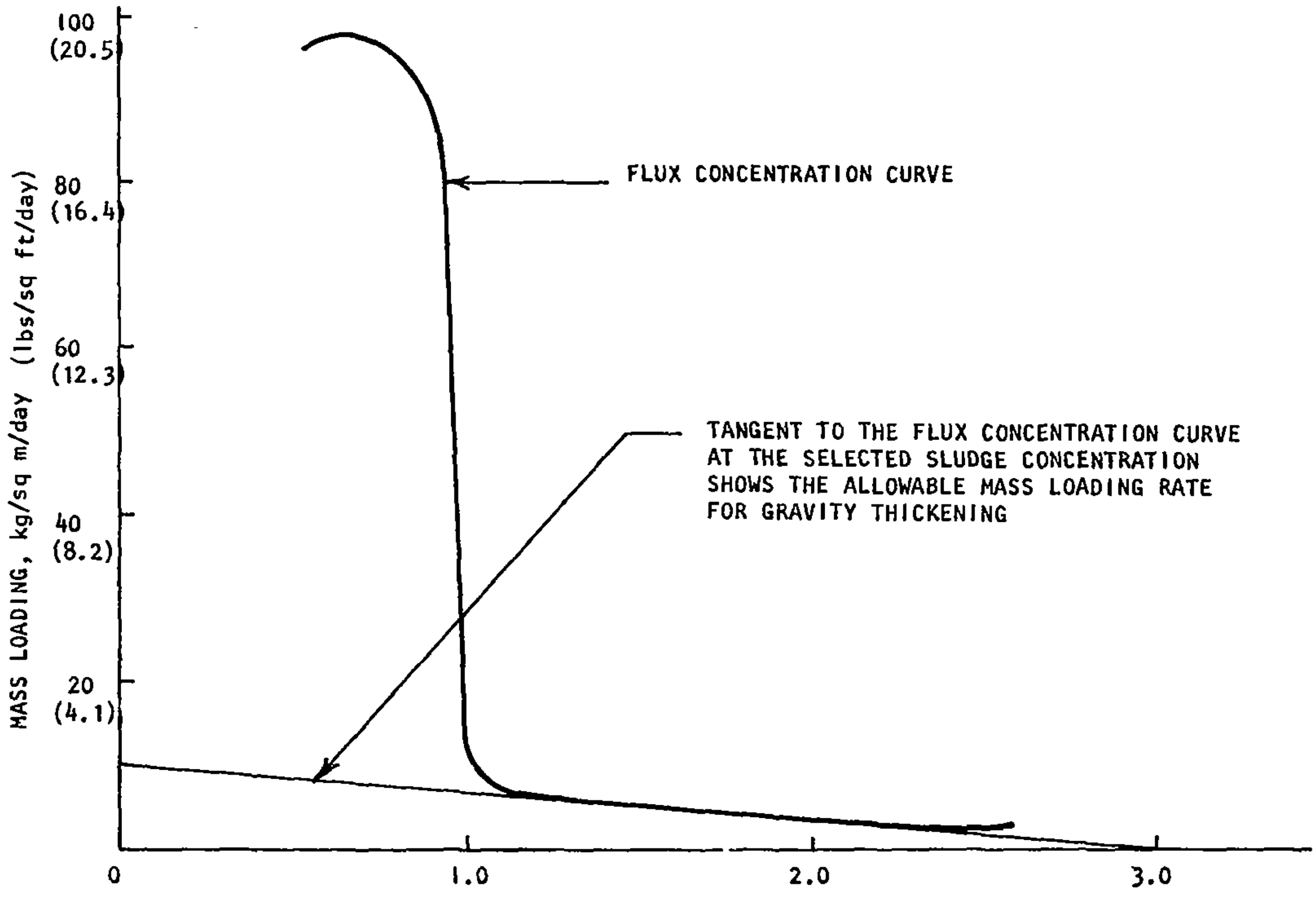


Figure 29. Flux concentration curve for New Providence, NJ, wet-weather secondary sludge (without chemicals)

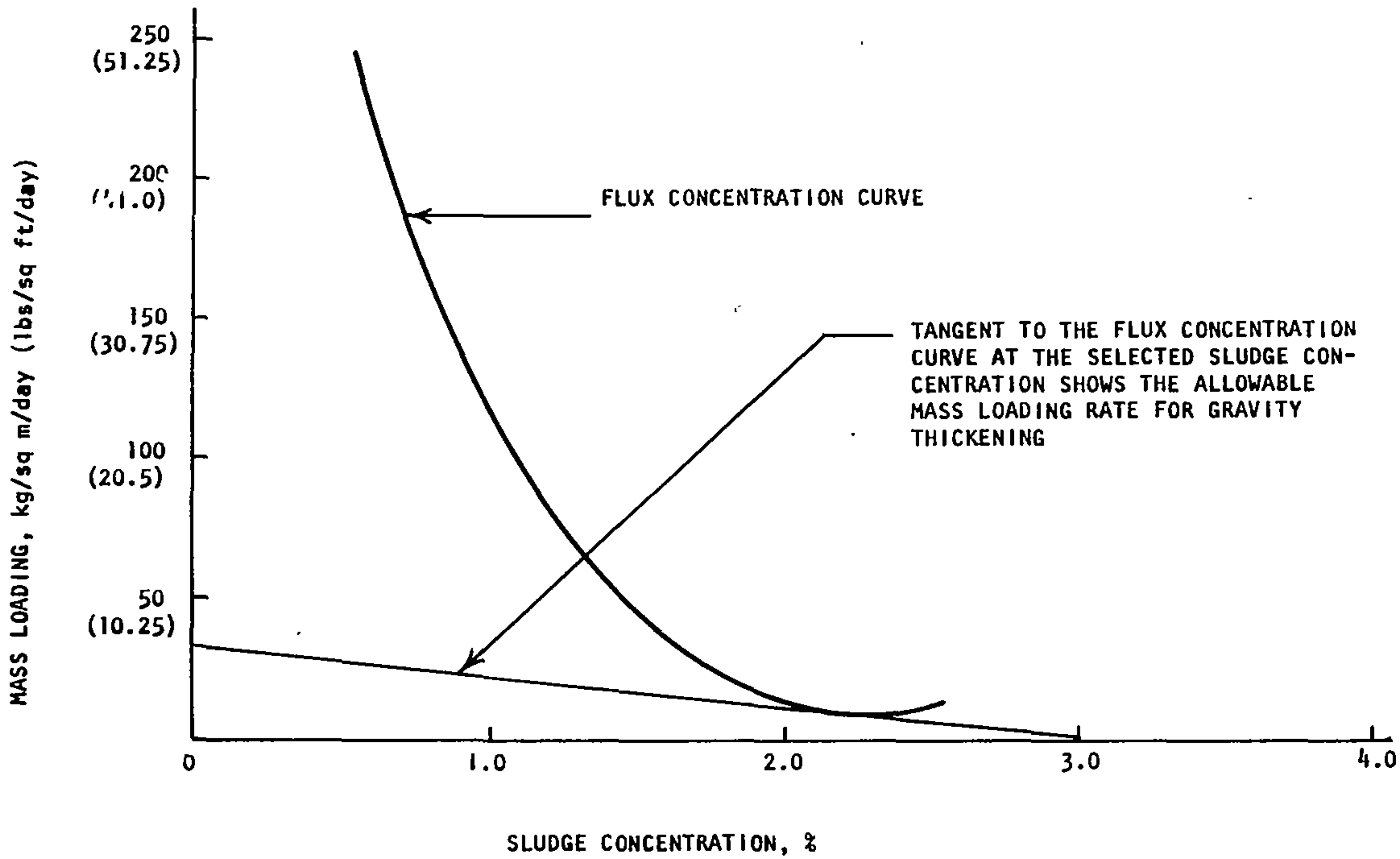


Figure 30. Flux concentration curve for New Providence NJ, wet-weather secondary sludge (with 105 kg/m ton ferric chloride and 2 kg/m ton magniflox 905N polymer)

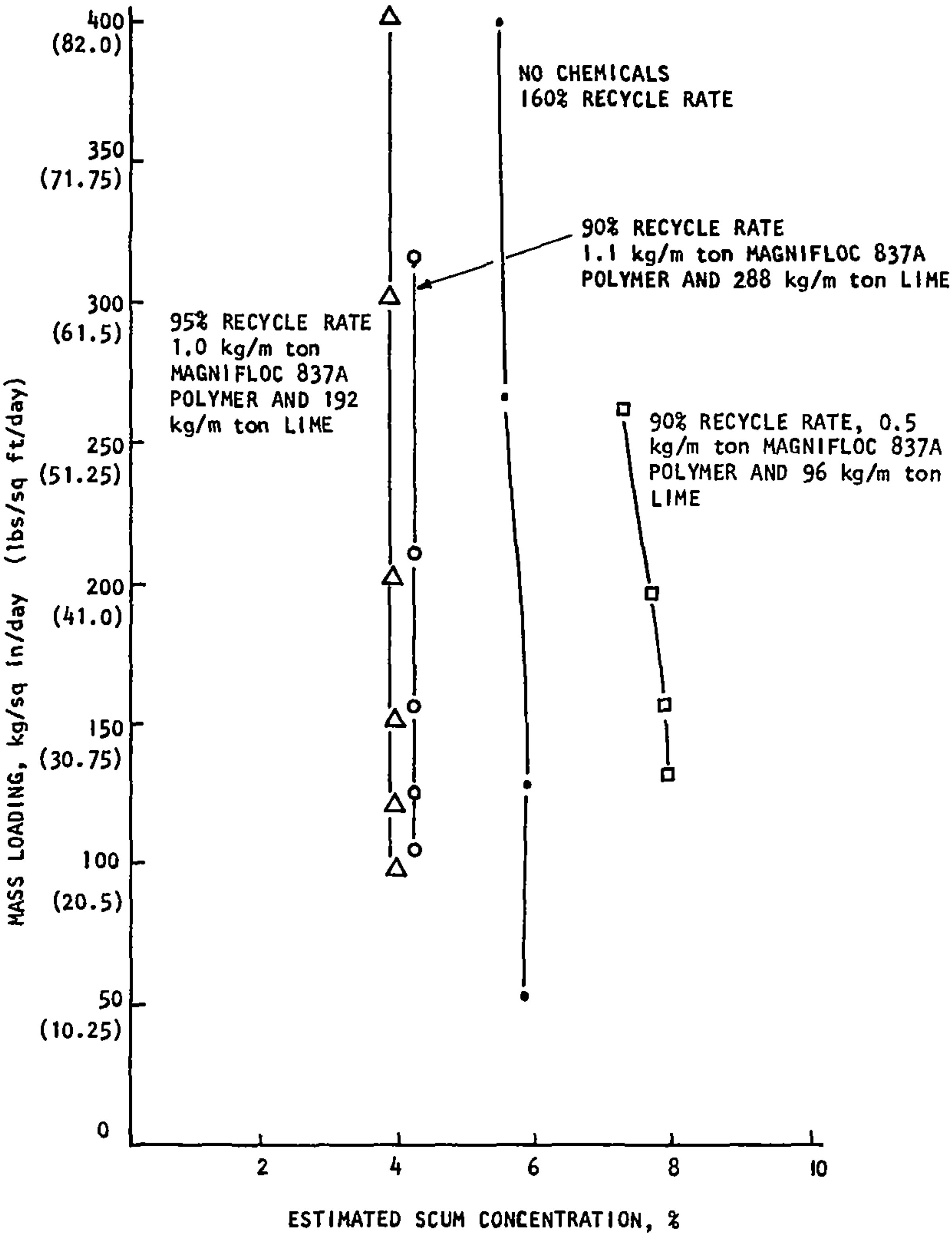


Figure 31. Flotation thickening test results for New Providence, NJ, wet-weather primary sludge

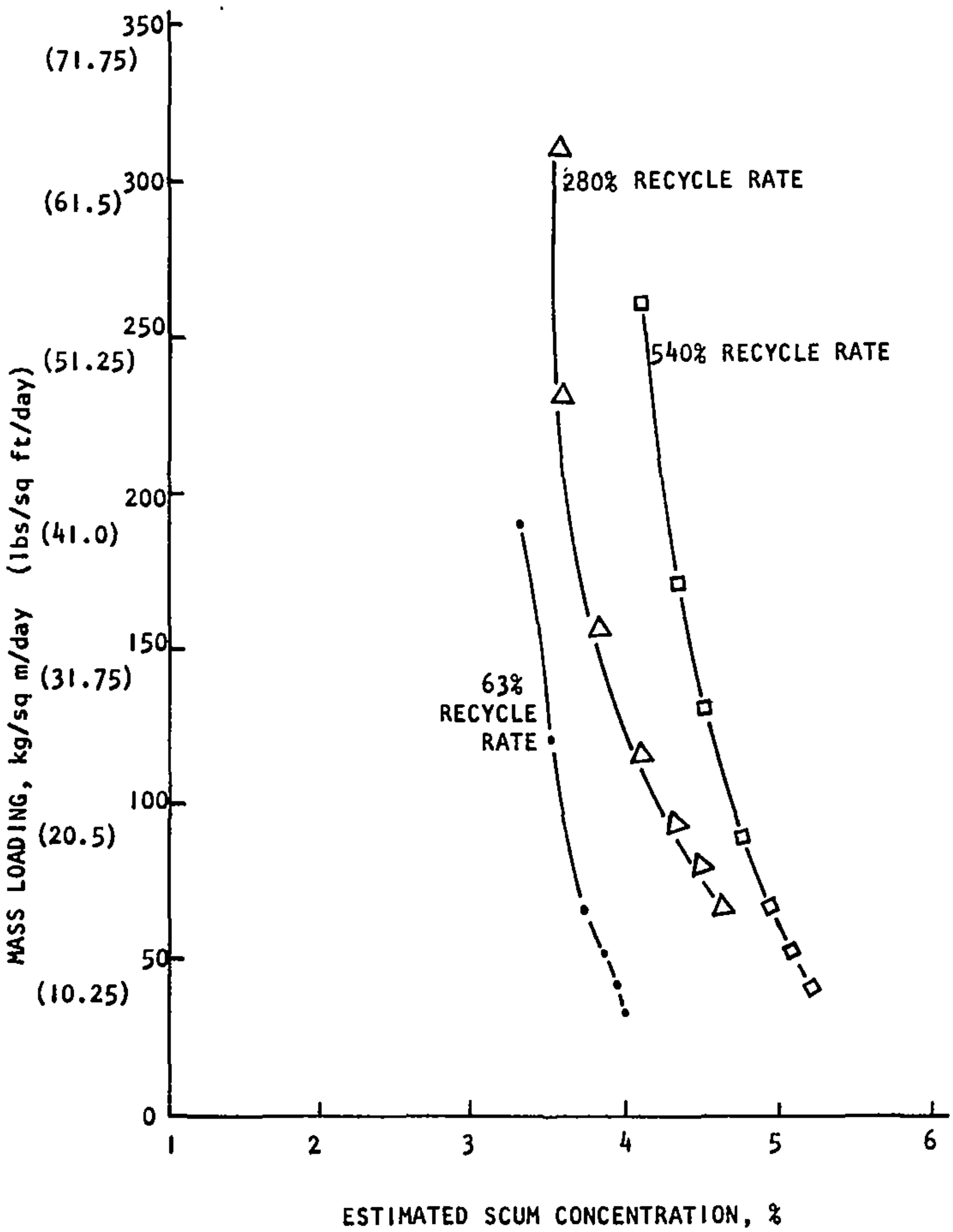


Figure 32. Flotation thickening test results for New Providence, NJ, wet-weather secondary sludge (without chemicals)

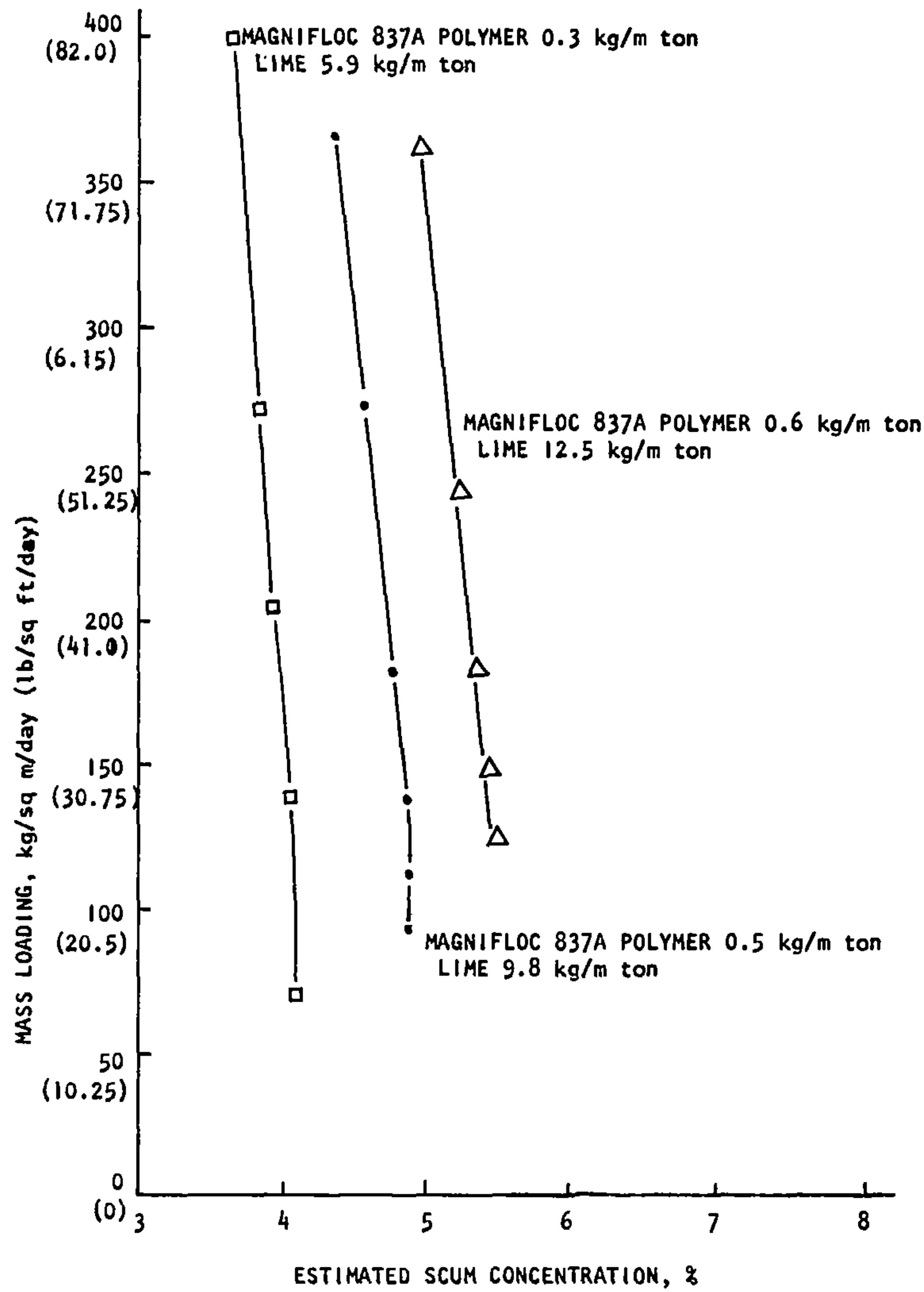


Figure 33. Flotation thickening results for New Providence, NJ, wet-weather secondary sludge (with chemicals)

Table 20. CENTRIFUGE TESTING RESULTS FOR NEW PROVIDENCE, NJ, WET-WEATHER TRICKLING FILTRATION PRIMARY SLUDGE

Test No.	Applied G force,"G's"	Spin time, sec	Feed solids, mg/l	Chemical	Dosage, kg/m ton	Centrate solids, mg/l	Centrate volume, ml	Penetrations, cm	Sludge depth, cm	Cake solids, %	Penetration, %	Recovery, %	Corrected recovery, %
10	1,000	30	1,200	none	none	313	69	0.55	1.5	1.14	63	73.9	70.6
11	1,000	60	1,200	none	none	206	70	0.6	1.15	1.51	48	82.8	76.9
12	1,000	90	1,200	none	none	208	70	0.55	1.3	1.51	58	82.6	78.1
13	1,000	120	1,200	none	none	222	70	0.4	1.35	1.49	70	81.5	78.6
14	700	30	1,200	none	none	550	67	0.7	1.75	0.66	60	54.1	51.4
15	700	60	1,200	none	none	338	69	0.95	1.35	1.11	30	71.8	63.6
16	700	90	1,200	none	none	234	69	0.85	1.6	1.23	47	80.5	74.6
17	700	120	1,200	none	none	340	70	0.65	1.4	1.32	54	71.6	67.2
18	400	30	1,200	none	none	992	69	1.2	1.45	0.36	17	17.3	14.5
19	400	60	1,200	none	none	516	68	0.85	1.5	0.78	43	57.0	52.4
20	400	90	1,200	none	none	449	68	1.0	1.6	0.85	38	62.5	56.7
21	400	120	1,200	none	none	545	67	0.95	1.55	0.68	39	54.5	49.6
22	1,000	30	1,200	837A+CaO	13.4+2,670	320	68	0.4	1.75	0.97	77	73.3	71.4
23	1,000	60	1,200	837A+CaO	13.4+2,670	325	69	0.45	1.65	1.13	73	72.9	70.6
24	1,000	90	1,200	837A+CaO	13.4+2,670	361	67	0.25	1.6	0.82	84	69.9	68.7
25	1,000	120	1,200	837A+CaO	13.4+2,670	200	68	0.35	1.5	1.09	77	83.3	81.1
26	700	30	1,200	837A+CaO	13.4+2,670	207	66	0.4	1.5	0.85	73	82.7	80.0
27	700	60	1,200	837A+CaO	13.4+2,670	216	68	0.5	1.45	1.08	66	82.0	78.6
28	700	90	1,200	837A+CaO	13.4+2,670	215	69	0.4	1.3	1.25	69	82.0	79.0
29	700	120	1,200	837A+CaO	13.4+2,670	212	69	0.5	1.0	1.26	50	82.3	76.7
30	400	30	1,200	837A+CaO	13.4+2,670	237	66	0.5	1.45	1.00	66	80.2	76.9
31	400	60	1,200	837A+CaO	13.4+2,670	187	67	0.55	1.55	0.97	65	84.4	80.8
32	400	90	1,200	837A+CaO	13.4+2,670	162	69	0.55	1.55	1.31	65	86.5	82.8
33	400	120	1,200	837A+CaO	13.4+2,670	178	68	0.55	1.5	1.11	63	85.1	81.3

Table 21. CENTRIFUGE TESTING RESULTS FOR NEW PROVIDENCE, NJ, WET-WEATHER TRICKLING FILTRATION SECONDARY SLUDGE

Test No.	Applied G force, G's	Spin time, sec	Feed solids, mg/l	Chemical	Dosage, kg/m ton	Centrate solids, mg/l	Centrate volume, ml	Penetration, cm	Sludge depth, cm	Cake solids, %	Penetration, %	Recovery, %	Corrected recovery, %
1	1,000	60	25,000	none	none	808	38	4.45	4.45	5.0	0	96.0	0[a]
2	1,000	90	25,000	none	none	528	43	3.7	3.9	5.8	5	97.4	72.3
3	1,000	120	25,000	none	none	658	44	3.3	3.8	6.0	16	97.3	80.8
4	700	60	25,000	none	none	1,380	38	4.65	4.65	4.9	0	94.4	0[a]
5	700	90	25,000	none	none	1,050	39	4.65	4.65	5.1	0	95.8	0[a]
6	700	120	25,000	none	none	637	41	3.65	4.1	5.4	11	97.4	78.0
7	400	60	25,000	none	none	1,480	33	4.95	4.95	4.3	0	94.0	0[a]
8	400	90	25,000	none	none	840	35	4.65	4.65	4.6	0	96.6	0[a]
9	400	120	25,000	none	none	850	36	4.4	4.4	4.7	0	96.6	0[a]
34	1,000	30	25,000	$FeCl_3$+905N	1458+40	174	43	1.65	3.9	5.8	58	99.3	93.9
35	1,000	60	25,000	$FeCl_3$+905N	1458+40	184	46	1.95	3.25	6.4	40	99.2	90.5
36	1,000	90	25,000	$FeCl_3$+905N	1458+40	136	49	1.65	3.45	7.2	52	99.4	93.1
37	1,000	120	25,000	$FeCl_3$+905N	1458+40	169	50	1.75	3.3	7.5	47	99.3	92.1
38	700	30	25,000	$FeCl_3$+905N	1458+40	231	39	2.25	4.3	5.2	48	99.0	91.9
39	700	60	25,000	$FeCl_3$+905N	1458+40	165	44	1.8	3.8	6.0	53	99.3	93.1
40	700	90	25,000	$FeCl_3$+905N	1458+40	190	43	2.3	3.8	5.6	39	99.2	90.4
41	700	120	25,000	$FeCl_3$+905N	1458+40	137	44	2.1	3.65	6.0	42	99.4	91.2
42	400	30	25,000	$FeCl_3$+905N	1458+40	252	37	3.0	4.3	4.9	30	98.9	87.7
43	400	60	25,000	$FeCl_3$+905N	1458+40	119	34	2.6	3.95	4.6	34	99.5	89.4
44	400	90	25,000	$FeCl_3$+905N	1458+40	157	40	2.65	4.05	5.3	34	99.3	89.3
45	400	120	25,000	$FeCl_3$+905N	1458+40	187	43	2.45	3.9	5.8	37	99.2	89.8

a. Denotes poor thickening performance for a scroll type centrifuge. See Appendix B for procedure.

solids of only 2% or less were achieved even with the aid of chemicals. For the secondary sludge, cake solids of approximately 7.5% were achieved with the aid of chemicals (ferric chloride and Magnifloc nonionic polyelectrolyte). Both samples showed poor scrollability and hence basket type centrifuge will be necessary for such sludges. No centrifugation tests were run on gravity thickened primary sludge samples. Based on the results of various other sludges evaluated in this study, it is indicated that significantly better centrifugation results on gravity thickened sludges can be expected.

The vacuum filtration tests on both the primary and secondary sludge samples were conducted on pre-sedimented samples. The feed solids concentrations after sedimentation were 2.5% and 3.2% for the two samples respectively. The test results are shown in Tables 22 and 23 respectively. Based on the results of the Buchner Funnel tests, a combination of ferric chloride and lime showed best filtration results for both sludge samples. Best cake discharge characteristics were obtained with multifilament polypropylene filter cloth. Cake solids of nearly 28% were achieved for the primary sludge, while solids concentrations of only 16 to 18% were achieved for the secondary sludge samples under optimum test conditions. The optimum filter yields for the two samples were approximately 18 kg/sq m/hr (3.5 lbs/sq ft/hr).

<u>Dry-Weather Sludge Samples</u> - A schematic of the dewatering techniques investigated on the dry-weather sludge samples from the primary and secondary clarifiers is shown in Figure 34. The present quantities of sludge being discharged from primary and secondary clarifiers are 68 cu m (26,150 gal.) per day respectively (Table 2). As mentioned earlier, these quantities are presently discharged without regard to the sludge strength. Both sludge samples procured for dewatering tests showed low solids concentrations of 0.38 and 0.46 respectively.

The flux concentration curves for the gravity thickening tests on the two samples are shown in Figures 35 and 36. Both these curves represent the test data without the addition of any flocculating chemicals. It was found that flocculating chemicals did not provide any improvement in the gravity thickening performance. For primary sludge, solid concentrations of only 2 to 3% were achieved at mass loading rates between 30 and 50 kg/sq m/day (6-10 lbs/sq ft/day). These values compared to approximately 8% solids at mass loading rates up to 100 kg/sq m/day (100 lbs/sq ft/day) for wet-weather primary sludge. The results were poorer for secondary sludge samples where a solids concentration of only 2% or less could be expected at solids loadings below 20 kg/sq m/day (4 lbs/sq ft/day). The dry-weather secondary sludge results were quite similar to the poor gravity thickening results for the wet-weather secondary sludge discussed earlier.

The results of flotation thickening tests are shown in Figures 37 through 39. For primary sludge, scum concentrations of greater than 5% solids could be expected at a mass loading rate of 65 kg/sq m/day (13 lbs/sq ft/day) with the use of 15.6 kg/m ton (31 lbs/ton) of Dow C-31 polyelectrolyte and at a recycle rate of 230%. However, for secondary sludge, use of chemicals did not aid in flotation thickening as shown by a comparison of Figures 38

Table 22. VACUUM FILTRATION TESTING RESULTS FOR NEW PROVIDENCE, NJ, WET-WEATHER TRICKLING FILTRATION PRIMARY SLUDGE

Feed Solids Concentration - 2.5%

Chemical dosage, kg/m ton $FeCl_3$	Chemical dosage, kg/m ton CaO	Cycle time, min	Pickup time, sec	Dry time, sec	Submergence %	Yield, $kg/hr/m^2$	Loading, kg/m^2	Cake solids, %	Filtrate solids, mg/l	Filtrate volume, ml	Type of cloth	Cake Discharge characteristics
54	160	4	60	120	25	13.35	0.89	27.4	116	420	multifilament polypropylene	Good
54	160	6	132	148	37.5	11	1.10	26.9	174	570	multifilament polypropylene	Good
54	160	2*	30	60	25	17.7	0.59	27.5	82	265	multifilament polypropylene	Good
54	160	3	66	73	37.5	18.2	0.91	27.8	92	430	multifilament polypropylene	Good
54	160	4	88	98	37.5	17.1	1.14	25.7	85	550	multifilament polypropylene	Good

Table 23. VACUUM FILTRATION TESTING RESULTS FOR NEW PROVIDENCE, NJ, WET-WEATHER TRICKLING FILTRATION SECONDARY SLUDGE

Feed Solids Concentration - 31,500 mg/l

Chemical dosage, kg/m ton $FeCl_3$	CaO	Cycle time, min	Pickup time, sec	Dry time, sec	Submergence %	Yield, kg/hr/m^2	Loading, kg/m^2	Cake solids, %	Filtrate solids, mg/l	Filtrate volume, ml	Type of cloth	Cake Discharge characteristics
85	254	4	60	120	25	18.45	1.23	18.5	231	460	multifilament polypropylene	Good
85	254	4	88	98	37.5	24.45	1.63	15.7	184	560	multifilament polypropylene	Good
85	254	6	132	148	37.5	16.9	1.69	16.5	188	600	multifilament polypropylene	Good
85	254	2	45	50	37.5	39.6	1.32	13.8	546	265	multifilament polypropylene	Good
85	254	3	66	73	25	34.8	1.74	15.0	441	360	multifilament polypropylene	Good
85	254	5	110	122	25	21.84	1.82	13.5	478	360	multifilament polypropylene	Good

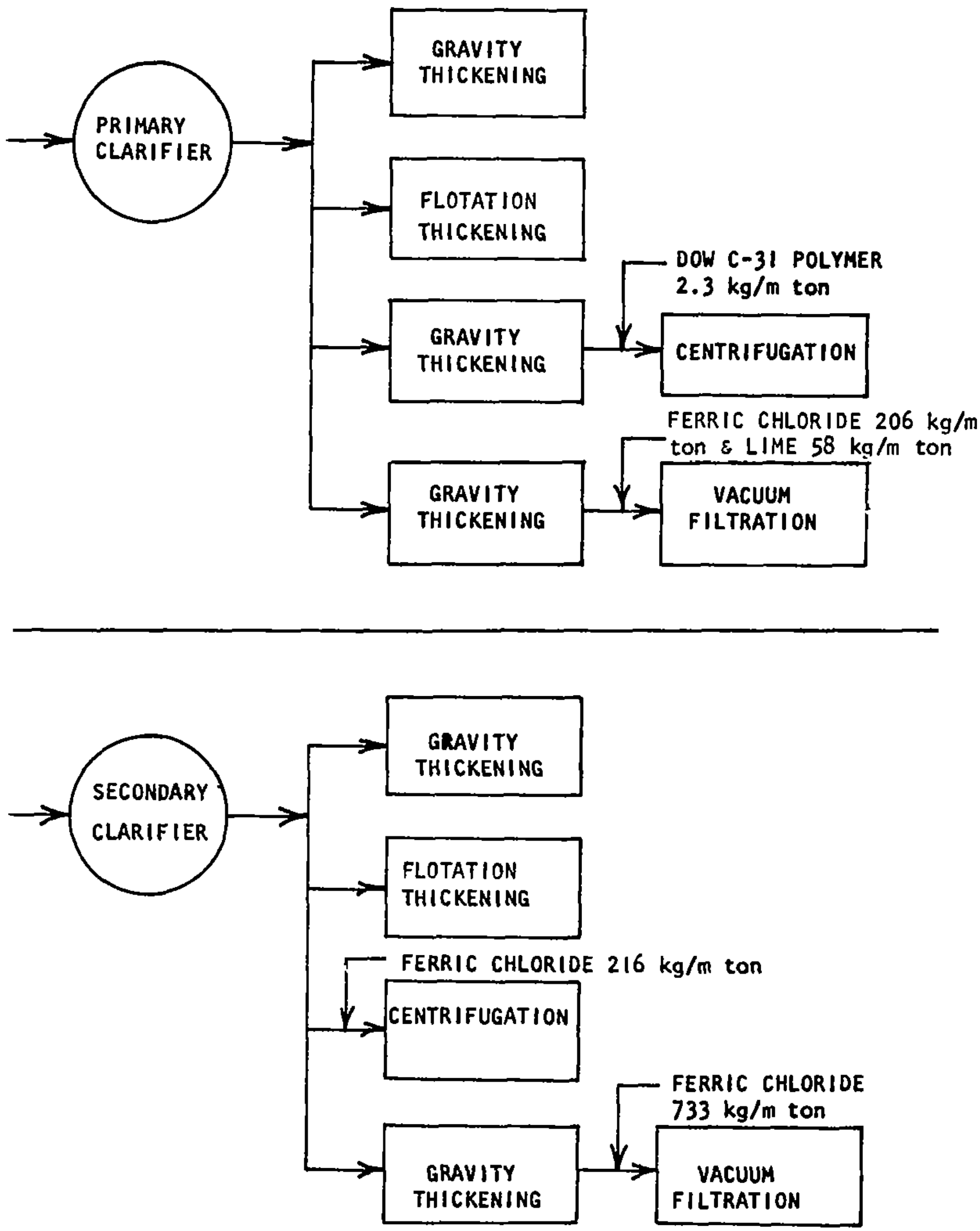


Figure 34. New Providence, NJ - bench scale dewatering tests (dry-weather)

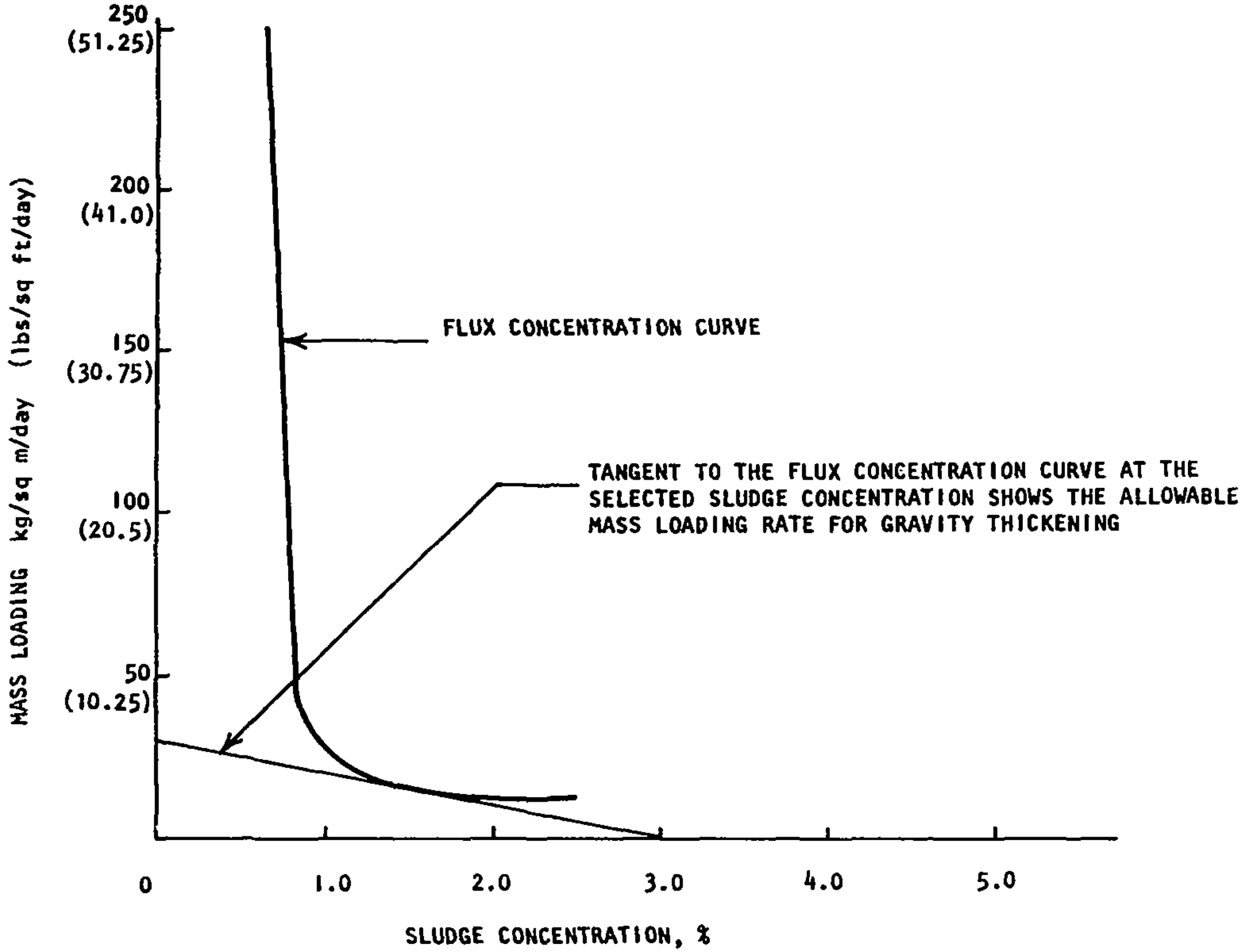


Figure 35. Flux concentration curve for New Providence, NJ, dry-weather primary sludge

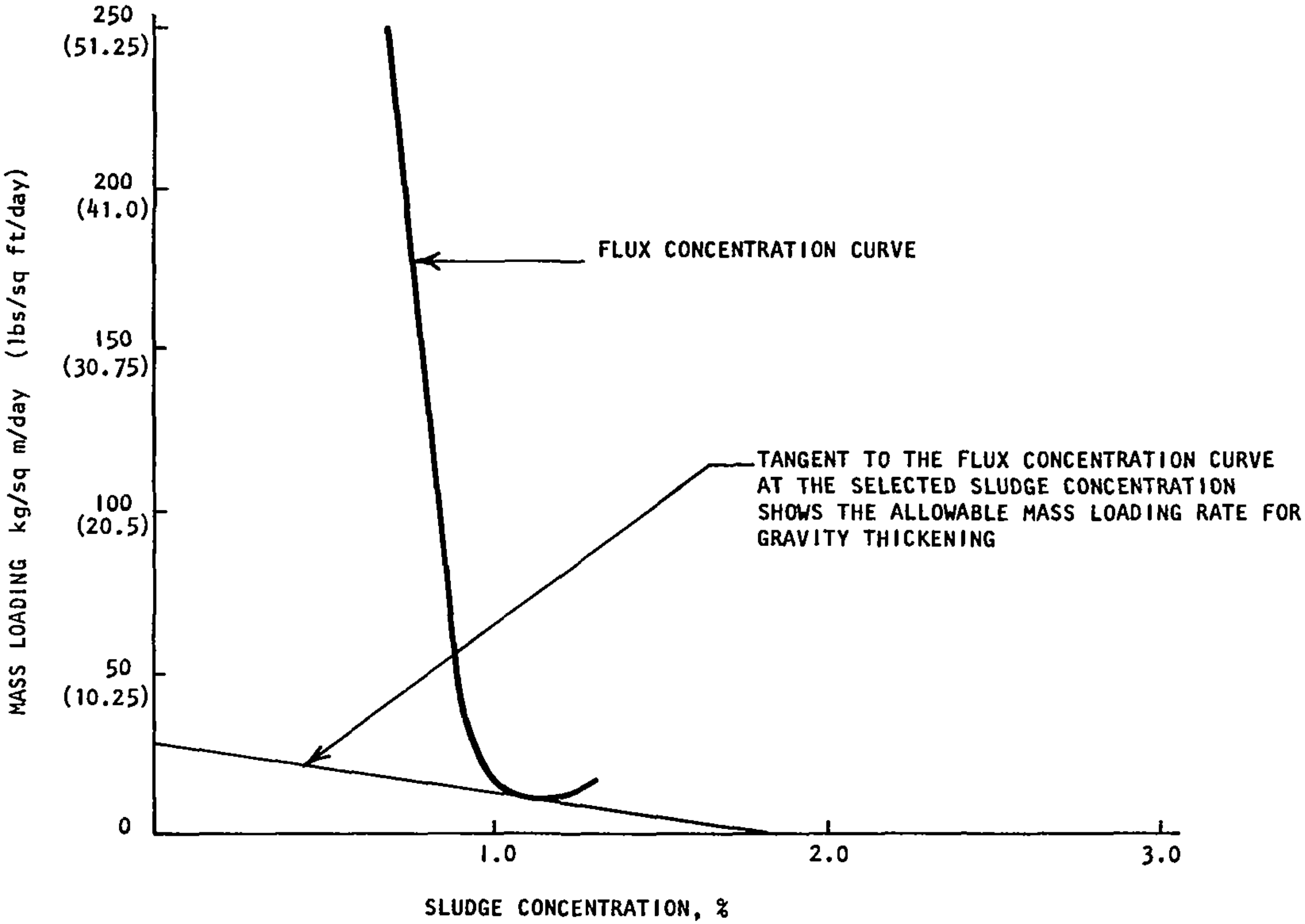


Figure 36. Flux concentration curve for New Providence, NJ, dry-weather secondary sludge

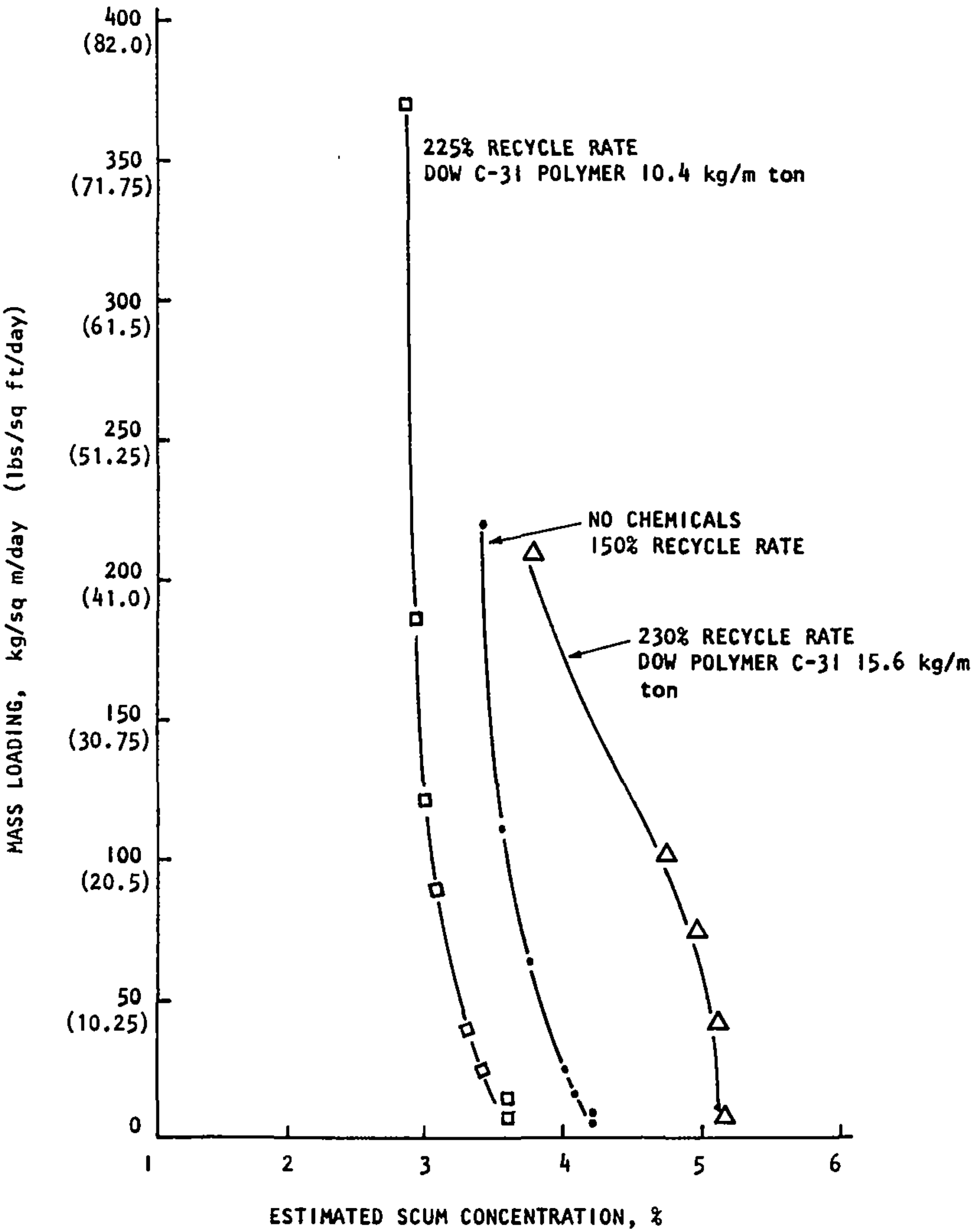


Figure 37. Flotation thickening test results for New Providence, NJ, dry-weather primary sludge

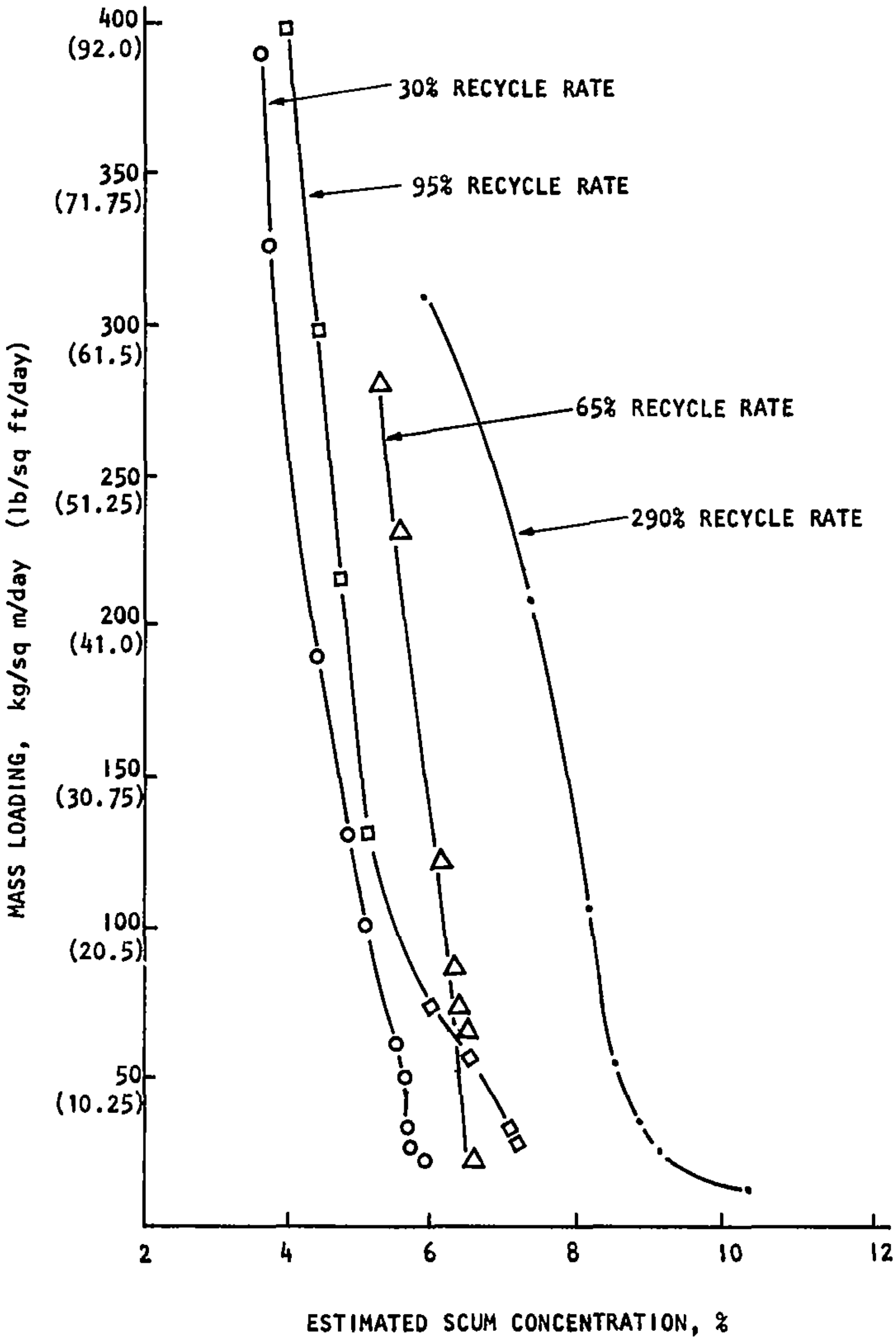


Figure 38. Flotation thickening test results for New Providence, NJ, dry-weather secondary sludge (without chemicals)

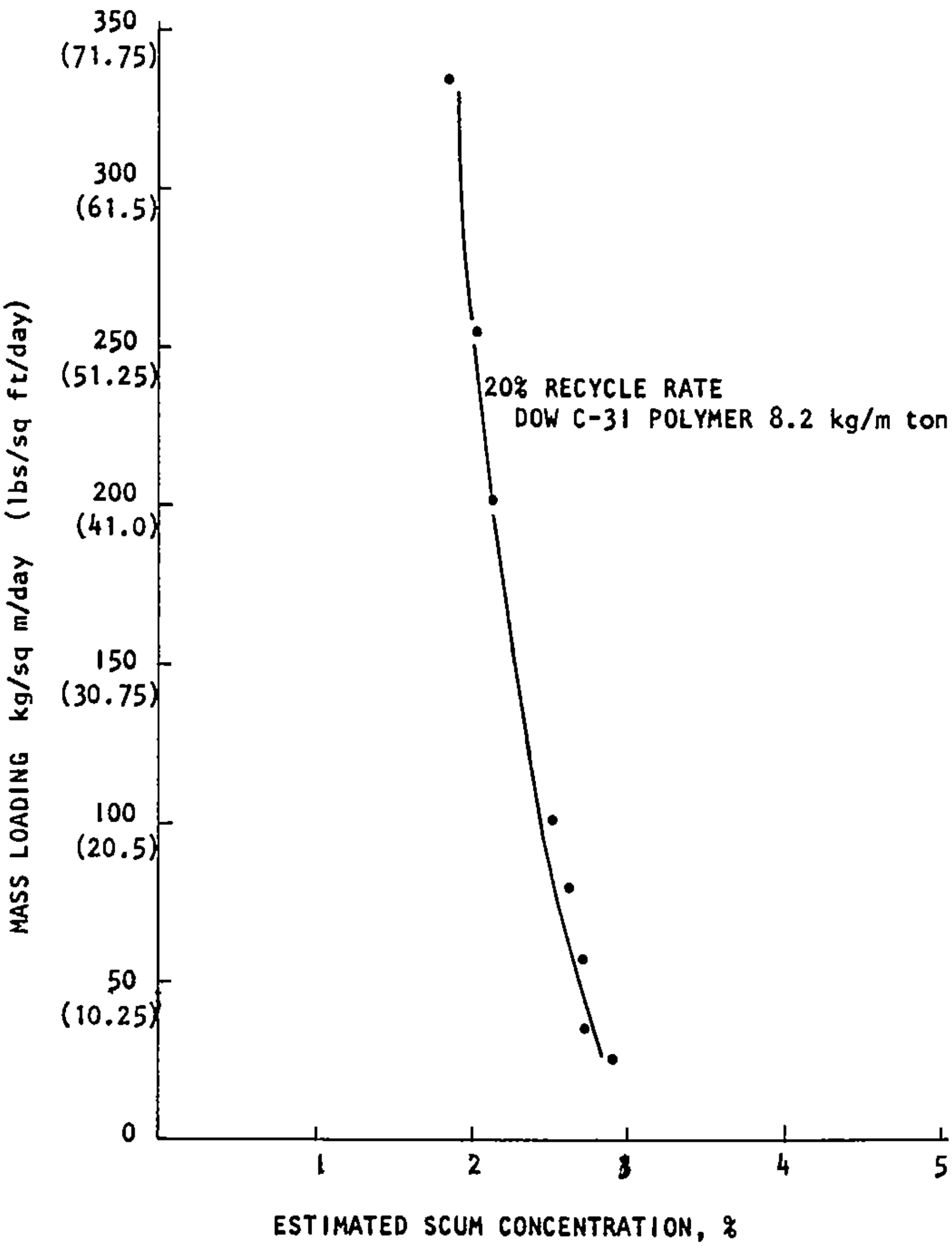


Figure 39. Flotation thickening test results for New Providence, NJ, dry-weather secondary sludge (with chemicals)

and 39. Scum concentrations as high as 8 to 10% solids could be achieved without use of any chemical aids at mass loading rates between 50 and 100 kg/sq m/day (10-20 lbs/sq ft/day). The optimum recycle rates varied between 200 and 300% for the two samples. Again, the dry-weather flotation thickening results were similar to the wet-weather thickening results.

Centrifugation test results are shown in Tables 24 and 25 for the two samples. For the primary sludge sample, these tests were conducted on a presedimented sample at a feed solids concentration of 1.8%. Optimum results were shown without the use of flocculating chemicals and cake solids up to 13% were achieved under optimum test conditions (700 to 1000 G and 60 to 120 seconds spin time). These results are in sharp contrast to the primary sludge samples during wet-weather, and confirm the earlier statement for the primary wet-weather sludge sample whereby it was indicated that significantly improved centrifuge performance may be expected for pre-thickened sludge samples. The tests on the secondary sludge samples were conducted without pre-thickening. Generally poorer results were shown as cake solids of only 2% or less were achieved. However, this performance may again be attributed to the dilute nature of the raw sample and significantly improved results can be expected on pre-thickened samples.

The vacuum filtration tests on both the primary and secondary dry-weather sludge samples were conducted on pre-thickened samples, similar to the wet-weather filtration tests. The feed solids concentrations after sedimentation of the raw samples were 2.6% and 1.9% respectively. The test results are shown in Tables 26 and 27. A chemical combination of lime and ferric chloride again provided optimum filtration results similar to the wet-weather sludge filtration tests. Best cake discharge characteristics were achieved with a 3 x 1, 100% olefin multifilament filter cloth for both the sludges. Cake solids of 20 to 22% for primary sludge and 12 to 14% for secondary sludge were achieved under optimum conditions. The optimum filter yields varied between 13 and 35 kg/sq m/hr (2.6 and 7 lbs/sq ft/hr) for primary sludge and between 10 to 15 kg/sq m/hr (2-3 lbs/sq ft/hr) for the secondary sludge. These results are very similar to the corresponding results for wet-weather sludges and indicate amenability to dual (dry/wet) treatment of sludges.

Treatment Costs for Biological CSO Sludges (Wet-Weather)

A summary of the estimated area and cost requirements of the various dewatering techniques for wet-weather biological treatment sludges is shown in Table 28. Again, the total costs include amortized capital, operating and hauling costs of ultimate residuals as shown in Appendix C. It is evident that for biological sludges, generally, vacuum filtration dewatering in combination with gravity or flotation thickening provided most effective and economic method of handling such sludges. However, the economic results for centrifugation in combination with gravity or flotation thickening were quite close to the corresponding costs for vacuum filtration. Because of the poor scrollability of biological sludges, cost estimates for centrifuges were based on basket type centrifuge units. A more detailed discussion of the overall sludge treatment needs is made in Section VIII of this report after discussion of the bleed back concept in Section VII.

Table 24. CENTRIFUGE TESTING RESULTS FOR NEW PROVIDENCE, NJ, DRY-WEATHER PRIMARY SLUDGE

Test No.	Applied G force, 'G's'	Spin time, sec	Feed solids, mg/l	Chemical	Dosage, kg/m ton	Centrate solids, mg/l	Centrate volume, ml	Penetration, cm	Sludge depth cm	Cake solids, %	Penetration, %	Recovery, %	Corrected recovery, %
1	1,000	120	17,500	None	None	314	65	2.45	2.45	12.9	40	98	90
2	1,000	120	17,500	C31	2.29	267	65	0.9	1.75	13.0	48	98	91
3	1,000	90	17,500	C31	2.29	146	63	1.05	1.75	10.9	40	99	90
4	1,000	60	17,500	C31	2.29	264	64	1.0	2.0	11.8	50	98	91
5	1,000	30	17,500	C31	2.29	480	61	1.4	2.25	9.2	37	97	88
6	700	120	17,500	C31	2.29	132	65	0.9	1.8	13.0	50	99	92
7	700	90	17,500	C31	2.29	188	64	1.2	2.0	11.8	40	99	90
8	700	60	17,500	C31	2.29	246	61	1.0	2.0	9.3	50	99	92
9	700	30	17,500	C31	2.29	510	62	1.45	2.35	9.8	38	97	88
10	400	120	17,500	C31	2.29	200	63	1.1	2.0	10.8	45	99	90
11	400	90	17,500	C31	2.29	290	64	1.4	2.05	11.8	29	98	87
12	400	60	17,500	C31	2.29	250	61	1.9	2.30	9.3	15	99	82
13	700	120	17,500	$FeCl_3$	5.7	94	63	0.75	2.05	10.9	63	99	95
14	700	90	17,500	$FeCl_3$	5.7	130	60	0.85	2.4	8.7	64	99	95
15	700	60	17,500	$FeCl_3$	5.7	122	61	1.1	2.2	9.3	48	99	92
16	700	30	17,500	$FeCl_3$	5.7	158	57	1.3	2.3	7.2	54	99	92
17	400	120	17,500	$FeCl_3$	5.7	156	58	1.3	2.85	7.7	42	99	90
18	400	90	17,500	$FeCl_3$	5.7	146	57	1.45	2.5	7.2	33	99	89
19	400	60	17,500	$FeCl_3$	5.7	292	50	1.65	2.45	5.2	8	98	76
20	400	30	17,500	$FeCl_3$	5.7	142	57	1.3	3.35	7.2	43	99	91

Table 25. CENTRIFUGE TESTING RESULTS FOR NEW PROVIDENCE, NJ, DRY-WEATHER SECONDARY SLUDGE

Test No.	Applied G force, "G's"	Spin time, sec	Feed solids, %	Chemical	Dosage kg/m ton	Centrate solids, mg/l	Centrate volume, ml	Penetration, cm	Sludge depth, cm	Cake solids, %	Penetration, %	Recovery, %	Corrected recovery, %
21	1,000	120	4,620	None	None	334	53	2.75	2.75	1.5	0	93	0
22	1,000	120	4,620	$FeCl_3$	21.6	128	54	2	3.0	1.6	33	96	86
23	1,000	90	4,620	$FeCl_3$	21.6	116	53	2.5	2.85	1.5	12	97	78
24	1,000	60	4,620	$FeCl_3$	21.6	98	51	3.1	3.1	1.4	0	98	0
25	1,000	120	4,620	$FeCl_3$	500	120	59	1.05	2.8	2.1	62	97	92
26	1,000	90	4,620	$FeCl_3$	500	74	52	1.25	2.85	1.5	56	98	92
27	1,000	60	4,620	$FeCl_3$	500	130	52	2.15	3.05	1.5	20	97	83
28	1,000	30	4,620	$FeCl_3$	500	108	49	3.05	3.05	1.3	0	98	0
29	1,000	120	4,620	C-31	12.9	325	55	3.0	3.0	1.6	0	93	0
30	1,000	120	4,620	$FeCl_3$	216	194	62	1.35	2.8	2.6	52	96	90
31	1,000	60	4,620	$FeCl_3$	216	175	59	2.1	2.85	2.1	26	96	83
32	1,000	30	4,620	$FeCl_3$	216	228	57	3.3	3.3	1.8	0	95	0
33	1,000	30	4,620	$FeCl_3$	1,080	112	44	3.5	3.5	1.1	0	98	0
34	1,000	120	4,620	$FeCl_3$	216	92	54	1.25	2.85	1.6	56	98	92
35	1,000	90	4,620	$FeCl_3$	216	104	53	2.05	3.1	1.5	34	98	88
36	1,000	60	4,620	$FeCl_3$	216	106	52	2.45	3.2	1.5	25	98	85
37	1,000	30	4,620	$FeCl_3$	216	134	47	3.55	3.55	1.2	0	97	0
38	700	120	4,620	$FeCl_3$	216	114	53	1.4	3.05	1.5	54	98	92
39	700	90	4,620	$FeCl_3$	216	128	52	1.60	3.4	1.5	44	[illegible]	89
40	700	60	4,620	$FeCl_3$	216	162	49	3.95	3.45	1.3	13	96	78
41	700	30	4,620	$FeCl_3$	216	320	44	4.0	4.0	1.1	0	93	0
42	400	120	4,620	$FeCl_3$	216	164	50	2.15	3.4	1.4	37	96	87
43	400	90	4,620	$FeCl_3$	216	198	46	3.65	3.65	1.2	0	96	0
44	400	60	4,620	$FeCl_3$	216	192	47	3.9	3.9	1.2	0	96	0
45	400	30	4,620	$FeCl_3$	216	396	33	5.3	5.3	0.8	0	91	0

Table 27. VACUUM FILTRATION TESTING RESULTS FOR NEW PROVIDENCE, NJ, DRY-WEATHER SECONDARY SLUDGE

Feed Solids Concentration - 1.9%

Chemical dosage, kg/m ton		Cycle time, min	Pickup time, sec	Dry time, sec	Submergence, %	Yield, $kg/hr/m^2$	Loading, kg/m^2	Cake solids, %	Filtrate solids, mg/l	Filtrate volume, ml	Type of cloth	Cake Discharge characteristics
$FeCl_3$	CaO											
620	0	5	110	122	37.5	7.48	0.62	9.8	67	430	3 X 1 twill olefin 100% multifilament	Poor
620	0	5	75	150	25	7.38	0.61	10.3	41	360	3 X 1 twill olefin 100% multifilament	Good
620	0	3	45	90	25	9.92	0.49	10.1	47	240	3 X 1 twill olefin 100% multifilament	Fair
733	0	5	75	150	25	7.09	0.59	11.5	37	400	3 X 1 twill olefin 100% multifilament	Good
733	0	4	60	120	25	7.66	0.51	13.2	21	285	3 X 1 twill olefin 100% multifilament	Good
567	212	5	75	150	25	6.23	0.52	12.6	166	355	3 X 1 twill olefin 100% multifilament	Good
567	212	4	60	120	25	8.73	0.58	12.8	79	335	3 X 1 twill olefin 100% multifilament	Good
567	212	3	45	90	25	15.16	0.78	13.6	51	445	3 X 1 twill olefin 100% multifilament	Good
567	212	2	30	60	25	16.86	0.56	12.9	73	340	3 X 1 twill olefin 100% multifilament	Good
567	212	3.5	30	120	14	11.46	0.66	13.8	45	365	3 X 1 twill olefin 100% multifilament	Good

Table 28. SUMMARY OF AREA AND COST REQUIREMENTS FOR WET-WEATHER BIOLOGICAL SLUDGES UNDER OPTIMUM TREATMENT CONDITIONS

Site.	Kenosha, WI				New Providence, NJ							
					Primary sludge				Secondary sludge			
	Sludge solids, %	Area, sq ft	(sq m)	Total annual cost[a], $/yr	Sludge solids, %	Area, sq ft	(sq m)	Total annual cost[a], $/yr	Sludge solids, %	Area, sq ft	(sq m)	Total annual cost[a], $/yr
Gravity Thickening	1	1593	(148)	520,700	8	172	(16)	21,100	4	732	(68)	59,900
Flotation Thickening	3	463	(43)	186,600	6	151	(14)	32,500	4	355	(33)	59,700
Centrifugation	9	205	(19)	90,100	13[b]	205	(19)	24,300	7.5	54	(5)	39,300
Vacuum Filtration	15[b]	614	(57)	79,800	27.5[b]	323	(30)	18,600	18.5[b]	581	(54)	35,300

a. Capital costs amortized for 20 year equipment life and 10% interest rate. For details of cost estimates, see Appendix C.

b. These tests conducted on gravity or flotation thickened sludge.

All costs based on December, 1974 prices.

Table 26. VACUUM FILTRATION TESTING RESULTS FOR NEW PROVIDENCE, NJ, DRY-WEATHER PRIMARY SLUDGE

Feed Solids Concentration - 2.6%

Chemical dosage, kg/m ton		Cycle time, min	Pickup time, sec	Dry time, sec	Submergence, %	Yield, kg/hr/m^2	Loading, kg/m^2	Cake solids, %	Filtrate solids, mg/l	Filtrate volume, ml	Type of cloth	Cake Discharge characteristics
$FeCl_3$	CaO											
206	58	5	75	150	25	18.5	1.55	22.8	73	830	3 X 1 twill olefin 100% multifilament	Blinds
206	58	2	30	60	25	33.8	1.13	20.1	84	470	3 X 1 twill olefin 100% multifilament	Poor
206	38	2	30	60	25	34.08	1.13	21.5	68	555	3 X 1 twill olefin 100% multifilament	Good
103	58	2	30	60	25	28.04	0.93	14.5	263	175	3 X 1 twill olefin 100% multifilament	Poor
154	58	2	30	60	25	12.54	0.41	17.2	117	330	3 X 1 twill olefin 100% multifilament	Good

SECTION VII

PUMPBACK/BLEEDBACK CONCEPT AND ITS APPLICABILITY

The determination of the efficiency of various sludge thickening and dewatering techniques for treating the sludges arising from combined sewer overflow treatment processes has been the main thrust of this research activity. However, the feasibility of actually pumping back or bleeding back these on-site sludges to existing dry-weather treatment facilities must also be considered. By controlled pumpback or bleedback of the CSO treatment residuals, additional cost of the on-site sludge treatment facilities may be avoided or minimized. At the dry-weather treatment plant, the diluted sludge can then be removed in the grit removal, primary sedimentation, or secondary treatment processes and become part of the treatment plant sludge.

In cases where the combined sewer overflow treatment facilities are located on the grounds of the municipal wastewater treatment plant, the question that has to be resolved is whether the existing sludge handling facilities (perhaps with unused capacity) can be used for the combined sewer overflow treatment sludges, or if separate facilities of a different type have to be constructed.

A typical mode of operation of a pumpback or a bleedback system would consist of monitoring instrumentation that would measure the flow rate and solids handling capacity at the treatment plant and feed this information back to the sludge holding facilities. When the capacity at the treatment plant is sufficient, the tanks automatically drain, or are pumped if necessary, to the interceptor sewer. Any significant increase in the flow rate at the treatment plant due to a rainfall or any other cause would be sensed and the sludge draining would cease.

LOADING ON THE DRY-WEATHER PLANT

When the sludge enters the sewerage system it will be diluted significantly by the dry-weather flow. The resultant increase in suspended solids concentration at the dry-weather plant will be a function of the 1) concentration of the sludge itself, 2) the amount and rate of sludge draining, 3) the dry-weather sewage suspended solids concentration, and 4) the dry-weather flowrate.

The primary effect on the treatment plant once the sludge has reached the treatment plant will be measured by 1) the change in hydraulic loading, 2) the change in grit and solids loading, and 3) the effect of slug loadings of toxic materials such as heavy metals or pesticides on the treatment processes (especially biological). The secondary effect on the treatment plant is 1) the increased sludge production which must be handled by the existing solids handling facilities and 2) the possibility of any disruption of the digestion process due to any slugs of heavy metals or pesticides or even grit if it were to get past the grit chambers into the primary sedimentation tanks.

To illustrate the pumpback/bleedback concept a hypothetical example is presented. Listed below are the criteria for a typical city, assuming that some type of combined sewer overflow treatment facility exists along with a conventional activated sludge treatment plant for dry-weather flow.

Sewered population	100,000 persons
Treatment plant design capacity	94,625 cu m/day (25 mgd)
Average daily flow	75,700 cu m/day (20 mgd)
Gross digestion volume	7400 cu m (300,000 ft^3)
Sewered area	4050 ha (10,000 acres)
Combined sewer area	2025 ha (5000 acres)
Overflow from a 2.5 cm (1.0 in) rain*	246,025 cu m (65 million gallons)
Sludge produced (assuming 200 mg/l solids removed)	49,485 kg (109,000 lbs)
Sludge volume at 2% concentration	2460 cu m (0.65 million gallons)

* Assuming approximately 50% of the rainfall results in overflow.

If the 2460 cu m (0.65 million gal.) were bled back to the treatment plant at a constant rate over a 24 hour period, this would be an average increase in flow rate of only 3.25%. However, the average increase in solids loading would be 338%. Figure 40 contains two graphs, the top shows a typical dry weather diurnal flow pattern with the additional flow due to the bleedback also shown. The bottom graph shows the dry-weather solids loading and the solids loading due to bleedback. A constant raw suspended solids value of 200 mg/l was used in determining the dry-weather solids loading.

The significant fact in Figure 40 is that although the increase in hydraulic loading at the dry-weather treatment plant is negligible, the solids loading is significant. Based on the hypothetical data used to calculate the graphs in Figure 40, the average suspended solids concentration in the raw flow during the period of bleedback would be 870 mg/l. If this concentration would cause significant solids deposition in the sewerage system, or if the added solids would be in excess of what the dry-weather plant facilities could handle, then bleedback would not be feasible. It may be possible to increase the duration of bleedback to reduce the rate of solids loading but there are limits on this time because of possible problems with sludge septicity, odors, necessity of aeration, and reduced amenability to certain thickening processes.

The possibility of settling occurring in the sewerage system during pump/bleedback will obviously depend on the hydraulic situation in the sewer to which the

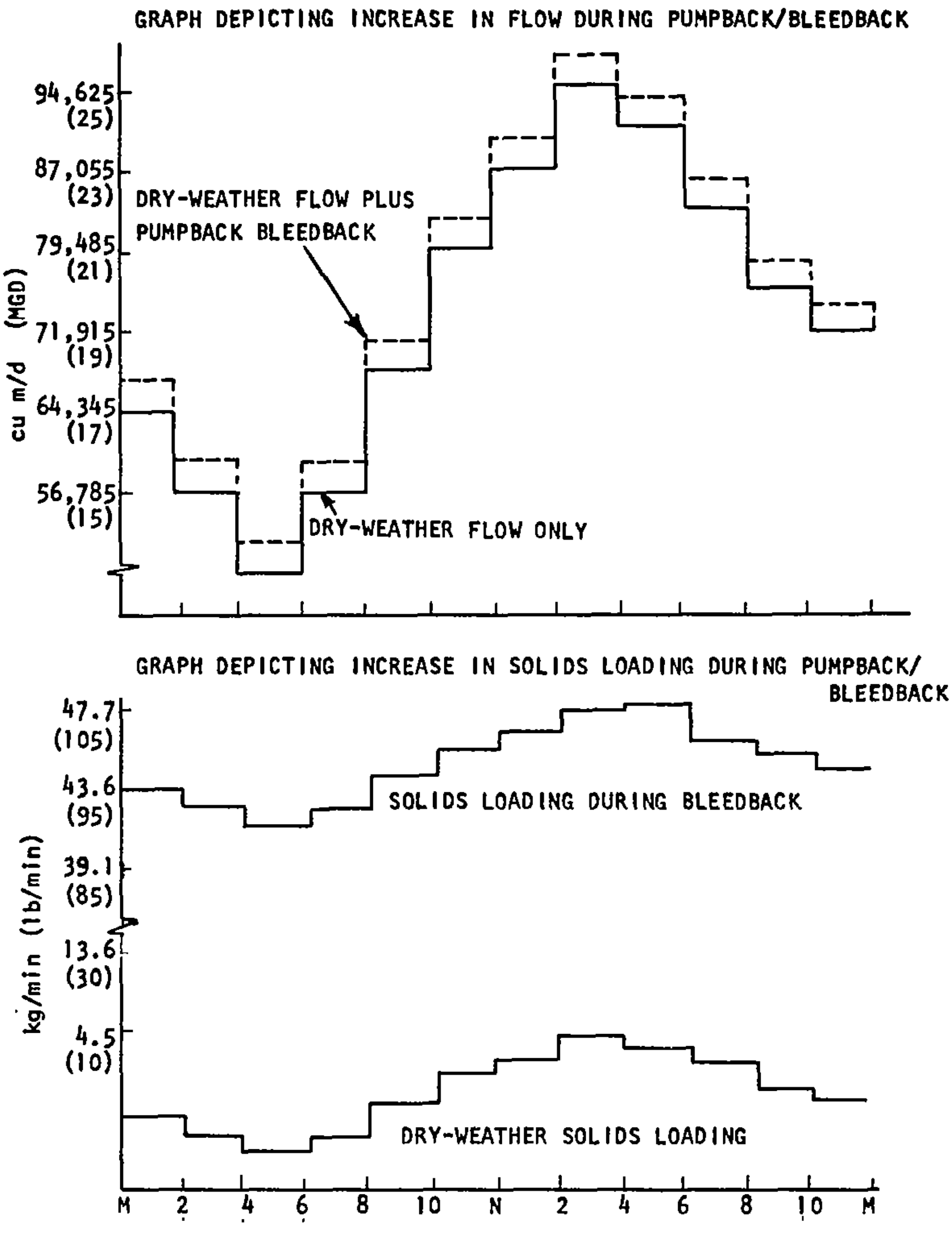


Figure 40. Graphs depicting the increase in hydraulic loading (top) and solids loading (bottom) during pumpback/bleedback to the treatment plant

produced sludge is pumped or bled. It is common practice for most sewers to be designed with a velocity of at least 0.6 cm/s (2 fps) to prevent solids deposition. However, in larger interceptor sewers at low flow, velocities can go below 0.6 cm/s (2 fps). In addition, particles having specific gravities significantly greater than 1.0 and with relatively large diameters require velocities in excess of 0.6 cm/s (2 fps) to prevent settling. The velocity required to keep a particle in suspension is a function of both particle specific gravity and diameter as designated below (23).

$$\text{Required velocity} = \sqrt{\frac{8B}{f} g \ (s-1) \ Dg}$$

where: B = dimensionless empirical constant
f = friction factor (0.025 for a full pipe)
g = acceleration due to gravity
s = specific gravity
Dg = particle diameter to be transported

It should be noted that required velocities to keep a particle in suspension change 1) with a change in diameter at a constant specific gravity and 2) with a change in specific gravity at a constant diameter. In many cases velocities of greater than 0.6 cm/s (2 fps) can be required, and these instances may arise with sludge being drained back to the sewerage system. Actual velocities required to keep materials in suspension have been determined. Table 29 has been developed by the American Society of Civil Engineers and contains the various velocities required to prevent deposition of materials, some of which may be analogous to sludge being pumped or bledback (23,24)

Table 29. VELOCITIES REQUIRED TO PREVENT SOLIDS DEPOSITION

Material	Clear water		Water transporting colloidal silts	
	m/s	f/s	m/s	f/s
Fine sand, non-colloidal	0.457	1.50	0.762	2.50
Sandy loam, non-colloidal	0.533	1.75	0.762	2.50
Silt loam, non-colloidal	0.609	2.00	0.914	3.00
Alluvial silts, non-colloidal	0.609	2.00	1.067	2.50
Ordinary firm loam	0.762	2.50	1.067	3.50
Fine gravel	0.762	2.50	1.524	5.00
Stiff clay, very colloidal	1.14	3.75	1.524	5.00
Alluvial silts, colloidal	1.14	3.75	1.524	5.00

Even if the excess solids passed through the sewerage system and settled in primary sedimentation, and a concentration of 5% were achieved, it is doubtful that this amount of sludge could be removed. At 5% this would amount to a volume of 980 cu m (35,000 ft^3), and if pumped to the digester in a 24 hour period this would displace over 10% of the digester contents. This does not include the additional solids that may be produced in secondary treatment by conversion of the soluble BOD associated with the pump/bleedback into biomass. Furthermore, as pointed out earlier in this report, the volatile percentage of the sludges produced at these combined sewer overflow treatment sites appears to be below 60%. This means that the digestion of this material will probably be very inefficient and have a minimum impact on reducing the putrescibility of the sludge.

Obviously, the hypothetical example discussed here is applicable only to itself. Each application will be unique and must be studied as such. In some applications the combined sewer area may be a smaller portion of the total area and the additional solids loading would not be a significant addition, or perhaps in some applications the primary removal and sludge handling facilities may be sufficient to handle the increased load. It should also be remembered that even if the present sludge handling facilities at the dry-weather treatment plant are of insufficient capacity, it may be more economical from a capital and operating cost perspective to build additional facilities at the dry-weather plant rather than at the combined sewer overflow treatment site.

TOXICITY CONSIDERATIONS

Toxicity to a biological treatment system as a result of pumpback/bleedback of sludges produced from combined sewer overflow treatment must also be considered. The primary concern is the heavy metals and pesticides which are concentrated in the sludge. It is difficult to determine what the specific limiting values of certain heavy metals entering a sewage treatment plant would be. The toxicity can be reduced by other chemicals which may precipitate the metals, form organo-metallic compounds, or by combining with other metals to have an antagonistic effect. Conversely the toxicity may be increased by other cations having a synergistic effect (25,26).

Many articles on the subject of metal toxicity to biological treatment processes have appeared in the literature. Since most data were developed in laboratory tests, some for continuous operations and some for batch, there is a variance in reported values. It has been reported (25) that for sewage treatment bacteria (as found in the activated sludge process) silver and nickel are the most toxic to sewage bacteria, with no bacterial growth occurring above 25 mg/l of either element. Copper and chromium were found to have no effect on sewage bacteria in concentrations lower than 25 mg/l, but were highly toxic at 100 mg/l. Zinc toxicity was considered moderate, with no toxicity effects at less than 100 mg/l concentrations.

Barth, et al (27) conducted extensive laboratory tests simulating an activated sludge plant. Reductions in aerobic treatment efficiency on a continuous dose basis were found at the levels listed below. It was also concluded that the activated sludge process could tolerate, with only about a 5% decrease in efficiency, concentrations of chromium, copper, nickel and zinc up to 10 mg/l, either singly or in combination. An interesting finding of this study was that although the threshold levels (those concentrations at which an effect on treatment can be noticed) may be low, e.g. 1-2 mg/l, there is a plateau effect being realized for a manifold increase in concentration. Figure 41 illustrates this point.

Metal	Concentration in influent sewage
Hexavalent chromium	10 mg/l
Copper	1 mg/l
Nickel	1-2.5 mg/l
Zinc	5-10 mg/l

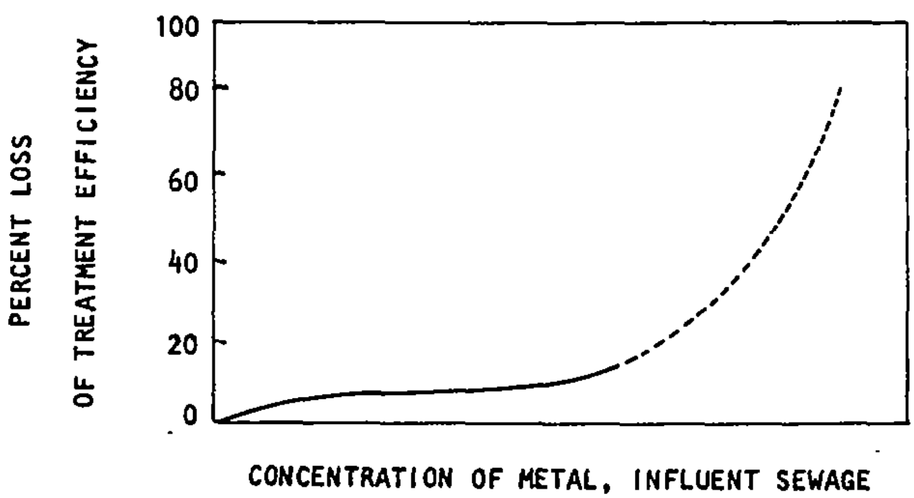


Figure 41. Response of System to Metal Dosage

The effects of sludge doses of four hour duration were also determined in this study by raising influent concentrations for four hours and measuring the decrease in effluent quality. The maximum sludge doses that could be tolerated were found to be:

Metal	Concentration in influent sewage
Hexavalent chromium	>500 mg/l
Copper	75 mg/l
Nickel	>50 -<200 mg/l
Zinc	160 mg/l

TABLE 31. DISTRIBUTION OF METALS THROUGH THE ACTIVATED SLUDGE PROCESS (CONTINUOUS DOSAGE)

	Outlet	Cr (VI) (15 mg/l)	Cu (10 mg/l)	Ni (10 mg/l)	Zn (10 mg/l)
Percent of metal fed	Primary sludge	2.4	9	2.5	14
	Excess activated sludge	27	55	15	63
	Final effluent	56	25	72	11
	Metal unaccounted for	15	15	11	12
	Average efficiency of process in removing metal	44	75	28	80
	Range of observations	18-58	50-80	12-76	74-97

Other reported metal toxicity levels to the activated sludge process from various studies include 10 mg/l for nickel (28) and 16.0 mg/l for nickel ($NiSO_4$), 0.40 mg/l for copper ($CuSO_4$), and 0.23 mg/l for chromium ($CrCl_2$) (29). Although chromium has been the subject of many toxicity studies (30,31,32), a wide range of values have been reported at the maximum allowable limits, e.g. up to 250 mg/l. However, it is agreed that reduced chromium has little effect on treatment and that hexavalent chromium is toxic, but at much higher concentrations than the other common heavy metals.

A notable effect reported in most studies is the inhibition of nitrification by the heavy metals. Values in the range of 1-2 mg/l of metals, even though not toxic, may completely stop nitification. This could have an important effect on any breakpoint chlorination step that would follow final settling or the oxygen demand on the receiving body of water when nitrification begins.

Just as important and perhaps even more critical than the effect of the heavy metals on treatment is the effect on digestion. Limits of 1 mg/l for copper, cyanide, and chromium, and 2.5 mg/l for zinc and nickel have been recommended as maximum concentrations for raw sewage subject to sludge digestion (33). Table 30 illustrates the various reported maximum limits for raw sewages subjected to sludge digestion.

Table 30. TOXIC LIMIT FOR METALS IN RAW SEWAGE SUBJECT TO SLUDGE DIGESTION (34)

Reference No.[a]	1	2	3[b]	4	5	6	7	8	9
Metal, mg/l									
Chromium	5.0	5.0	0.05			1.0		1.5	
Cyanide	2.0	1.0	0	0.1	1-1.6				
Copper	1.0	1.0	0.30	0.2		1.0	0.7		
Iron	5.0								
Zinc		5.0	0.3	0.3					>5.0
Nickel			2.0						

a. See Reference 34 for references.
b. For streams and sewers.

Various sources (32,34,35) have noted that heavy metals in the feed to a digester will concentrate in the digested sludge. It appears that when concentrations approach the 1000 mg/l level of heavy metals, digester failure may be realized. The Barth study (27) mentioned earlier traced the fate of heavy metals through the activated sludge process and the results are summarized in Table 31.

TABLE 31. DISTRIBUTION OF METALS THROUGH THE ACTIVATED SLUDGE PROCESS (CONTINUOUS DOSAGE)

	Outlet	Cr (VI) (15 mg/l)	Cu (10 mg/l)	Ni (10 mg/l)	Zn (10 mg/l)
Percent of metal fed	Primary sludge	2.4	9	2.5	14
	Excess activated sludge	27	55	15	63
	Final effluent	56	25	72	11
	Metal unaccounted for	15	15	11	12
	Average efficiency of process in removing metal	44	75	28	80
	Range of observations	18-58	50-80	12-76	74-97

This same study listed the highest allowable dosages for raw feed to anaerobic digestion as follows:

Metal	Primary sludge	Primary and secondary sludge
Hexavalent chromium	>50 mg/l	>50 mg/l
Copper	10 mg/l	5 mg/l
Nickel	>40 mg/l	>10 mg/l
Zinc	10 mg/l	10 mg/l

One of the most important conclusions relative to the question of the feasibility of bleeding combined sewer overflow treatment sludges containing heavy metals back to the treatment plant is the fact that if a digester fails, it completely fails. Unlike the activated sludge process which can have a reduction in efficiency caused by the presence of metals, the anaerobic digestion process will continue to operate at very close to normal efficiencies until the critical level has been reached at which point digester failure will occur.

Table 32 has been developed showing the concentrations of certain heavy metals in the sludges resulting from treatment at the various combined sewer overflow sites. As seen by the data in Table 32 some of the sludges do contain heavy metals in excess of the toxic concentrations discussed earlier. If these sludges are bled back to the treatment plant resulting in a significant concentration dilution, the toxicity dangers are greatly reduced. However, it must also be realized that the above sludge samples only represent one event from each site and are not truly representative of a complete year of operation. In addition, the synergistic effect of these various metals cannot be fully predicted nor can the effect of the possible shock loading on the biological treatment process be predicted without the use of empirical methods. These types of methods are strongly recommended when the concept of sludge pump/bleedback is being considered.

Therefore, it is indicated that it may be more feasible to thicken and dewater the sludge on site rather than pump/bleedback these residuals to the treatment plant. However, the problem of ultimate disposal remains. If it is found that a sludge can be brought up to a 20% solids concentration, the transportation costs of conveying this sludge to a place of ultimate disposal will be greatly reduced. However, this is based on the assumption that the sludge can be disposed of without any form of digestion. If digestion of some type is required (e.g. anaerobic digestion, heat treatment, wet oxidation) then the logistics of concentrating the solids, followed by transport to a digestion process, followed by further dewatering become questionable. Therefore, on the following pages the combined sewer overflow treatment site studies are analyzed for the feasibility of on-site treatment of the residual sludges resulting from treatment as compared to solids pump/bleedback or other alternatives.

Table 32. HEAVY METAL CONCENTRATIONS IN THE SLUDGES RESULTING FROM COMBINED SEWER OVERFLOW TREATMENT

Site	Type of treatment	Type of sludge	Total solids mg/l	Zinc mg/l	Zinc mg/kg	Lead mg/l	Lead mg/kg	Copper mg/l	Copper mg/kg	Nickel mg/l	Nickel mg/kg	Chromium mg/l	Chromium mg/kg	Mercury mg/l	Mercury mg/kg
Racine, WI	Screening/Dissolved Air Flotation	Backwash and	9769	16.0	1638	10.0	1023	4.7	481	2.1	215	2.1	215	0.022	2.3
Hawley Road, Milw., WI	Screening/Dissolved Air Flotation	Float	42700	36.5	855	7	164	10.2	248	7.4	173	6.4	150	0.09	2.1
San Francisco, California	*Dissolved Air Flotation*	*Float*	2400	17	708	38	1583	8.8	367	<2	<83	40	1667	0.093	3.9
Philadelphia, Pennsylvania	Screening	Backwash	8660	10.3	1189	21.2	2448	1.73	200	2.5	289	0.45	52	0.018	2.1
Kenosha, WI	Contact Stabilization	Return Activated	8527	61	7154	4.5	528	12.4	1454	4.5	528	10.9	1278	0.022	2.6
New Providence, *New Jersey*	Trickling *Filter*	Primary Sedimentation	2010	1.4	694	<1	<498	2	995	2	995	1.5	746	0.202	100
		Secondary Clarification	25500	33	1294	9	353	26	1020	20	784	63	2471		
Humboldt Ave. Milw., WI	Storage Tank w/Mixing	*From Settling* Test	18900	15.1	799	39	2063	3.8	201	3	159	4.6	243	0.051	2.7
Cambridge, Massachusetts	Storage	Settled in Tank	126,900	120	496	160	1261	96	757	16	126	33	260	1.55	0.01

PHYSICAL TREATMENT

Milwaukee, WI - Storage

The Humboldt Avenue storage tank in Milwaukee serves approximately 231 ha (570 acres) out of a total of 7000 ha (17,300 acres) of combined sewer area in the city. The unit is designed to handle a 1.3 cm (0.5 in.) rainfall utilizing 15,140 cu m (4 million gal.) of storage. Thus, scaling up the storage volume for the entire combined sewer area for a unit rainfall analysis (2.54 cm [1.0 in.]), a total storage volume of 912,185 cu m (241 million gal.) would be required (36,37). Since this type of detention tank is equipped with mixers, the raw suspended solids concentration is usually the same as the pump/bleedback concentration. However, when the storage tank has its capacity exceeded, the mixers are not operated and the tank functions similar to a sedimentation basin. When this occurs it becomes possible for the pump/bleedback concentration to be higher than the raw discharge. The average raw flow concentration of suspended solids at Humboldt Avenue is estimated from operating records to be 192 mg/l.

The metropolitan Milwaukee area is served by two sewage treatment plants--the Jones Island Plant and the South Shore Plant. The Jones Island Plant is the major plant and handles almost all of the city's combined sewer areas and therefore, will be the subject of this feasibility analysis. The treatment consists of primary screening (instead of primary sedimentation) followed by the conventional activated sludge process, and chlorination. Primary sludge (screenings) is incinerated. The waste activated sludge is gravity thickened, vacuum filtered, and then processed into fertilizer (Milorganite). Data from 1970-1973 indicated that the plant had an average daily flow of 650,263 cu m/day (171.8 mgd) with average raw flow concentrations of 236 mg/l suspended solids, (153,517 kg/day [338,143 lbs/day]), and 232 mg/l BOD, (151,565 kg/day [333,845 lbs/day]).

Examining the concept of pump/bleedback of the contents of holding tanks serving the entire combined sewer area over various durations of time, the following percentage increases in hydraulic loading and solids loading would result.

	Percentage increases	
Bleedback duration	Hydraulic loading	Solids loading
6 hrs	561	456
12 hrs	281	229
24 hrs	140	114
48 hrs	70	57
72 hrs	47	38
96 hrs	35	28

The Jones Island Plant can handle approximately 757,000 cu m/day (200 mgd), therefore, the shortest duration of time in which the tank contents could be pumped or bledback would be 96 hours. The sludge handling capacity at the plant is 199 metric tons per day (220 tons/day), and the facilities run near design capacity at all times. If the 96 hour pump/bleedback duration was used the increase in solids loading during this period would be 28%. Obviously the only way this additional solids loading could be handled is by constructing additional solids handling facilities for this excess material.

As part of this study a sample of the mixed contents in the storage tank was taken and allowed to settle (see Section IV). The initial sample had a suspended solids concentration of 181 mg/l and the settled sludge compacted to 17,400 mg/l, occupying 0.9% of the original volume, resulting in a SVI of 50 ml/gm. If the solids were allowed to settle in this manner and the supernatant pumped or bledback to the treatment plant, the hydraulic loading on the dry-weather treatment plant would be almost identical to that described earlier for pump/bleedback of the entire contents. However, if the supernatant had a suspended solids concentration of 35 mg/l, as found in the settling tests, the increase in solids loading would be as follows:

Bleedback duration	% increase in solids loading
6 hrs	83
12 hrs	42
24 hrs	21
48 hrs	11
72 hrs	7
96 hrs	5

From this data it would appear that pump/bleedback to the dry-weather treatment plant of the supernatant from settling would be possible from a solids loading consideration over a period of more than two days. However, the limiting factor in this case would be the hydraulic loading.

The settled sludge at a solids concentration of 1.74% would constitute a volume of 8,213 cu m (2.17 million gal.) resulting from a rainfall of 2.54 cm (1.0 in.). Direct hauling of this volume of sludge would appear to be both very expensive (at 2.64¢/liter [10¢/gal.] this would amount to $217,000) and logistically be impractical. Therefore a further solids concentration step would be required.

It was found from the bench scale testing (Section VI) that centrifugation was the optimum dewatering method. It is estimated that a settled sludge of 1.74% can be increased to 30% solids through centrifugation with polymer addition. The centrate quality should have a suspended solids concentration of approximately 110 mg/l and the volume of centrate would be 7,835 cu m (207 million gal.). If this material were to be bledback, the increase in solids and hydraulic loading would not be significant. The solids at a 30% concentration from the centrifuge will amount to a volume of 363 cu m (96,000 gal.) which can be directly hauled to ultimate disposal at a reasonable cost, probably less than $10,000 as opposed to the $217,000 cost of hauling the raw sludge.

A unique consideration for Milwaukee is the fact that their waste activated sludge is converted to a commercial fertilizer known as Milorganite. Thus, even if the sewerage system and solids handling facilities were adequate to handle the solids being bledback, the effect on the ferilizer production process may be the most significant.

Cambridge, MA - Detention

The detention tank used to treat combined sewer overflows in Cambridge, MA known as the Cottage Farm facility, is actually a combination storage/ chlorination and "rough" sedimentation tank. The total holding volume of the facility is approximately 4,920 cu m (1.3 million gal.) with the storage/ chlorination tanks having a volume of 4,550 cu m (1.2 million gal.). The facility was designed to handle an average of 22 overflows per year ranging from 1,514 to 302,800 cu m (0.4 to 80 million gal.) with an average overflow volume of 23,845 cu m (6.3 million gal.) and a total of 15% of the overflow being retained (12). The design criteria used in choosing the 15% total capture is not fully understood. During actual testing of the facility the average overflow was 33,308 cu m (8.8 million gal.).

The detention facility receives overflow from a combined sewer area of 13,500 ha (33,333 acres); however, there are many overflow points from this system in addition to that discharging into the detention facility. There are only an additional 1,270 ha (3,136 acres) of combined sewers present which are not connected in any way to the Cambridge overflow facility. Thus, there are a total of 14,770 ha (36,470 acres) of combined sewered area out of a total of 105,624 ha (259,911 acres) of sewered area in the metropolitan area. However, many of the combined sewers are in the process of being separated.

Using the unit rainfall analysis, 2.54 cm (1.0 in.) of rainfall will result in an overflow volume (assuming 50% of the rainfall results in overflow) of 1.87 million cu m (495.3 million gal.). Extrapolating on the 15% retention volume used in the demonstration system, the resulting holding volume would be 280,000 cu m (74.3 million gal.) and the bypass volume would be 1.59 million cu m (421.0 million gal.). During the actual overflow period when the sludge samples were taken and analyzed as part of this study, the raw flow had a suspended solids concentration of 165 mg/l and the effluent concentration was 93 mg/l. The settled sludge had a concentration of 4.4%. Thus if the same removal efficiencies and sludge concentrations are applied to the unit rainfall analysis, a total of 161,191 kg (355,046 lbs) of solids would be produced and 3,671 cu m (968,000 gal.) of sludge at a 4.4% concentration would result. It must also be noted that this hypothetical example is based on the allowance that 1.59 million cu m (421 million gal.) of overflow be discharged to the receiving body of water after chlorination, and the suspended solids concentrations would be about 100 mg/l in the effluent.

There are two treatment plants, the Deer Island and Nut Island plants, serving the entire 105,624 ha (259,911 acre) metropolitan area (38). However, the Cottage Farm facility drains to an interceptor sewer leading to the Deer Island treatment plant. This plant has an average design capacity of 1,298,255 cu m/day (343 mgd), with a maximum 24 hour capacity of 2,172,590 cu m/ day (574 mgd). Treatment consists of screening and grit removal (located at discrete headworks where the feeding sewers terminate), pre-chlorination, pre-aeration, primary sedimentation, and post chlorination. Sludge treatment consists of gravity thickening, anaerobic digestion and ocean disposal.

The sludge handling capacity is 1,514 cu m/day (0.4 mgd). During 1973 the average daily flow to the Deer Island Treatment Plant was 1,298,255 cu m/day (343 mgd) and the average daily sludge production was 1,200 cu m/day (0.3 mgd) or 84,600 kg (188,000 lbs).

Examining the feasibility of pump/bleedback as opposed to on-site treatment of the sludge, it is obvious that the existing plant could easily handle the additional hydraulic loading of 280,000 cu m (74.3 million gal.) in a period of 24 to 48 hours. The excess sludge handling capacity is approximately 18,160 kg/day (40,000 lb/day). Thus pump/bleedback of the tank contents at the rate of 18,160 kg/day (40,000 lbs/day) would take approximately nine days. Pump/bleedback at the rate of 22,700 kg/day (50,000 lbs/day) and 27,240 kg/day (60,000 lbs/day) would reduce the required time to seven days and six days, respectively. For overflows having lower solids concentrations the pump/bleedback concept would take proportionately less time.

From the above calculations, it appears that the concept of sludge pump/bleedback to the dry-weather treatment plant may be feasible; however, it must be noted again that only 15% of the total overflow is retained and of the 85% of the overflow still discharging to the receiving body of water, the suspended solids concentration would be approximately 100 mg/l. It was also assumed that the solids being pumped or bledback were held in suspension in the sewerage system and did not settle out before reaching the treatment plant.

Although it has just been shown that pump/bleedback from this type of system may be feasible in Cambridge from a hydraulic and solids loading standpoint, the practicality of sludge pump/bleedback has not been examined. The Deer Island treatment plant has a raw sludge volatile solids percentage of 70.4 and a digested sludge volatile percentage of 47.7. The volatile percentage of the sludge analyzed from the Cottage Farm facility was 37.6 while the suspended solids content of the settled sludge on the bottom of the detention tank was 4.4%.

Another significant concern when studying the possibility of sludge pump/bleedback that is especially significant in the case of Cambridge is the heavy metal concentrations. With the exception of mercury, the heavy metal concentrations are very high, and in some cases an order of magnitude higher than the concentrations found at other sites. Below are the heavy metal and analytical results:

	Wet basis, mg/l	Dry basis, mg/kg
Zinc	120	946
Lead	160	1,261
Copper	96	757
Nickel	16	126
Chromium	33	260
Mercury	1.55	0.01

Even if a 1:100 dilution were to occur during pump/bleedback, the synergistic effect of the heavy metals may upset treatment or digestion. Also if a majority of the heavy metals were found to be in the particulate form, then the high concentrations would be very dangerous to digestion.

Centrifugation of the settled sludge was found from the laboratory tests to be the most optimum method of dewatering with an expected solids concentration of 20% at 90% recovery and a sludge volume reduction of 89%. Thus, if the settled sludge produced from the treatment of a 2.54 cm (1.0 in.) rain, which is calculated to be 2,671 cu m (968,000 gal.) at a 4.4% solids concentration, were subjected to centrifugation, this would result in a centrate volume of 3,267 cu m (861,500 gal.) at approximately 2,500 mg/l suspended solids concentration of 20% suspended solids. Assuming that ocean disposal of sludge is permitted there would be two apparent alternative methods of solids handling. These would be 1) sludge pump/bleedback to the sewerage system and treatment plant or 2) direct disposal from the treatment site to the ocean. The only way the second choice would be considered the most attractive alternative would be if it was felt that pump/bleedback to the sewerage system would cause severe solids deposition or if the bledback sludge would receive no benefit by going through digestion and only reduce the effective digestion volume available for the normal treatment plant sludge.

If ocean disposal is not permissible it will be necessary for not only the sludge from the detention facilities but also the sludges from the dry-weather treatment plant to be disposed of on land in some form. Therefore it would be necessary to take the digested sludge now being transferred to sea and put this sludge through a further dewatering step(s) before finally disposing of it on the land. Again there are two alternatives if ocean disposal is not permitted. These are 1) sludge pump/bleedback to the sewerage system and treatment plant with the sludge being thickened, digested, dewatered and disposed of with the normal treatment plant sludge and 2) on site sludge centrifugation followed by disposal with the centrate bledback to the sewerage system. The objectives to the first alternatives are the same as in the previous cases. However, assuming pump/bleedback is feasible, the comparison between the two alternatives is whether it is more economical to re-thicken, digest, and dewater the sludge at the treatment plant or to centrifuge the sludge at the detention tanks and dispose of it. Also, if the sludge were to be sent back to the dry-weather treatment plant there is the possibility that some of the grit would not be removed by the existing grit facilities and therefore additional classification equipment may be required. It is estimated that the operating costs for centrifugation would be 84¢/cu m (0.32¢/gal.) or 2¢/kg (0.91¢/lb). This cost does not include amortization of the capital equipment costs. The operating cost would then have to be compared to the handling costs at the treatment plant and the lesser chosen. This type of comparison assumes, however, that land disposal of the centrifuged sludge (at 37% volatile solids) would be permissible without any digestion or oxidation step such as lime stabilization. It is estimated that the land disposal costs of the dewatered sludge would be approximately the same for both alternatives. Some recent land (or alternative) disposal method costs are listed below (39).

Method	Cost range ¢/kg	¢/lb
Pipeline to land	0.55 - 2.20	0.25 - 1.0
Trench to land	2.20 - 0.50	1.0 - 2.5
Rail to land	3.30 - 11.0	1.5 - 5.0
Drying	3.3 - 5.5	1.5 - 5.0
Compost	0.55 - 1.1	0.25 - 0.5
Incineration	4.4 - 5.5	2.0 - 2.5

Philadelphia, PA - Screening

Studying the feasibility of on site treatment compared to sludge pump/bleedback for the treatment system being tested in Philadelphia requires a great deal of data synthesis since the flow capacity and drainage area of the study site is so small compared to the large combined sewer area in the City of Philadelphia. The 23 μ microscreening unit in operation has an average design capacity of 1000 l/min/sq m (25 gpm/ft^2) and serves an area of 4.5 ha (11.1 acres). The entire sewered area of metropolitan Philadelphia is 92,600 ha (228,600 acres) with the combined sewer area being 64,800 ha (160,000 acres). Using a unit rainfall analysis (1.0 inch [2.54 cm]) with the assumption that half of the rainfall results in overflow, the total overflow volume treated would be 8,221,020 cu m (2,172 million gal.). From actual operating data (40) it is estimated that a backwash sludge volume of 520,000 cu m (137 million gal.) would be produced at a suspended solids concentration of 2,000 mg/l resulting in a dry solids production of 1,045,000 kg (2,300,000 lbs).

The metropolitan Philadelphia area is served by three sewage treatment plants--the Northeast, Southeast and Southwest plants. The Northeast plant, which has secondary treatment, has a design capacity of 662,375 cu m/day (175 mgd) and in 1972 the average daily flow was 681,300 cu m/day (180 mgd). The sludge from the plant is digested and then barged to sea for ultimate disposal. During 1972 the average daily sludge production was 2,157 cu m/day (0.57 mgd) with an average suspended solids concentration of 4.4% (94,962 kg [209,167 lb]). The other two treatment plants consist of only primary treatment with a cumulative design flow rate of 1,029,520 cu m/day (272 mgd), and an actual cumulative flow rate of 991,670 cu m/day (262 mgd) during 1972. The sludge from the Southeast plant is piped to the Southwest plant where it is digested, centrifuged, and then lagooned prior to barging. During 1972 the cumulative sludge production was 3,255 cu m/day (0.86 mgd), with an average suspended solids concentration of 5.4% (175,850 kg [387,310 lbs]). The combined solids handling capacity of the plant is estimated to be about 20% higher than actually used in 1972. However, there presently exists a restriction against increasing the amount of sludge barged to sea, which in effect means that any additional sludge produced by the City of Philadelphia will have to be disposed of by an alternate means.

Studying the feasibility of sludge pump/bleedback to the Philadelphia treatment plants for digestion purposes, with alternate disposal being other than to the ocean, the increases in daily solids production are as follows for various pump/bleedback periods:

Pump/Bleedback duration days	% increase in solids
1	385
3	127
5	76
7	54
9	42

It would appear that the shortest pump/bleedback duration possible, with a slight overload on the dry-weather treatment plant, would be at least nine days. This length of time would allow the possibility of odoriferous conditions to occur and the solids would surely settle out in the backwash holding tank (unless some means of aeration were implemented). The settling of the solids would have no significant effect (other than a higher pump/bleedback concentration when the bottom sludge was being removed) provided that provisions for the removal of the sludge were made.

Once the sludge is digested at the treatment plant, the sludge in excess of the present daily production must be split off and disposed of in some other manner than ocean disposal. Regardless of the alternate type of disposal chosen some type of dewatering step will most likely be utilized to minimize disposal transportation costs. It is calculated for Philadelphia's annual rainfall of about 102 cm (40 in.) that the weight of sludge produced from combined sewer overflow treatment by microscreening would be approximately 38% of the total annual sludge produced by the existing treatment plants. Even if only half the annual overflow in the CSO area were treated, the weight of sludge would still be 19% of Philadelphia's annual production.

Since these additional dewatering facilities will be required either at the combined sewer overflow sites themselves or on the grounds of the conventional treatment plants, the major factors in deciding where the solids handling facilities should be located would be the effect of the extra solids on the dry-weather plant (primary sedimentation sludge removal facilities), the necessity of digestion, and the cost of many separate sludge handling facilities compared to one or two facilities located at the dry-weather treatment plants.

The obvious effect on the dry-weather treatment plant is the increased solids loading resulting in an increased sludge volume which must be handled, thus reducing the effective processing time for the conventional plant dry-weather sludges. In the case of the combined sewer overflow sludge at the Philadelphia test site, as is the case for most sites, the volatile percentage of the suspended solids was very low (25%). From this fact it can be seen that conventional aerobic or anaerobic digestion will have little effect on reducing the volatile content of this sludge. Thus, pumping or bleeding the sludge back to the treatment plant will only displace volume in the digesters and reduce the effective digestion period of the conventional plant solids.

One method of reducing the volume of wet weather sludge that would utilize dry-weather sludge digestion facilities would be to degrit the wet weather sludge prior to digestion. By degritting, much of the inert material (that not amenable to digestion) could be separated prior to digestion, thus greatly reducing the ultimate volume of wet weather sludge to be handled. Obviously, the optimum location for degritting this sludge would be at the wet weather treatment site itself, prior to pump/bleedback into the sewerage system. However, in actual application it would have to be determined if the highly inert wet weather sludge were discharged into the sewerage system and diluted, would the inert material in fact be removed by the conventional grit removal facilities at the dry-weather plant.

Regarding the matter of cost, it is obvious in the case of solids handling that the larger the capacity of the facility, the lower the unit cost will be. However, in this particular case, if it is assured that digestion is not required for the combined sewer overflow produced sludges, it would still be necessary to increase the sizes of the digestion equipment at the conventional treatment plant unless degritting facilities were constructed, since the combined sewer overflow sludge would be mixed with the conventional plant solids. If on-site treatment of the solids were utilized, only thickening and centrifugation or vacuum filtration would be required. The solids could then be transported to ultimate disposal.

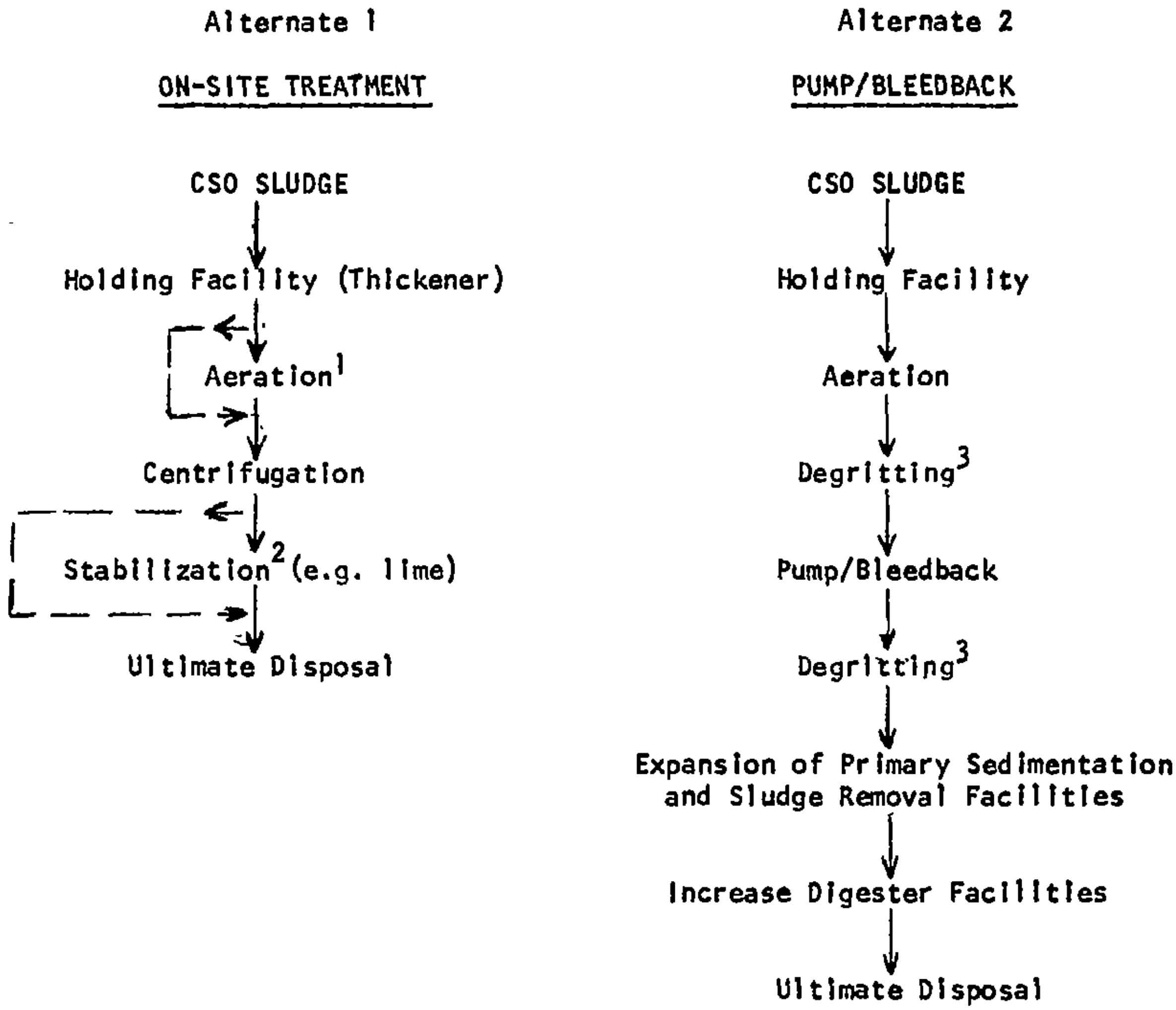
The thickening process could serve a dual function by acting as a holding tank (or vice versa), thus reducing the flow rate to the dewatering process and resulting in a smaller capacity unit. Also, an economic study could be performed to determine if a centrally located dewatering facility, with the sludges from the combined sewer overflow sites being pumped to this site, could be constructed and operated at a lower cost than discrete on-site units.

Thus for the case of Philadelphia, a large city with a high percentage of its drainage area being served by combined sewers, a pump/bleedback of solids produced from combined sewer overflow treatment does not appear to be the obvious solution for handling the wet weather sludges. The optimum solution can only be determined by comparing the specific costs of on-site treatment facilities versus the facilities needed for pump/bleedback. Figure 42 illustrates the requirements of either alternative.

PHYSICAL CHEMICAL TREATMENT

Racine, WI - Screening/Dissolved-Air Flotation

The combined sewer overflow facilities in Racine, WI from which sludge samples were obtained for this study utilize the screening/dissolved-air flotation process. The facilities consist of two adjacent but separate treatment plants having capacities of 166,540 cu m/day (44 mgd) and 52,990 cu m/day (14 mgd) for a combined capacity of 219,530 cu m/day (58 mgd). The units serve a combined sewer area of 190 ha (470 acres) and are designed to handle a 1.27 cm/hr (0.5 in./hr) rainfall. The floated scum from the flotation units plus the screen backwash is retained in holding tanks until after the level in the interceptor sewer leading to the treatment plant drops to such a level that the tanks can be bled into the interceptor.



1. Depending on the design rate of the centrifugation facility.
2. May or may not be needed, depending on regulations.
3. Degritting facilities only required in one of the two locations shown.

Figure 42. Comparison of the requirements of on-site treatment of wet weather sludges versus pump/bleedback to the dry-weather treatment plant

The existing dry-weather treatment plant serving the City of Racine consists of full primary treatment rated at 87,055 cu m/day (23 mgd) and secondary treatment (activated sludge) rated at 45,420 cu m/day (12 mgd). During the calendar year of 1973 the average daily flow was 91,597 cu m/day (24.2 mgd). Waste activated sludge is returned to the primary sedimentation tanks where it is settled out with the primary sludge and this sludge is then anaerobically digested and vacuum filtered. The sludge is then disposed of at a landfill site. The total volume of the two stage digestion system is 7,570 cu m (2 mg). In 1973 an average of 341 cu m/day (90,090 gal./day) of sludge at a solids concentration of 7.48% resulting in 25,450 kg/day (56,080 lb/day) of dry solids was produced.

Scaling up the screening/dissolved air flotation units to treat the entire combined sewer overflow area (284 ha [701 acres]) for a 2.54 cm (1.0 in.) rainfall, the volume of overflow is estimated to be 35,957 cu m (9.5 million gal.).

From operating experience at the combined sewer overflow treatment sites in 1972 and 1973 it is estimated that 1,798 cu m (0.47 million gal.) of sludge at a suspended solids concentration of 8,400 mg/l would be produced. It should be noted that the low solids concentration is caused by mixing the floated scum and screen backwash. The floated scum alone can be expected to have a solids concentration of 2.4%; however, the dilute screen backwash (<3000 mg/l) causes the resultant sludge in the holding tanks to be of very low solids concentration.

Examining the feasibility of sludge pump/bleedback in Racine, it is obvious that the 1,798 cu m (0.47 million gal.) of sludge at a concentration of 8,400 mg/l could be handled by the dry-weather plant over a one to two day period with no significant increase in flow. However, at the present time the average daily flow to the treatment plant is greater than design, so even though the flow would be a small percentage increase, it would be flow above the capacity of the plant. From a solids loading standpoint, the bleedback of 14,982 kg (33,000 lbs) of solids would represent the following percentage increase:

Pump/Bleedback Period, days	% Increase in solids
1	59
2	29
3	20
4	15
5	12
6	10

From the above data it would appear that sludge pump/bleedback would be feasible over a period of greater than two days. However, at the present time the digestion and solids handling capacity of the Racine treatment plant is rated at 22,700 kg/day (50,000 lbs/day). Therefore, the plant is already operating above capacity and theoretically could not handle any more solids, thus necessitating on-site treatment of the solids. However, the Racine treatment plant is scheduled to undergo expansion in the near future and the possibility of utilizing sludge pump/bleedback of the combined sewer overflow sludge would be greatly improved if the new solids handling facilities had the capacity to handle these extra solids.

Making a rough economic comparison of the costs (capital and operating) of building additional solids handling facilities at the existing dry-weather plant versus building a centralized wet-weather sludge facility, the data generated by Burd (21) in 1968 can be used. Although these costs are outdated, they are valid for use in making a relative comparison assuming equal escalation of all costs. The additional dry-weather sludge handling facilities (including thickening, digestion, dewatering and landfilling) are estimated to have an annual capital and operating cost of 1.1-5.5¢/kg dry solids ($10-50/ton) with an average cost of 2.8¢/kg ($25/ton). This cost does not reflect any additions for degriting facilities which may be necessary. However, if degriting facilities were used, the amount of solids sent on to further digestion and dewatering would be reduced, thus lowering those costs.

A centralized wet weather solids handling facility consisting of thickening, centrifugation and landfilling is estimated to have an annual capital and operating cost of 0.8¢-5.0¢/kg dry solids ($7.5-$45/ton) with an average cost of 2.0¢/kg ($18/ton). Although the cost for on-site treatment of the solids is shown to be 0.8¢/kg ($7.5/ton) cheaper than construction and operation at the dry-weather plant, it must be realized that no provisions were made for stabilizing the highly inert (only 40% volatile) wet weather sludges. If stabilization is required, then the associated costs for this process must be considered.

If on-site treatment were utilized for solids handling, it is calculated that by subjecting the screen backwash to thickening, the net volume of sludge to be handled can be reduced to 378 cu m (0.1 million gal.) with the supernatant from thickening being returned to the sewage treatment plant. This 378 cu m (0.1 million gal.) at a suspended solids concentration of 4.1% would be dewatered by centrifugation to an expected cake solids of 11-33% at 93-96% corrected recovery. At the expected cake solids the ultimate sludge to be disposed of would be reduced to a volume of 50-150 cu m (0.013-0.04 million gal.). Over the course of a year, based on an estimated 75 cm (30 in.) of rainfall, the total volume of sludge to be hauled to land disposal would be 1500-4500 cu m (0.4-1.2 million gal.) Of course the volume of sludge to be handled would be proportionately less for any amounts generated by less than 75 cm (30 in.) of rainfall if it were decided to treat less.

Milwaukee, WI - Dissolved-Air Flotation

The dissolved-air flotation combined sewer overflow treatment site in Milwaukee, (the Hawley Road site) is a 18,925 cu m/day (5 mgd) pilot unit and served as the forerunner of the system constructed in Racine, WI. The system does in fact contain a screening unit, as in Racine, but since this was a pilot facility, the screen backwash flows directly to a sanitary sewer near the treatment site. Therefore, the screen backwash was not mixed with the floated scum from flotation and was not part of the laboratory tests, hence this case is being studied as only dissolved air flotation. This assumption is certainly valid since the screenings, in a full scale application, would probably have a very high grit content and could be elutriated and disposed of directly to a landfill site. However, as seen by the Philadelphia discussion earlier, if a final study were being performed to decide which alternative would be optimum, serious consideration would have to be given to the volume and weight of solids in the backwash.

The sewage treatment facilities in Milwaukee were described earlier in this section, and of course apply to this analysis also. In summary, the average daily flow at the treatment plant is 651,020 cu m/day (172 mgd) with a daily solids loading of 153,517 kg/day (338,143 lb/day) and the waste activated sludge from secondary treatment is ultimately marketed as fertilizer.

Using the unit rainfall analysis as the basis for comparison, it is calculated that a 2.54 cm (1.0 in.) rainfall over the 7,000 ha (17,300 acres) of combined sewer area would result in a treated overflow volume of 885,690 cu m (234 million gal.). From this it is estimated that the flotation process would produce about 3,200 cu m (0.85 million gal.) of sludge at a solids concentration of 3.65% for a total dry weight of 116,919 kg (257,630 lbs). The calculated increase in solids loading at the Jones Island treatment plant for various pump/bleedback durations would be as follows:

Pump/bleedback period days	% increase in solids
1	76
2	38
3	25
4	19
5	15
6	13
7	11

Based on the premises that the sludge could be transported to the treatment plant in the sewerage system without settling, and that the solids could be removed at the treatment plant, then the slight excess capacity for solids handling at the Jones Island treatment plant would make pump/bleedback feasible over approximately a four day period. Again it is noted that the screen backwash has not been considered.

However, the logistic feasibility of pumping or bleeding back this sludge becomes questionable when it is considered that the sludge has already achieved a solids concentration of 3.65% in the flotation process. It appears to be somewhat a wasted effort to dilute these solids in the sewerage system and then use space in the gravity thickener at the Jones Island treatment plant to re-thicken these solids to their original state. It should also be noted that the Jones Island treatment plant utilizes grit chambers followed by screening, rather than primary sedimentation, and the solids pumped or bled back that were removed in screening would be subjected to incineration. The fuel value of the floated scum at Hawley Road was determined to be 1,654 cal/gm (2996 BTU's/lb), which is not especially good for incineration purposes. However, if upon further study it was found that the pumped or bledback sludge going to and being removed in the final clarifiers contained significant concentrations of nitrogen and phosphorus, then the sludge may prove advantageous in the production of Milorganite. However, again it is found that the volatile solids percentage of the sludge is on the low side, 32%, and this casts doubt upon the quality of this material as a fertilizer. It also indicated that the sludge may have a high grit content and therefore expansion of the existing grit removal facilities would probably be required if the sludge were to go to the dry-weather plant.

The type of on-site treatment chosen as best in the laboratory testing was direct centrifugation of the floated scum. The bench scale tests indicated that a 20% cake solids could be achieved, with a centrate suspended solids concentration of 200 mg/l through centrifugation. The cake solids would have to be hauled to a land site for ultimate disposal.

San Francisco, CA - Dissolved-Air Flotation

The combined sewer overflow prototype unit in San Francisco is similar to those found in Racine and Milwaukee, WI with the exception that screening does not precede flotation. The test unit serves an area of 68 ha (168 acres) while the entire drainage area of the city (all of which is served by combined sewers) is 12,150 ha (30,000 acres). Applying the unit rainfall analysis an estimated overflow volume of 1,540,500 cu m (407 million gal.) would be produced. Estimating the volume and solids concentration of the sludge produced for this test site was very difficult. The grab sample taken of the floated scum during this project had a suspended solids concentration of 2.25%, however, operating data from the San Francisco sites indicates that a float concentration of 1000-2000 mg/l can be expected. Also, the combined sewer overflow at the San Francisco site has a very low average raw suspended solids concentration and thus the net suspended solids removals are only in the range of 20 mg/l.

For a volume of 1,540,500 cu m (407 million gal.) this 20 mg/l would amount to 30,821 kg (67,800 lbs) of solids. At a concentration of 1,000 mg/l this would be a volume of 30,772 cu m (8 million gal.) and at a 2.25% concentration the volume would be 1,363 cu m (0.36 million gal.).

The metropolitan San Francisco area is served by three separate primary sewage treatment plants with a total design capacity of 1,135,500 cu m/day (300 mgd). An estimated 57,000 kg (125,000 lbs) of solids are gravity thickened, anaerobically digested, and vacuum filtered (to a solids concentration of >25%) before being disposed of in a landfill or used as a soil conditioner. The volume of sludge produced from combined sewer overflow sites (1,363 or 30,772 cu m [0.36 to 8 million gal.]) could be pumped or bled-back to the treatment plants without any hydraulic problems. Although the present solids handling facilities at San Francisco are running at capacity, pump/bleedback of the 30,831 kg (67,880 lbs) of solids over a two to three day period would only increase the loading on the solids handling facilities by a matter of about 15%. However, an especially important aspect of pump/bleedback which must be considered in the case of San Francisco is the solids removal efficiencies being achieved at the treatment plant. In San Francisco, the weighted average removal of suspended solids is approximately 50%. Assuming these removal efficiencies held true during periods of sludge pump/bleedback, then half of the solids which were removed at the combined sewer overflow facilities would escape in the effluent from the dry-weather treatment plant.

Ironically, although the hydraulic and solids loadings appear to be feasible in the case of the San Francisco test site, the low suspended solids removals achieved at the dry-weather treatment plant would make solids pump/bleedback impossible. Thus for San Francisco it would appear that on-site treatment is necessary in order to make the effort put into treating the combined sewer overflow worthwhile. The on-site treatment process found to be best for San Francisco consisted of thickening followed by vacuum filtration. Since the solids produced from the treatment of the combined overflow must be stored on-site until the flow rate in the sewer decreases if pump/bleedback is going to be utilized, the thickener requirements are not really an extra cost. However, if the concentration of the flotation scum can be consistently in the vicinity of 2% rather than 1,000-2,000 mg/l, the size of the holding tank could be greatly reduced. It is estimated that utilizing vacuum filtration on the floated scum in excess of 2%, a cake of 18% solids could be achieved. This would result in net volume of <171 cu m (45,000 gal.) of sludge to be hauled away. If the scum from flotation is very dilute and must be thickened to 0.5-1.5% prior to vacuum filtration, it is estimated that the cake solids produced would be 10-20%. This would result in a volume for disposal of 150-300 cu m (40,000-80,000 gal.).

BIOLOGICAL TREATMENT

Kenosha, WI - Contact Stabilization

The combined sewer overflow treatment system tested in Kenosha is significantly different than those discussed earlier in this report because it is located on the same grounds as the existing conventional dry-weather treatment plant. In fact, since the system utilizes biological treatment it depends on the dry-weather plant as a source of active biomass. Waste activated sludge from the dry-weather treatment plant is continuously fed through the combined sewer overflow treatment system stabilization tank, where it has a hydraulic retention time of approximately five days before going on to flotation thickening. When the combined sewer overflow treatment system is put into operation, the contents of the stabilization tank are pumped to a contact tank (mixed liquor aeration) instead of to thickening. A complete description of the system operation can be found in Appendix A.

The conventional dry-weather treatment plant at Kenosha is a 87,055 cu m/day (23 mgd) activated sludge process. Waste activated sludge, approximately 314 cu m/day (0.083 mgd) at a solids concentration of 1.47% (approximately 4,540 kg/day [10,000 lb/day]) is flotation thickened to about a 5% solids concentration before going on to anaerobic digestion. The digested solids are then further dewatered by means of a filter press.

The total daily loading on the digesters, primary and waste activated sludge combined, is 190 cu m/day (0.05 mgd) resulting in a dry solids weight of 11,035 kg (24,307 lbs). When the additional loading of solids due to combined sewer overflow treatment is considered, the stabilization tank must be examined as the source of these solids. This is due to the fact that the contact stabilization process does not utilize any primary sedimentation, therefore all solids, both particulate matter and solubles converted into biomass, settle out in the final clarifier as part of the sludge blanket. This sludge is then returned to the stabilization tank as part of the waste sludge. The excess solids produced as a result of the treatment of the combined sewer overflow will either cause an increase in the blanket depth of the final clarifier necessitating an increase in the flow rate to the stabilization tank, or cause the sludge blanket, and thus the sludge pumped to the stabilization tank, to have a higher solids concentration.

The entire sewered area of Kenosha is 3,735 ha (9,222 acres) of which 539 ha (1,331 acres) are combined. Assuming the excess flow can be conveyed to the treatment plant and that adequate combined sewer overflow treatment facilities can be constructed, it is estimated that a 2.54 cm (1.0 in.) rainfall would result in an excess flow volume of 68,130 cu m (18 mg). From actual operating data in Kenosha (36) it is estimated that the treatment of this volume would produce 23,850 kg (53,530 lbs) of solids which constitutes a volume of 2,384 cu m (630,000 gal.) at a concentration of 1%. Also, the sample of the sludge analyzed as part of this study had a relatively high volatile solids percent (63.0), thus necessitating digestion before going to land disposal.

The alternatives available in the case of Kenosha are not really whether pump/bleedback is feasible or not, but rather whether the existing form of sludge handling should be expanded and utilized or whether an alternate method should be employed for sludge handling. This is the case for centrally located wet weather systems as opposed to satellite treatment systems which face the pump/bleedback question. Therefore, there appearsto be three actual alternatives; 1) enlarge as necessary the existing flotation thickening, digestion, and dewatering facilities, 2) build completely separate thickening and dewatering facilities (assuming digestion is not required) or 3) use some of the existing sludge handling facilities and also construct some additional new facilities.

Assuming that this excess sludge must be subjected to digestion, and based on the fact that the existing digesters are already at capacity, it appears obvious that additional digesters would be required. However, 1972 operating data from the Kenosha treatment plant indicated that the flotation thickeners were only operated at an average daily loading of 20 kg/day/sq m (4.1 lb/day/ft^2) (13). If it is estimated that loadings of up to 100 kg/day/sq m (20 lbs/day/ft^2) are possible (13), then the existing thickeners could easily handle the additional solids within two days. Thus, only additional digesters would be needed since the filter press facilities are also capable of handling the excess solids.

If digestion is not required, it would appear from the bench scale testing done that thickening followed by vacuum filtration or centrifugation would be the optimum combination to utilize. With either procedure a cake solids concentration of at least 15% should be attainable. This would reduce the volume of sludge to be ultimately disposed of from 2,384 cu m (630,000 gal.) down to approximately 159 cu m (42,000 gal.). Again, as in the case above, the existing flotation equipment could be utilized with new dewatering facilities provided. It should be noted here that if the thickened solids could go straight to dewatering prior to disposal, the feasibility of utilizing the excess filter press capacity for dewatering the undigested sludge should be tested and the results compared to those obtained in the tests for dewatering undigested sludge by means of vacuum filtration and centrifugation. Another aspect of the Kenosha system which could possibly render digestion unnecessary is the fact that the stabilization tank also serves as an aerobic digester. Therefore, if the excess solids produced as a result of combined sewer overflow treatment were withdrawn from the stabilization tank over a period of more than two days it can be expected that a significant destruction in the volatile solids concentration may occur.

The alternative of building all new facilities does not seem practical in any situation. The fact that excess capacity is available in the existing flotation thickeners, coupled with the amenability of biological sludges to flotation thickening, makes the use of these facilities imperative. The only decision to be made, if in fact complete combined sewer overflow treatment were carried out in Kenosha, would be whether to expand the existing digestion facilities or to build separate mechanical dewatering facilities (vacuum filtration or centrifugation) or to use the existing filter press facilities if possible. From an economic standpoint, it appears possible in Kenosha if satisfactory digestion were accomplished in the stabilization tank, that the existing flotation thickeners and filter press would be sufficient to handle the extra wet weather solids and no new facilities would be required.

New Providence, NJ - Trickling Filter

Of all the combined sewer overflow sites studies, the trickling filter system tested in New Providence was the most unique since the concept of solids bleedback is utilized as part of the normal mode of operation for this installation. As discussed in detail in Appendix A the two trickling filters which normally run in series during normal flow periods are converted to parallel operation during periods of high flow. The solids settling in the final clarifier are recycled to the primary sedimentation tank where they settle out with the primary solids. This combined sludge is then drained to a sewer which flows to a larger sewage treatment plant downstream. Apparently the downstream treatment plant has the capacity to remove and handle the solids produced at the New Providence facility.

This facility does not really treat combined sewer overflow, but actually handles the high flows caused by infiltration into the sanitary sewers. Therefore, since the present plant can handle the high flows experienced during rainfall periods, it is not forecasted that any appreciable increase in flow can be expected in future years. Thus, it is not applicable in this case to compare on-site treatment versus bleedback since the existing form of bleedback appears to be functioning as planned and will continue to be used in the future. If this type of arrangement were to be utilized at another site not being able to discharge the excess solids to another treatment facility, feasibility studies for the optimum means of on-site thickening, digestion and dewatering would be required. However, these feasibility studies would be conducted in the same manner as those normally associated with dry-weather treatment plants.

SUMMARY

After reviewing the eight combined sewer overflow sites which were part of this study for the feasibility of utilizing pump/bleedback of treatment produced solids as compared to on-site treatment, it is apparent that no specific conclusions can be drawn for all cases, but instead each case must be studied on an individual basis. In general, it does not appear possible to pump or bleedback the solids produced from the treatment of an entire combined sewered city to the dry-weather treatment plant. This is due primarily to the possibility of solids settling in the existing sewerage system and to the overloading of the dry-weather treatment plant sludge handling facilities. Also, in cases of combined sewer overflow storage, it may not be possible from a hydraulic consideration to pump or bleedback the entire stored contents to the dry-weather treatment plant. These facts become especially critical when the dry-weather plants under study are near design capacity for either hydraulic or solids handling facilities. If only a portion of a city's drainage area is served by combined sewers, then controlled pump/bleedback of the combined sewer overflow treatment produced sludges may be possible.

In most cases where on-site treatment of the sludges produced from combined sewer overflow treatment is utilized, the hydraulic and solids loadings resulting from the pump/bleedback of centrates, supernatants, and filtrates from sludge thickening and dewatering processes such as flotation, centrifugation, or vacuum filtration will be possible. However, in many cases pump/bleedback of the concentrated sludges has been shown to be a problem. Table 33 summarizes the increase in solids loading on dry-weather treatment plants resulting from the treatment of 1.2 cm (0.5 in.) of runoff. The amounts of sludge were determined from the data generated at the existing combined sewer overflow treatment demonstration systems. The figure only represents those sites where satellite treatment was tested.

A very important consideration which can easily be overlooked when comparing the concept of pump/bleedback versus on-site treatment is the efficiency of removal at the existing dry-weather treatment plant. It is not possible to accurately estimate, without actual field testing, what effect pump/bleedback will have on the percentage removals at the dry-weather treatment plants. However, even if it is assumed that the percentage removals obtained during normal operating periods hold true during the pump/bleedback periods when the flow rates increase, the percentage of contaminants ending up in the receiving body can still be significant. For example, if a combined sewer overflow treatment site achieves 70% removal of suspended solids and these solids are pumped or bled back to a treatment plant achieving 80% removal of suspended solids, the net removal of the combined sewer overflow treatment site is:

$$(0.70) \times (0.80) = 0.56 \text{ or } 56\%$$

This can greatly increase the true cost of combined sewer overflow treatment when studied on a cost per mass removal basis.

Another example analogous to the above would be the effect of pump/bleedback which caused effluent quality to decrease only a slight amount. Using the City of Milwaukee as an example, if pump/bleedback raised the average raw flow rate

Table 33. SUMMARY OF SOLIDS INCREASES AT DRY-WEATHER TREATMENT PLANTS FOR PUMP/BLEEDBACK OF CSO PRODUCED SLUDGES FROM 1.25 cm (0.5 in.) OF RUNOFF

Pump/ Bleedback duration, days	Milwaukee, WI storage (total contents) % increase	Milwaukee, WI storage (only settled sludge) % increase	Cambridge, MA Storage % increase	Philadelphia, PA microscreening % increase	Racine, WI S/DAF % increase	Milwaukee, WI DAF only % increase
0.5	229	42	294	770	118	152
1.0	114	21	138	385	59	76
2.0	57	11	60	193	29	38
3.0	38	7	34	127	20	25
4.0	28	5	21	97	15	19
5.0	23		14	76	12	15
6.0	19		8	63	10	13
7.0	16		5	54	9	11
8.0	14			48	7	10
9.0	12			42	6	8

by 10% for a period of 3 days and the average effluent suspended solids concentration increased by only 2 mg/l, the following additional loading of solids would enter the receiving body of water:

651,020 cu m/day [172 mgd]) (1.1) (3 days) (2 mg/l) (constants) =

(4300 kg [9500 lbs])

Thus, over a three day period the increase of 2 mg/l in effluent concentration would have an actual increase loading to the receiving body of water of 4300 kg (9500 lbs) which is significant.

Other important considerations that must be made when studying the concept of pump/bleedback are 1) the possibility of toxicity of heavy metals or other elements to the associated dry-weather treatment plant biological processes 2) the need and practicality of subjecting the combined sewer overflow solids, which appear to have a low volatile percentage to digestion, and 3) the possibility of overloading the grit removal and primary sludge removal facilities, thus necessitating additional degritting facilities either at the head end of the treatment plant or at the overflow treatment site itself.

Although this section has analyzed the feasibility of pump/bleedback of CSO sludges versus on-site treatment, its purpose has only been to demonstrate the voluminous ramifications (specifically for the requirement of additional facilities) and problems resulting from either alternative. Specific answers to determine the best method for each municipality requires a thorough economic study of all the alternatives available. No general recommendations can be made.

SECTION VIII

DISCUSSION

The characterization data presented in Section V of this report has unquestionably demonstrated the magnitude of the problem posed by the sludge residuals generated as a result of combined sewer overflow treatment. The data has shown that the volumes and characteristics of these residuals vary widely. The pump/bleedback of the entire amount of residuals to dry-weather treatment facilities does not seem to be a promising method of disposing these residuals as discussed in Section VII. However, partial pump/bleedback in specific situations may be possible. Therefore, on-site handling and treatment of these residuals is necessary for a satisfactory solution to this important problem. The treatability test results (Section VI) have demonstrated that several dewatering techniques may be applicable for the on-site thickening of the various residuals.

Dilute sludges such as the retained contents of storage/settling treatment or screen backwashes require a concentration step before any thickening treatment may be utilized. Therefore, for CSO treatment sites employing a combination of storage and screening/dissolved-air flotation treatment, perhaps a more logical and economical step would be to keep the dilute tank residuals and screen backwash separated from the concentrated residuals such as settled solids or flotation scum. After concentration of the dilute residuals by sedimentation with or without chemicals, the clarified supernatant may be best discharged to the sanitary sewer or the receiving body of water while the clarified sludge can then be combined with flotation scum and further dewatered by smaller size dewatering equipment. It is estimated that such a modification of keeping the dilute wastes separated from already concentrated wastes, for example, in Racine, WI, may provide as much as 30% to 40% reduction in the total cost of sludge treatment estimated earlier. Furthermore, in any actual system, the presence of grit or inorganic matter is expected to be significant and separate means of removing grit may be required in any CSO residual handling treatment facility.

From the treatment feasibility test results, generally it was shown that centrifugation or vacuum filtration were both applicable for dewatering after sludge thickening by gravity or flotation thickening. However, when overall results were compared based on performance, cost and area requirements, centrifugation was found to be the optimum dewatering method for all physical and physical/chemical residuals except alum treated San Francisco sludge and the biological sludges. Centrifugation alone or in combination with gravity or flotation thickening offers several other advantages that must be kept in mind in the final selection of an optimum dewatering step at any specific CSO treatment site:

1. Centrifugation is quick to start up and shut down in the field for intermittent uses in line with unpredictable timing of CSO occurrences.

2. The process is less sensitive to flow and concentration changes and can be geared for various applications in a short time. This can provide optimum utilization of the equipment even during dry-weather periods.

3. It can be automated to reduce labor costs. Savings in chemical costs are also possible because chemical conditioning is not required in all cases as for vacuum filtration. Furthermore, the power costs for equipment operation are also lower compared to vacuum filtration.

4. Centrifugation requires less space and because of its compactness can be easily mounted on portable equipment which may then be utilized at a number of CSO outfall treatment locations in a metropolitan area.

Because of the above advantages and only limited number of sites that utilize biological treatment for combined sewer overflows, it is recommended that additional development work be continued on centrifugation treatment of CSO sludges with and without gravity or flotation thickening. The centrifuge equipment, both scroll and basket type units, should be evaluated at several CSO treatment locations. This may best be accomplished by using a portable treatment unit and utilizing it for a 6 to 8 week period at each site. The costs developed during this study should be re-evaluated and demonstrated based upon the operational data developed in Phase II. Furthermore, the organics making up the volatile solids in the CSO sludges may be far more putrescible than digested sludges and most probably will require stabilization prior to ultimate land disposal. On-site digestion facilities such as anaerobic digestion are not considered to be appropriate for CSO sludges because of the quick on-off characteristics of CSO treatment. However, stabilization by other methods such as lime stabilization may be appropriate and necessary prior to the ultimate disposal of the CSO sludges. These ultimate disposal considerations should be investigated and evaluated in detail in Phase II.

However, it should be noted that the ultimate choice of such sludge treatment concepts is expected to be site specific. The selection of the final treatment method must be based on treatability tests at the specific sites under consideration since no one method of handling and/or treatment would be applicable to every situation.

SECTION IX

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APPENDIX A
SITE DESCRIPTIONS

1. HUMBOLDT AVE., MILWAUKEE, WI

Dry-Weather Treatment

Two dry-weather treatment plants serve the 60,704 ha. (149,888 ac.) area within the limits of the Milwaukee Metropolitan Sewerage District. The older of these plants (Jones Island) serves 16,155 ha (39,888 ac) and provides secondary treatment for flows up to 757,000 cu m/day (200 mgd). The South Shore plant has primary treatment and is capable of treating a 1,211,200 cu m/day (320 mgd) flow. New secondary treatment facilities capable of treating 454,200 cu m/day (120 mgd) were completed at the South Shore plant in 1974. Following is a brief description of each of these plants (41).

Jones Island Treatment Plant - All sewage entering the Jones Island plant is passed through mechanically cleaned bar screens to remove the coarse contents such as garbage, rags, and wood from the raw wastewater flow. The screened sewage then enters degritting chambers where the velocity is reduced to approximately one foot per second. There are eight grit chambers 2.4x2.4x27.4m (8x8x90 ft) long. The flow is regulated by individually controlled gates placed at inlet and outlet points.

The sewage flows from the grit chambers to the fine screen house. The sewage passes through a series of rotary drums having 0.24 cm(3/32 in.) slots, continuous across the face of the drum. Solids too large to pass through these slots are brushed off of the drums and on to a belt conveyor. The screenings are then conveyed to a collection hopper and pneumatically ejected to the incinerator building where they are incinerated along with the coarse screenings and grit. Approximately 54,400 wet kg (60 wet tons) of these materials are incinerated each day.

Screened sewage flows from the fine screen house into mixing channels where controlled columns of activated sludge are applied. Mixing with air continues in feed channels until this mixture reaches the aeration tanks where biological treatment takes place. The aeration tanks have ridge and furrow type aeration and provides two way reverse flow. The aeration tanks are designed to aerate the mixed liquor for an average period of six hours.

Activated sludge is removed by quiescent settling. Both Dorr and Tow-Bro type clarifiers are used for final sedimentation. The settled sludge is withdrawn from the bottom of the clarifiers and the effluent is discharged to Lake Michigan.

A portion of the sludge is returned to the incoming sewage for seeding. The remaining increment is conditioned with ferric chloride and dewatered by vacuum filtration on any of 24 vacuum filters at the plant. The filter cake has a moisture content of about 83%.

After vacuum filtration, the sludge is conveyed to an indirect-direct counter-flow rotary drum type dryer. These dryers reduce the moisture content of the sludge to about 5%. The dried solids are then crushed and screened and sold as fertilizer.

South Shore Treatment Plant - The sewage enters the South Shore Plant through 2.54 cm (1 in.) mechanically cleaned bar screens. Solids removed from the screens are hand-fed to hammermill type grinders and returned to sewage flow.

After screening the sewage flows into the grit basins. Flow through the grit basins proceeds at about 0.3048 m/sec. (1.0 fps). The grit is removed from the chambers and washed. Cleaned grit is stored and hauled away by truck to a sanitary landfill or an incineration site. The organics washed from the grit are returned to the sewage flow.

The sewage then flows to the distribution chambers from which it is routed to the settling basins. The sixteen tanks provide a detention period of 3 hours at 227,100 cu m/day (60 mgd). When the secondary treatment plant is added and the flow is upgraded to 454,200 cu m/day (120 mgd) the settling period will be 1.5 hours. Straight line mechanical sludge collectors convey the sludge to cross collectors which, in turn deposit the sludge in a vault. The effluent overflows from the settling tanks and is dispersed to Lake Michigan.

Sludge from the vault or directly from the hoppers, is pumped by four positive displacement pumps to the digestion tanks. The total volume of the digestion tanks is 44,800 cu m (1,600,000 cu ft). The sludge temperature is maintained at 29.4 to 32.2 ^{o}C (85^{o} to 90^{o}F) by heaters which can burn either natural gas or digester gas.

Sludge flows from the digesters by gravity and is pumped to four lagoons. The lagoons are approximately 118.9 m square (390 ft square) with a minimum depth of 4.6 m (15 ft) and have a total capacity between 224,000 and 280,000 cu m (8 and 10 million cu ft). They are estimated to be adequate for 20 years without removal of sludge.

Wet-Weather Treatment

Humboldt Avenue, Milwaukee, WI (42) - The detention tank at Humboldt Avenue receives the combined sewer overflow from a 205 ha (570 ac). drainage area containing approximately 33.8 km (21 miles) of combined sewers and representing 1/27 of the combined sewer area in Milwaukee. The area is residential and commercial in character and contains primarily combined sewers with a few separate storm sewers intercepted within the project area. Two relief sewers which traverse the area and the Milwaukee Sewerage Commission's intercepting sewer remove from the system a substantial amount of the total combined sewage generated within the study area before it reaches the detention tank.

Flow to the tank is by gravity, through a 198 cm (78 in.) sewer. Upon entering the tank inlet channel, the flow passes through a mechanically cleaned 3.8 cm (1.5 in.) bar screen. All solid material retained on the screen are deposited in a 2.25 cu m (3 cu yd) portable refuse container.

Seven rotary mixers are located within the tank. Only one of these seven mixers is equipped with a two-speed motor drive and is operated at low speed prior to and during periods of tank overflow to distribute chlorine for disinfection. Facilities for pre and post-chlorination of the CSO are provided. The pre-chlorination diffuser header is located just ahead of the tank inlet and runs across the inlet channel. The post-chlorination diffuser distributes chlorine across the entire 22.9 m (75 ft) width of the tank at a point about 3.7 m (12 ft) above the tank floor and 53.9 m (177 ft) from the overflow weir.

Combined sewer overflows in excess of the tank capacity (3.9 million gal.) [14761.5 cu m] during periods of overflow are discharged from the tank to the Milwaukee River. After the overflow has subsided, all mixers are activated to resuspend settled solids. The resuspended tank contents are then pumped to the Jones Island Treatment Plant.

2. CAMBRIDGE, MA

Dry-Weather Treatment

There are two dry-weather treatment plants serving a 165 ha (407.5 ac.) drainage area. These plants are the Deere Island Treatment Plant, 1,298,255 cu m/day (343 mgd) and the Nut Island Treatment Plant, 1,286,900 cu m/day (340 mgd). The following is a description of these plants (38).

Deere Island Treatment Plant - This treatment plant has been in operation since June, 1968 and serves 22 communities with a population of approximately 1,400,000. Seven pumping stations are located throughout the contributing area.

The facilities include three remote headworks which are connected to the main pumping facility by two deep rock tunnels. The tunnel from the Ward Street and Columbus Part Headworks is approximately 11.3 km (7 miles) long. An additional facility, the Winthrop Terminal Facility, located on the main plant site, provides sewerage service for local areas and is connected directly to the Deere Island Plant through a separate direct pump discharge. Each headworks provides screening and grit removal for the sewage flowing through the headworks.

Treatment at the Deere Island Plant starts with pre-chlorination and pre-aeration. The pre-searation tankes place in two channels, each 121.9x6x4.3 m (400 x 20 x 14 ft), with a detention time of 10 minutes. The flow then passes to the sedimentation tanks which have a detention time of 60 minutes. The effluent is then post-chlorinated and discharged through two marine outfalls located in approximately 15.2 m (50 ft) of water in Boston Harbor.

The treatment of raw sludge is accomplished by separate sludge thickening prior to high rate digestion. Three primary digesters, equipped with fixed cover, internal heaters, and draft tube mixers, have a sludge recirculation system via a common manifold. A fourth digester, equipped with a fixed cover and separate liquid recirculation system, serves as a storage tank, receiving all primary digested solids and overflow to allow controlled discharge of digested material to the sea during periods of outgoing tides.

Nut Island Treatment Plant - The Nut Island Plant has been treating waste from 21 cities and towns with a population of 775,000 since 1962.

The treatment processes include pre-chlorination, coarse screening and grit removal for incineration, pre-aeration of the effluent for 20 minutes, primary sedimentation, and post-chlorination of plant effluent prior to discharge through a 152.4 cm (60 in.) outfall pipe some 1,828.8 m (6,000 ft) off shore in deep tidal water.

The treatment of raw sludge is accomplished by modified high rate digestion. Two primary tanks, which have fixed covers, and one primary tank with a floating cover are equipped to provide continuous recirculation of the tank contents. A secondary digestion tank of the same capacity is equipped with a floating cover and supernatant drawoff. The digested sludge is disposed of through a 30.5 cm (12 in.) submarine pipe line which extends a distance of 6.8 km (4.2 miles) from the treatment plant into deep tidal water on the south side of President Road.

Gas produced by the digestion process is the principal source of fuel for all plant power and heating purposes. One or more of the six waste gas burners, provided for burning excess gas, are in continuous use.

Wet-Weather Treatment

Cottage Farm, Cambridge, MA (43) - The Cottage Farm Combined Sewer Detention and Chlorination Station is located on the north bank of the Charles River just upstream of the Boston University (B.U.) Bridge in Cambridge, MA. The Cottage Farm Station diverts, stores and treats excess CSO which cannot be carried to Deere Island Sewage Treatment Plant from the communities in the Charles River sewer system. It is one element of the Metropolitan District Commission's comprehensive sewage system expansion program to reduce pollution in the Charles River basin.

The outfall from the facility is located so as to provide effective discharge and mixing of the effluent with the river water. Flows up to 2.1 times the 1986 dry weather flow, or 552,610 cu m/day (146 mgd) can be carried to the Ward Street Headworks, and from there to the Deere Island Sewage Treatment Plant. Flows in excess of 552,610 cu m/day (146 mgd) are diverted to the Cottage Farm Detention and Chlorination Station. The design capacity, 882,283 cu m/day (223 mgd), of the Cottage Farm Facility was established by the capacity and need for diversion of the Charles River Sewer System at the B.U. Bridge. Any overflows from these systems are discharged through relief outlets into the river basin.

During a rainstorm, when the relief sewers contributing flows to the Cottage Farm Station reach their individual downstream capacity, they become surcharged. The flow enters the inlet channel to the plant and activates the plant when the flow depth reaches 35.6 cm (14 in.). As the flow enters the plant, it is directed to three channels, each designed for 454,200 cu m/day (120 mgd). In the channel, the flow passes through a coarse bar screen followed by a fine bar screen. The coarse bar screen has openings of 8.9 cm (3.5 in.) and the fine bar screen has an opening of 1.3 cm (0.5 in.). Both of these screens are mechanically cleaned.

From the screen chambers, the flow enters the wet wells from where it is pumped into one of the discharge channels. Chlorine is added at the discharge side of the pumps. From the discharge channel, the flow is divided into six diversion channels which distribute the flow into six detention tanks. Flows in excess of the detention tank's capacity discharge into the Charles River Basin through a 243.8 cm (96 in.) outfall.

After an activation, the detention tanks are dewatered by gravity through a pipe in the bottom of each tank and drained back to the North Charles Relief Sewer. The residual waste is ultimately disposed of at the Deere Island Treatment Plant. The screen channel is cleaned by recirculating the chlorinated flow retained in the first detention tank to the inlet structure and then back through the channels into the wet well from where it is pumped to the North Charles Relief Sewer. The detention tanks, pump discharge channel, wet well, and screen room are then manually washed by a maintenance crew.

3. RACINE, WI

Dry-Weather Treatment (44)

The treatment of wastewater at Racine, WI is accomplished by a full primary treatment, a 45,420 cu m/day (12 mgd) secondary treatment plant, chlorination, sludge digestion and vacuum filtration. The average flow to the plant for 1970, 1971, and 1972 was 79,257.9 cu m/day (20.94 mgd).

The wastewater flows through a mechanically cleaned bar screen to four comminutors, each rated 45,420 cu m/day (12 mgd). The wastewater then flows to the degritting chambers which consist of three grit channels. Two of these are 2.9 m (9.5 ft) wide and 12.2 m (40 ft) long and the third is 5.9 m (19.5 ft) wide and 12.2 m (40 ft) long. All channels have a flow depth of 0.9 m (3 ft) and are provided with mechanical scrapers. The grit is removed from the grit basins by the scrapers. A screw type cross conveyor and screw type grit washer remove and further cleanse the grit for satisfactory disposal as fill materials. Four primary clarifiers, each 10.5 (34.5 ft) wide and 41.8 m (137.3 ft) long can hold a total of 4,920.5 cu m (1,300,000 gal.). Mechanical scrapers push the sludge to hoppers from where it is sent to digesters. Clarified effluent flows over weirs to the secondary plant. The sludge from the primary treatment goes to a 3,785 cu m (1,000,000 gal.) primary digester. A gas recirculation system is provided for mixing of the sludge, and a heat exhcnager is provided for heating the sludge. The temperature is maintained at 35°C (95°F). During this process methane gas is produced and utilized as a fuel supply for the engines and boilers. After primary digestion, the sludge is pumped to the secondary digesters. The total volume of the secondary digesters is 3,785 cu m (1,000,000 gal.). The digested sludge is then pumped to the vacuum filtration system.

Secondary treatment consists of an activated sludge type treatment system utilizing the Kraus process. Four aeration tanks having a total volume of 8,516 cu m (2,250,000 gal.) handle an average of 3,797 cu m/day (12 mgd) of settled wastewater. The tanks can be operated in several alternate modes. Settled wastewater can be introduced into the tanks, together with return activated sludge. The contents are then mixed with air provided through diffuser tubes. This air also serves as a supply of oxygen for the microorganisms. The resulting mixed liquor is transferred from the aeration tanks to two final settling tanks each having a volume of 1,892.5 cu m (500,000 gal.) and a detention time of 2 hours. The effluent is conveyed to a chlorine contact tank prior to discharge into Lake Michigan.

The residual sludge from the various operations is dewatered by vacuum filtration. Two 3 m (10 ft) by 3 m (10 ft) vacuum filters are utilized. Each filter has its own conditioning tank where chemicals are added to aid coagulation and improve filterability. Chemicals utilized are lime and ferric chloride. The filter cake is disposed of, by truck, to a land fill site.

Wet-Weather Treatment (11)

The entire combined sewer system for the City of Racine covers 284 ha. (700 ac.) of the central city. Two satellite treatment plant units are provided at the (CSO) outfalls to treat a maximum flow of 219,500 cu m/day (58 mgd from a contributing area of 190 ha. (469 ac.), or 67 percent of the entire combined sewer area.

The treatment units consist of two basic operations: screening followed by dissolved-air flotation. The CSO enters the site wet well and passes through a mechanically cleaned bar screen to a spiral screw pump. The pump discharges into a channel leading to the drum screen. The screen employed to remove suspended matter in the flow has 297 micron openings (50 mesh). When headloss through the screens become excessive, backwash water is pumped from the screen chamber and sprayed on the outer surface of the screens to flush solids from the inner surface. These solids along with the backwash are collected in a hopper and flow by gravity to a screw conveyor which delivers them to the sludge tank where they are held until the overflow event is over.

The CSO then flows to the flotation tanks where it is blended with air saturated pressurized flow. The floated sludge is periodically skimmed from the top of the tanks and deposited in the screw conveyor which delivers it to the sludge tank.

This system does not employ effluent recycle for air mixing and pressurization. Instead, approximately 20 percent of the raw flow is pressurized for this purpose. Ferric chlorine and polymer are added to the raw CSO to facilitate the coagulation of particulate matter before flotation. Ferric chloride is added in the wet well ahead of the spiral screw pump. Polymer is added in the drum screen effluent channel. Chlorine is also added in the drum screen effluent channel for disinfection purposes.

The sludge holding tanks are drained back to the city sewer system when the water level in the sewer has decreased to the point where the tank contents can be drained without causing an overflow at a point farther downstream in the interceptor sewer.

4. HAWLEY ROAD, MILWAUKEE, WI

Dry-Weather Treatment

The dry-weather treatment plant for Milwaukee, WI has been previously described in conjunction with the Humboldt Avenue detention and chlorination facility.

Wet-Weather Treatment (20)

The Hawley Road screening/dissolved-air flotation system is a 18,900 cu m/day (5 mgd) pilot demonstration treatment facility. The combined sewer area served is 200 ha (495 ac.) and is a completely developed residential area in one of the older sections of thecity. The treatment site is located at one of 110 combined sewer overflow points in the Milwaukee area. The entire combined sewer area in the City of Milwaukee is 70 sq km (27 sq mi).

The demonstration unit consists of two basic operations: screening followed by dissolved-air flotation. The CSO passes through a bar screen and then enters the drum screen. The water passes through the screen media and into a screened water chamber directly below the drum. The drum rotates and carries the removed solids to the spray cleaning system where they are flushed into a hopper inside the screen and washed to a drain pipe that discharges to the city sewer system.

The screened CSO then flows to the head end of the flotation tank where it is mixed with the air saturated pressurized flow coming from the pressurization tank. A portion of the flotation tank effluent or the raw CSO can be used as the source of pressurized flow. The floated scum is scrapped off the flotation tanks and flows by gravity to the city sewer system.

Provisions are also made in the system for the addition of ferric chloride and polymer to the flow before it enters the flotation tank similar to the Racine CSO treatment system described earlier.

5. SAN FRANCISCO, CA

Dry-Weather Treatment (45)

The San Francisco Bay metropolitan district has a total drainage area of 11,340 ha (28,000 ac) of which 9,720 ha (24,000 ac) drains to public sewer systems while the remainder drains to private sewer systems. Sanitary flows from both public and private sewers are treated at one of the three waste treatment plants in the Bay area. The domestic and industrial flows are estimated to be 138 million cu m (36.5 billion gal.) per year while the storm-water runoff is estimated to be 33 million cu m (8.8 billion gal.) per year. Of this total flow of 171 million cu m (45.3 billion gal.) per year, only 149 million cu m (39.3 billion gal.) can be handled through the dry-weather treatment facilities. The remainder of 22 million cu m (6 billion gal.) per year is discharged to the San Francisco Bay as combined sewer overflow. A brief description of the three dry-weather treatment plants serving San Francisco area follows:

North Point Plant - The plant serves a tributary area of 3037 ha (7500 ac.) of combined residential. commercial and industrial land uses. The treatment consists of pre and post-chlorination, pre-aeration and primary sedimentation. The treatment capacity of the plant is 246,025 cu m/day (65 mgd). Any flows in excess of the plant capacity are bypassed via upstream diversion structures to the San Francisco Bay without any treatment.

Primary settling takes place in six combination pre-aeration - sedimentation tanks. Total detention time including pre-aeration at the design flow capacity of 246,025 cu m/day (65 mgd) is two hours. Under normal conditions all six tanks are in operation. About once a year each tank is taken out of service for maintenance and repair.

The North Point Plant does not include facilities for treatment of sludge. Sludge is pumped to the Southeast Plant at an average flow of 3217.3 cu m/day (850,000 gpd) and a solids concentration of about 1 percent.

Richmond-Sunset Plant - The plant serves a tributary area of 4236.3 ha (10,460 ac), most of which is residential. The plant provides primary treatment for a peak wet-weather flow of 264,950 cu m/day (70 mgd). The treatment capacity of the plant is 264,950 cu m/day (70 mgd). Any flows in excess of the plant capacity are bypassed at two separate points. The treatment consists of primary sedimentation and effluent chlorination prior to discharge to the Pacific Ocean. The residual solids are first stabilized in aerobic digestion tanks and then conditioned by elutriation and coagulation addition prior to dewatering by vacuum filtration. The stabilized-filtered sludge is then used as a soil conditioner. At the present time, the average raw sludge flow to the digesters is 378.5 cu m/day (100,000 gpd) at a solids concentration of 2.0-2.5 percent. Present cake production is approximately 1088.4 m tons (1200 tons) of dry solids per year at an average solids concentration of 25%.

Southeast Plant - This plant serves nearly 4048 ha. (10,000 ac.) of heavy industrialized areas of San Francisco and approximately 810 ha. (2000 ac) of San Mateo counties. The treatment consists of primary sedimentation and effluent chlorination. The residual solids from both the North Point as well as the Southeast plants are processed at this facility through gravity thickeners, digestors and vacuum filters after elutriation and chemical conditioning. Approximately 19,000 m tons (21,000 tons) of sludge cake is produced per year from this plant at an average solids concentration of 28%.

Wet-Weather Treatment (46)

The wet-weather treatment system, called the "Baker Street Plant", is a dissolved-air flotation system and is used for the treatment of CSO in San Francisco, CA. The treatment facility receives the drainage from 68 ha. (168 ac.) and has a hydraulic capacity of 9,084 cu m/day (24 mgd). The facility is comprised of two "modules" of 4,542 cu m/day (12 mgd) capacity and each is capable of operation independent of the other. Each module has the following key components: flotation tank equipped with sludge and scum removal systems; recycle system piped to permit intake of recycle flow from either the flotation tank at a point just under the effluent launder or from the raw influent stream; chemical feed systems for handling alum, caustic, polyelectrolyte, and sodium hypochlorite solutions; solids handling system providing for the air lifting of solids for subsequent gravity flow to a solids sump and the ultimate transfer of solids to the city sewer system.

From storm generated flows, the treatment system can receive up to 9,084 cu m/day (24 mgd); anything in excess of this flow is bypassed to the Bay. The influent flows through a bar screen and a magnetic flow meter before it is split and fed into the two flotation tanks. The effluent from these tanks is discharged into San Francisco Bay.

The system is designed such that the water needed for air saturation can be split from the influent stream or taken as recycle from the flotation tank. This water is pumped by a recycle pump into a pressurization tank. At the recycle pump, air is introduced into the stream by an air compressor.

In the pressurization tank, air-water interface is provided to obtain high rates of air solution. The pressure in the tank is maintained at the desired level by a downstream pressure reduction valve. Nominal detention time in the tank is generally about one minute. The pressurized flow is then blended with the raw flow in a mixing zone at the influent end of each flotation tank. Independent chemical feed systems, consisting of tankage, pumpage and alternative chemical introduction points, are provided. Feed pH is automatically adjusted to desired levels using caustic. Other chemicals that are utilized are alum and polyelectrolyte to aid in solids flocculation and separation.

There are two sources of sludge in this system: the solids that are floated and the solids that settle to the bottom of the flotation tanks. The floated solids are skimmed off the flotation tanks during operation and flow by gravity to a solids sump. Any settled solids at the bottom of the tank are washed to a corner of the tank and pumped to the solids sump. These accumulated solids are then pumped to a city sewage pumping station.

6. KENOSHA, WI

Dry-Weather Treatment (47)

The dry-weather treatment facilities consist of primary sedimentation with a maximum design capacity of 113,500 cu m/day (30 mgd) followed by a 87,055 cu m/day (23 mgd) conventional activated sludge system and chlorination. Raw sewage enters the plant by gravity from a 183 cm (82 in.) diameter interceptor sewer. Flows in excess of the plant capacity are diverted by a hydraulic control gate.

The raw sewage entering the plant is pumped through two grit removal facilities which operate in parallel. The discharge from the grit chamber flows by gravity to 6 primary settling basins which have a total surface area of 2,303 sq m (24,760 sq ft) and a volume of 7,213 cu m (257,600 cu ft). The maximum hydraulic capacity of the facility is rated at 113,500 cu m/day (30 mgd), resulting in surface overflow rates of 49.7 cu m/day/sq m (1,212 gpd/sq ft) and a detention time of 1.54 hours. Effluent from primary sedimentation is conveyed to the mixed liquor aeration tanks where it is mixed with return activated sludge (RAS). There are four mixed liquor tanks having a total volume of 13,328 cu m (476,000 cu ft) and an aeration time of 3.72 hours at a maximum design capacity of 87,055 cu m/day (23 mgd). The mixed liquor from the aeration tanks flows to three 25.9 m (85 ft) diameter final clarifiers, having a total surface area of 1,581 sq m (17,020 sq ft). The surface overflow rate at maximum flow is 55.1 cu m/day/sq m (1,350 gpd/sq ft) and the detention time (not including RAS) is 1.32 hours. The waste activated sludge (WAS) from the final clarifier is thickened by means of two dissolved-air flotation units having a total capacity of 8,080 kg (20,000 lb) of solids per day.

The effluent after final clarification is chlorinated in a contact tank having a volume of 605.6 cu m (160,000 gal.). At a flow of 113,550 cu m/day (30 mgd) the detention time in this tank is 7.7 minutes plus an additional 7.3 minutes in the discharge conduit to Lake Michigan.

Wet-Weather Treatment (12)

The process for treating combined sewer overflows at the Kenosha demonstration site is contact stabilization. The main difference between the demonstration project and normal contact stabilization plant is the periodic usage of the system. Due to this, provisions for borrowing waste activated sludge from the dry-weather plant were made. This provision was never utilized because there was always sufficient volume of sludge in the stabilization tank, prior to system deployment, to provide a sufficient reaeration time during operation.

The original grit basins had a maximum hydraulic capacity of 34,056 cu m/day (9 mgd) and would not be able to handle a higher loading. In order to provide more grit removal capacity, an unused mixing and flocculation basin was converted into a grit basin. The new grit basin is conveniently located between the pump room and the site for the contact stabilization tanks. The modified tank is designed to handle a flow of 75,700 cu m/day (20 mgd) at a velocity of 0.06 m per second (0.2 fps). The floor of the tank is sloped so that all extremities drain to the middle 6m (20 ft) of the west wall. At this location a telescoping valve and a screen well are installed to drain the tank after a run. The deposited grit on the floor of the tank is flushed to the west wall where it is suction pumped to a truck and hauled to a landfill site.

The contact and stabilization tanks are located on a structure which is divided by concrete walls into four compartments. Two contact tanks are designed to handle a maximum flow of 75,700 cu m/day (20 mgd) and a stabilized sludge flow of 11,355 cu m/day (3 mgd) for a 15 minute contact period. This requires a volume of approximately 946 cu m (250,000 gal.). The contact tanks have a volume of 620.7 and 304.5 cu m (164,000 and 80,465 gal.), with a combined volume of 925.3 cu m (244,456 gal.).

Aeration is supplied to the contact tank by means of a fixed air disperser system located along the bottom of the northern wall of the contact tank. The dispersers are supplied by the existing blower system and are capable of delivering up to 106.4 cu m/min (3,800 cfm) of air.

The stabilization tank is also divided into two tanks so that various stabilization times may be studied. Both tanks are identical, having a volume of 1,386 cu m (366,329 gal.) each. One tank may be filled without filling the other. This allows for a short stabilization time if desired. The two tanks are connected by permanent openings in the concrete wall divider 2.19 m (7.17 ft) above the floor of the tank. After this height is reached, both tanks must be filled simultaneously.

Aeration for the stabilization tanks is provided by 8 mechanical surface aerators, four in each tank. The aerators are 50 horsepower each and have a total design transfer rate of 454 kg (1,000 lb) per hour.

Two 37,850 cu m/day (10 mgd) pumps are provided to transfer the stabilized sludge to the contact tanks. This combined capacity allows up to 75,700 cu m/day (20 mgd) of stabilization sludge to be transferred, which is equal to 100 percent of the combined sewer flow. A 1,892.5 cu m/day (0.5 mgd) pump is also needed during dry-weather to transfer unused stabilized sludge to the existing thickeners. All three pumps are located on a concrete platform between the contact and stabilization tanks.

The clarifier is designed for use during both dry-weather flow and overflow conditions. During dry-weather, the mixed liquor from the existing plant is fed to the new clarifier for sedimentation. The settled sludge from the clarifier is pumped back into the existing plants sludge return system. The clarifier doubled the existing plant's clarification area.

The entire biosorption process is completely automated and is directed from a main control board. The main control board receives and sends information from and to all operations of the process. The information regulates all flow rates which in turn determine contact times, mixed liquor concentrations, stabilization times, air supply rates, and settling times. This is done by setting all variable flows as a percentage of the raw sewage flow.

During dry-weather the only activity performed by the wet-weather facility is to store waste activated sludge in the stabilization tank for a set period of time before going on to the existing thickener. The rate of wasted sludge flow from the existing treatment plant to the stabilization tank is manually set at the main control board. By allowing the tank to fill to the desired volume and then settling the flow out of the tank equal to 100 percent of the flow into the tank, a constant stabilization detention time is achieved.

7. NEW PROVIDENCE, NJ

Dry and Wet-Weather Treatment (14)

The dual-use of treatment plants, using wet-weather facilities to treat dry-weather flows, is demonstrated well in New Providence. Unlike the other sites, the New Providence area has a totally separated sewer system. High infiltration/inflow conditions during periods of wet-weather may increase flows to rates as high as 10 times the dry-weather flow. To treat these flow variations while maintaining high levels of treatment, a unique trickling filter operation has been installed.

The plant is designed to handle a dry-weather flow of 1892 cu m/day (0.5 mgd) and wet-weather flows of up to a maximum of 22,710 cu m/day (6 mgd). The treatment facilities include primary clarification, trickling filtration, secondary clarification, and post chlorination. Residual sludges up to 5,678 cu m/day (1.5 mgd) are pumped to the city of Summit, NJ solids handling facilities under a "Pumping Rights" agreement.

Two comminutors are provided at the inlet facilities for shredding the coarser solids in the raw sewage. The raw sewage is pumped by low lift pumps (three at 18,925 cu m/day (5 mgd) each) to the primary settling reservoir, a 1,608.6 cu m (425,000 gal.) tank which provides the first phase of treatment at the facility. The clarifier has a two fold function: it removes organics, inorganics, scum, grease and oil from the flow and the large volume of the tank allows equalization of flow to the treatment plant. The sludge from this tank is pumped daily to the City of Summit during a period of about three hours.

One of the two filters is a plastic media filter 11 m (36 ft) in diameter and 4.4 m (14.3 ft) deep. The primary tank effluent plus the recirculated flows are distributed on the filter by a pair of distributor arms which rotate by virtue of the liquid head created in the center column to which the rotating arms are attached.

During dry-weather operation, the effluent from the plastic media filter is pumped to the high rate rock trickling filter. The rock filter is 19.8 m (65 ft) in diameter, 1.8 m (6 ft) deep and is constructed of concrete. From here the effluent flows to the final clarifier.

The final clarifier is 21m (70 ft) in diameter and has a sidewall depth of 2.4m (8 ft). The bottom scraper arms operate at about 2 revolutions per hour. During periods of dry-weather, recirculation pumps with a capacity of 3,028 cu m/day (0.8 mgd) provide the minimum hydraulic loadings for the trickling filters. The sludge at the bottom of the final clarifier flows, by gravity, to the inlet of the plant.

The unique feature of this plant is its ability to operate under a wide range of hydraulic loadings. During dry-weather the plant operates in series with the plastic filter being the lead filter. During periods of wet-weather, when the flow increases above 10,598 cu m/day (2.8 mgd), automatic transfer to parallel operation takes place and is maintained until flow drops to the series range. A portion of the total filter flow is then conveyed to the plastic media filter and the remainder to the rock trickling filter. The effluents from the two filters are combined and conveyed to the final clarifier. When in parallel operation, the second stage and recirculation pumps are automatically turned off.

The flow to each filter can be varied, either on a preset ratio basis or a preset constant flow basis. These operations can be controlled as follows: An adjustable preset constant flow to the plastic filter can be maintained automatically by the control circuit. Under this mode of operation, a constant flow is applied to the plastic media trickling filter with any excess flow discharged onto the rock media trickling filter. Similarly, an adjustable preset constant flow can be maintained to the rock media trickling filter with any excess flow applied to the plastic media trickling filter. In addition, a constant ratio of flow can be maintained between the plastic media trickling filter and the rock media trickling filter. This ratio can be set between 0.2 and 4.0, i.e., if the indicator is set at 1.0, it would indicate that both filters--the plastic and the rock--would be receiving the same flow. If the total filter flow exceeds 17,033 cu m/day (4.5 mgd), the raw sewage pumps which pump to Summit at a constant rate of 5,678 cu m/day (1.5 mgd) are automatically turned off. When the wet-weather flow decreases to 11,355 cu m/day (3 mgd), the Summit pumps are automatically turned back on. At a flow rate of 7,750 cu m/day (2 mgd), the secondary treatment system will switch automatically from parallel to series operation, resulting in the turning on of the second stage and recirculation pumps.

Under the foregoing conditions, an extreme amount of flexibility is provided in the operation of the plant for the treatment of both dry-weather and wet-weather flows.

APPENDIX B

ANALYTICAL PROCEDURES

The following analyses were performed according to Standard Methods for the Examination of Water and Wastewater, 13th Edition, 1971 (SM) (6) and Methods for Chemical Analysis of Water and Wastes, 1971, EPA Water Quality Office (WQO), Cincinnati, Ohio (7).

pH	WQO, p. 230
Total Solids	WQO, p. 280
Total Volatile Solids	WQO, p. 282
Suspended Solids	WQO, p. 278
Volatile Suspended Solids	WQO, p. 282
BOD	SM, p. 489
TOC	WQO, p. 221
Total Phosphate	WQO, p. 239
Kjeldahl Nitrogen	WQO, p. 149
Nitrate	SM, p. 458
Nitrite	WQO, p. 195
Metals Zn, Pb, Cu, Ni, Cr	Digestion - WQO, p. 88 recommended by the manufacturer for the instrument used (Perkins-Elmer Model 403).
Mercury	Digestion - Nitric acid reflux procedure (see below). Analysis: Perkin-Elmer Mercury Analysis System Operating Directions 303-3119.
Density	Pycnometer method (wide mouth pycnometer)
Heat Value	Instructions for 1241 and 1242 Adiobatic Colorimeters, Manual No. 142, Parr Instrument Company, Moline, IL
Pesticides and PCB's	Details of the pesticide analytical procedure are included later in this appendix.
Soluble Parameters	Samples were filtered through 0.45 micron membrane filters to remove suspended solids in preparation for measurement of soluble parameters.

Nitric acid reflux digestion procedure for mercury - A suitable sample volume was placed in a 250 ml round bottom flask and 10 ml of concentrated nitric acid was added. The flask was then connected to a reflux condensor (about 60 cm in length) and heated with a heating mantle causing the acid to reflex gently. The mixture was heated for two hours before allowing it to cool at room temperature. The cooled mixture was washed down in the column with about 60-70 ml of distilled water. The sample was then filtered through Whatman No. 42 paper to remove insoluble material and the filtrate was made up to 100 ml with distilled water. A suitable aliquot was then analyzed for mercury.

PESTICIDE ANALYSIS

Introduction

The method described here was used for the extraction and isolation of organochlorine pesticides and certain polychlorinated biphenyl (PCB) mixtures from stormwater and combined sewer overflow sludges. This method is based on EPA approved procedures with slight modifications to adapt it to CSO sludges. The limit of detection was 1 µg/l for Arochlor related PCB's and the following organochlorine pesticides: BHC, lindane, heptachlor, aldrin, heptachlor epoxide, dieldrin, endrin, Captan, DDE, DDD, DDT, methoxychlor , endosulfan, dichloran, mirex, pentachloronitrobenzyene and trifluralin.

The selected cleanup procedures permitted the analyst to eliminate certain anticipated interferences and allowed for separation of analogs of Arochlor #1254, #1260, #1262, #4465, from organochlorine pesticide.

Summary

PCB's and organochlorine pesticides were coextracted either by liquid-liquid extraction or for samples of high solids by mixing with anhydrous Na_2SO_4 and soxhlet extraction. A combination of the standard Florisel column cleanup and silicic acid column chromatography were employed to separate PCB's from organochlorine pesticides (48). Identification was made with a gas chromatograph equipped with an electron capture detector through the use of two or more unlike columns. Further confirmation by chemical modification using a microscale alkali treatment was used as recommended in the literature (49).

Interferences

1. All glassware, solvents, reagents, and sampling hardware must be demonstrated to be free of interferences under the conditions of analysis. Therefore,all glassware was fired at 230°C after Lamberton et al. (50).

2. Organochlorine pesticides and PCB's are mutually interfering. The silicic acid column cannot separate Arochlors #1221, #1242, #1248, #5442 and #5460 completely from DDT and its analogs. (Early eluting peaks from the Arochlors may occur in the polar eluate). For this reason the use of the chemical modification confirmating technique was utilized as recommended in the literature (49).

Apparatus

1. Gas chromatograph equipped with recorder

2. Detector, Electron Capture

3. Gas chromatograph columns

   Two unlike columns of non-polar and semipolar type suitable for pesticide analysis (e.g. glass 1/4" x 6 ft packed with 10% DC200 silicone fluid on 80-100 mesh Anakron ABC.)

4. 500 ml Kuderma-Denish glassware (Kontes K-570000)

5. Chromatographic column 400 x 22 mm(Kontes K-420550, C-4) with adapter, hose connector type (Kontes K-185030)

6. Separating funnel 250 ml (Kontes K-633030)

7. Evaporative Concentrator (Kontes K-569250)

8. Concentrator tube (Kontes K-570050) graduated in 0.1 ml to 1 ml

9. Separatory funnels (125 ml, 1000 ml with Teflon stopcocks)

10. Volumetric flask 250 ml

11. Florisil-PR Grade (60-100 mesh) prepared after the method of Hall (44)

12. Silicic acid, Mallickrodt 100 mesh

13. Glass Wool - hexane extracted

14. Centrifuge tubes 40 ml Pyrex

15. Soxhlet Extractor, 250 ml

16. Magnetic stirrer with teflon control bar, hexane extracted

17. 1 gallon sample bottles, with teflon caps

18. 10 ml transfer pipette

19. Celite 545 washed

20. Air regulator

Reagents, Solvents, and Standards

1. Sodium chloride ACS saturated solution

2. Sodium sulfate ACS granular anhydrous, conditioned for 4 hrs at 400°C

3. Diethyl ether - nanograde

4. Hexane, acetonitrile, methanol, methylene chloride, petroleum ether (BR 30-60°C) - pesticide grade

5. Standards - appropriate organochlorine and arochlors for elements in question

Calibration

1. Gas chromatograph conditions were considered acceptable when response to heptechlor epoxide was 50% of full scale for < 1 ng (nanogram) injection (full scale - 1×10^{-9} amp). Detector response for quantitative work was kept in the demonstrated linear range.

2. Standards were injected frequently as a check on detector and column stability.

Sample Preparation

1. Adjusted pH to near 7.0.

2. If the solids content of the combined sewer overflow sample was high (as with sludges and some influent samples), liquid-liquid partition was not possible due to emulsion formation. Under these conditions the sample aliquot was centrifuged and the supernatant treated as detailed in the extraction section below. The solids were combined with anhydrous Na_2SO4 and extracted as discussed below.

3. For a sensitivity of 1 μg/l, sample aliquots were between 50 to 100 ml.

Extraction

1. Two methods of extraction could be employed depending on the nature of the sample. Unless the sample appeared to be low in solids and organics, such as a well treated effluent sample, it was necessary to separate the solids from the liquid and extract each separately. The extracts could then be combined and concentrated as a single extract.

2. Liquid - liquid extraction was employed for samples of low solids and organic content. The procedure used for liquid-liquid extraction is described as follows:

Place an aliquot of the sample in a one liter separatory funnel and make the column up to 500 ml using distilled water. Add 30 ml of 15% methylene chloride in hexane (V:V) and shake vigorously for two minutes. Allow the phases to separate and drain the water layer into a clean Erlenmeyer flask. Pass the organic layer through a 3-4" column of anhydrous Na_2SO_4 and collect in a 500 ml K-D flask. Return the water phase to the separatory funnel and rinse the Erlenmeyer with a second 30 ml volume of solvent. Add the solvent to the separatory funnel and complete the extraction procedure. The water phase should be extracted with three 30 ml aliquots of solvent. Concentrate the extract on a water bath to 5 ml.

3. If an emulsion was formed between the water and solvent phases, it was necessary to remove the solids using the following procedure:
   Place suitable aliquots of the high solids content sample in clean (hexane washed) glass centrifuge tubes. Decant the supernatant into a one liter funnel and extract the pesticides as outlined in item 2 above. Remove as much of the centrifuge cake as is possible with a glass rod and combine it with hexane washed anhydrous sodium sulfate in a large mortar and pestle. Work the sample to free flowing dry state by continuously adding small amounts of anhydrous sodium sulfate. Add a small amount of sodium sulfate to the centrifuge tube to dry any remaining sample and aid in removing it. Combine all the dried sample and pour it into a glass Soxhlet extraction thimble. To prevent the dried sample from packing too tightly, layer glass beads at about 1 inch intervals in the extraction thimble. Place the filled thimble in a soxhlet apparatus by pouring them through the filled extraction thimble. Extract the sample for 6 to 8 hours. Take the extract just to dryness on a water bath in a K-D assembly, cool and wash the K-D assembly with hexane and adjust sample to 5 ml.

4. The concentrate was analyzed quantitatively to determine:

   a. If organochlorine pesticides were present
   b. If PCB's were present
   c. Combination of a and b
   d. If elemental sulfur was present
   e. If response was too complex to determine a, b, or c

5. If a, determined organochlorine pesticides.

6. If b, determined PCB's

7. If c, compared peaks obtained to standard arochlors and determined which Arochlors were present. If Arochlor peaks were analogs of #1254 and #1260, the PCB's were separated from DDT and its analogs by the combination of Florisil column and silicic acid column technique. If other Arochlor analogs were present, further confirmation with the micro-alkali technique was employed.

8. If d, remove sulfur.

9. If e, the applicable separation procedures described below were followed.

Cleanup and Separation Procedures

(i) Acetonitrile Partition for removal of fats and oils. (note: not all pesticides are quantitatively recovered by this procedure. Efficiency of partitioning for pesticides of interest should be demonstrated).

Transfer the 5 ml concentrated extract to a 125 ml separatory funnel and add enough hexane washings to bring volume to 15 ml. Extract the sample with four 30 ml portions of hexane saturated acetonitrile by shaking vigorously for one minute. Combine and transfer the acetonitrile phases to a one liter separatory funnel and add 650 ml of distilled water. Add 40 ml of saturated sodium chloride solution. Mix thoroughly and extract with two 100 ml portions of hexane. Combine the hexane extracts in a one liter separatory funnel and wash with two 100 ml portions of water. Discard the water layer, pass the hexane layer through a 3-4 inch sodium sulfate column into a K-D flask and rinse the funnel and column with three 10 ml portions of hexane. Concentrate the hexane extracts to 6-10 ml and analyze via GLC unless further cleanup is required.

(ii) Sulfur Interference - Elemental sulfur is encountered in most sediment samples, marine algae and some industrial wastes. The solubility of sulfur in various solvents is very similar to the organochlorine and organophosphate pesticides; therefore, the sulfur interference follows along with the pesticides through the normal extraction and cleanup techniques. The sulfur will be quite evident in gas chromatograms obtained from electron capture detectors, flame photometric detectors operated in the sulfur or phosphorus mode, and Coulson electrolytic conductivity detectors. If the gas chromatograph is operated at the normal conditions for pesticide analysis, the sulfur interference can completely mask the region from the solvent peak through aldrin.

This technique eliminates sulfur by the formation of copper sulfide on the surface of the copper. There are two critical steps that must be followed to remove all the sulfur: (i) all oxides must be removed to give copper a shiny, bright appearance that would make it highly reactive; (ii) the sample extract must be vigorously agitated with the reactive copper for at least one minute (46).

It will probably be necessary to treat both the 6% and 15% Florisil eluates with copper if sulfur crystallizes out upon concentration of the 6% eluate.

Certain pesticides will also be degraded by this technique, such as the organophosphates, chlorobenzilate and heptachlor (see Table B-1). However, these pesticides are not likely to be found in routine sediment samples because they are readily degraded in the aquatic environment.

If the presence of sulfur is indicated by an exploratory injection from the final extract concentrate (presumably 5 ml) into the gas chromatograph, proceed with removal as follows:

a. Under a nitrogen stream at ambient temperature, concentrate the extract in the concentrator tube to exactly 1.0 ml.

b. If the sulfur concentration is such that crystallization occurs, carefully transfer, by syringe, 500 µl of the supernatant extract (or a lesser volume if sulfur deposit is too heavy) into a glass-stoppered, 12 ml graduated, conical centrifuge tube. Add 500 µl of iso-octone.

c. Add 2 µg of bright copper powder, stopper and mix vigorously one minute on a Vortex Genie mixer.

NOTE: The copper powder as received from the supplier must be treated for removal of surface oxides with 6N HNO_3. After about 30 seconds of exposure, decant off acid, rinse several times with distilled water and finally with acetone. Dry under a nitrogen stream.

d. Carefully transfer 500 µl of the supernatant-treated extract into a 10 ml graduated evaporation concentrator tube. An exploratory injection into the gas chromatograph at this point will provide information as to whether further quantitative dilution of the extract is required.

NOTE: If the volume transfers given above are followed, a final extract volume of 1.0 ml will be of equal sample concentration to a 4 ml concentrate of the Florisil cleanup fraction.

(iii) Florisil Column Cleanup - Place a charge of activated Florisil (the weight of the charge is determined by its Lauric Acid Value, see Hall (51)) in the Chromaflex column and settle by gentle tapping. Add a 1 cm layer of anhydrous sodium sulfate and pass 50-60 ml of petroleum ether through the column. When the petroleum ether is about 5 mm from the sodium sulfate, transfer the sample extract by decantation and petroleum ether washings to the column and elute with the following mixed ethers at 5 ml/minute. (NOTE: For both column chromatography procedures the elution rate is important. To quickly adjust this rate the lower part of a broken 25 ml burette equipped with teflon stopcock placed between the chromaflex column and the receiving vessel is most useful in making repetitive low adjustments without losing eluate.). Collect each eluate in a 500 ml K-D flask.

Table B-1. EFFECT OF EXPOSURE OF PESTICIDES TO MERCURY AND COPPER

Compound	Percentage Recovery Based on Mean of Duplicate Tests: Mercury	Copper
BHC	81.2	98.1
Lindane	75.7	94.8
Heptachlor	39.8	5.4
Aldrin	95.5	83.3
Heptachlor Epoxide	69.1	96.6
pp'-DDE	92.1	102.9
Dieldrin	79.1	94.9
Endrin	90.8	89.3
DDT	79.8	85.1
Chlorobenzilate	7.1	0
Arochlor 1254	97.1	104.3
Malathion, diazinon, Parathion, Ethion, Trithion	0	0

Note: If the microalkali dehydrochlorination procedure is used, elemental sulfur is removed.

To the first elution (6% eluate) add 200 ml of 6% ethyl ether in petroleum ether (V/V); second elution, 200 ml 15% ethyl ether in petroleum ether. Most pesticides of interest will be in these eluates. Refer to Reference 52 for more details.

6% Eluate

Aldrin	Heptachlor	Strobane
BHC	Heptachlor epoxide	Toxaphene
Chlorodane	Lindane	Treflurolin
DDD	Methoxychlor	PCB's
DDE	Mirex	
DDT	Pentachlornitrobenzene	

15% Eluate

Endosulfan I	Dechloran
Endrin	Phtholate
Dieldrin	

Concentrate the eluates and analyze by GLC.

(iv) Silicic Acid Column Separation Procedure

A. Silicic Acid Preparation

a. Celite 545 must be oven dried and free of electron capturing substances (acid washed).
b. Silicic Acid - Oven dry for a minimum of seven hours at 130°C to remove water. Cool the silicic acid and weigh into a glass stopper bottle and add 3% water. Stopper bottle and shake well. Allow 15 hours for equilibrium to occur. Determine separation achieved by loading 40 µg of Arochlor #1254 and pp 'DDT in hexane on the column. Inadequate separation will mean readjustment of the water content of the silicic acid in recommended increments of 0.5%. More water is required when the PCB elutes in the polar solvent with pp 'DDE; less water when pp 'DDE elutes in the petroleum ether portion. Standardization is required for each new lot of silicic acid purchased. Once a batch of silicic acid is hydrated activity remains for about 5 days.

B. Column Preparation - Weigh 5 g of celite and 20 g of silicic acid and combine in a 250 ml beaker. Immediately slurry with 80 ml of petroleum ether. Transfer the slurry to the chromatographic column, keeping the stopcock open. Stir the slurry in the colunn to remove air bubbles, then apply air pressure to form the petroleum ether through the column. Do not allow the column to crack or go dry and close the stopcock when air pressure is not being applied. Stop the flow when the petroleum ether level is 3 mm above the surface of the silicic acid. The adsorbent at this point should be firm and not loose shape if tapped.

C. Elution Patterns - Large amounts of PCB's or pesticides placed on the column will result in incomplete separation. The extracted sample placed on the column should contain no polar solvents and be ≷ 5 ml in volume. Place a 250 ml volumetric flask beneath the column and carefully add a suitable aliquot of the 6% florisil eluate, taking care not to disturb the surface of the silicic acid. Apply slight air pressure until the solvent level is each 3 mm from the surface of the silicic acid. Carefully position the 250 ml separatory funnel containing 250 ml of petroleum ether on the column and allow the petroleum ether to run down the sides of the column until the space above the silicic acid is one half full. Apply air pressure and adjust the flow rate to 5 ml/minute. When exactly 250 ml are collected, replace the volumetric flask with a 500 ml K-D flask and elute @ 5 ml/min with 200 ml of methylene chloride, hexane and acetonitrile (80:19:1, V/V) to recover the pesticides. Quantitatively transfer the petroleum ether eluate containg the PCB's to a 500 ml K-D and concentrate both eluates to 5 ml. Analyze via GLC. NOTE: the separation between the PCB's and pp 'DDE is very narrow; great care should be exercised in adjusting the elution flow rate and volume of the petroleum ether portion.

<u>Petroleum Ether Eluate</u>

Aldrin

Arochlors	#1221[a]	#1254
	#1252[a]	#1260
	#1258[a]	#1262

Hexachlorbenzene

Polar Eluate (Acetonitrile, Methylene Chloride, Hexane)

Arochlors	#1221[a]	Endrin
	#1242[a]	Heptachlor
	#1248[a]	Heptachlor epoxide
BHC		Lindane
pp'DDE		Toxaphene
pp'DDT		
pp'DDD		

a. These Arochlors divide between the two eluates. The earliest eluating peaks may occur in the polar eluate.

D. Confirmation Techniques - Qualitative confirmation by comparing relative retention time (RRT) of the constituents on two or more unlike columns is suggested as a minimum criteria for identification after appropriate cleanup and column chromatography.

If an Arochlor analog which does not completely occur in the petroleum ether eluate is suspected, the alkali-dechlorination procedure is strongly recommended (see Young et al (49)). In any event such confirmational techniques add greatly to the reliability of the residue analysis in the absence of more sophisticated mass spectroscopy instrumentation.

BENCH SCALE TEST METHODS

Gravity Sludge Thickening

The bench scale tests described herein can be used to determine whether sludge is amenable to thickening by gravity sedimentation with or without chemical aids. Data obtained using this procedure can be used for design of gravity thickening equipment. An example of thickener design using the Coe & Clevenger (8) and Mancini (9) methods is presented.

Procedure-

1. Obtain a sample of the sludge at the concentration typical of the expected sludge concentration.

2. Obtain a sample of this sludge for analyses (suspended solids and total solids).

3. Measure and record in centimeters the distance between the 100 ml and 1,000 ml marks on a 1 liter graduated cylinder.

4. Fill the cylinder with sludge to the 1,000 ml mark.

5. Start the stopwatch.

6. Record the position of the interface (in ml) with respect to time (in minutes). Continue recording at 2-10 min. intervals (or more frequently if necessary) for 2 hours or until no further settling or compaction occurs.

7. During the above (step 6) set aside the remaining sludge sample and allow it to settle for approximately 2 hours. After that time decant off the supernatant and save it for dilution water. Measure the total volume of supernatant and the total volume of settled

sludge and record. Obtain a sample of the settled sludge (250-300 ml) for analyses. (suspended solids, total solids, and specific gravity)

8. Conduct settling rate tests at several concentrations between the original (C_i) and the settled sludge (C_f) concentrations. These concentrations are obtained by appropriate dilutions of the settled sludge with the supernatant. These dilutions should cover the complete range between C_i and C_f. Recommended values are obtained by using the concentrations of $C = C_f - r(C_f - C_i)$; where 'r' is an arbitrary factor value of which can be selected to provide suitable concentrations between C_i and C_f. For example 'r' can have values such as 0.25, 0.5 and 0.75. The proper dilutions can then be made using the following equations.

The initial sludge concentration, Ci, can be expressed as:

$$C_i = \frac{V_s C_s + V_f C_f}{V_i}$$

where C_i = solids concentration of the original sludge

C_s = solids concentration of the supernatant (assumed = 0)

C_f = solids concentration of the settled sludge

V_i = total volume of sludge before settling = $V_s + V_f$

V_s = volume of the supernatant

V_f = final sludge volume after settling

or

$$C_i = \frac{V_f}{V_s + V_f} \quad C_f$$

One liter of sludge of the desired concentration is obtained using the following equation:

$$M_f C_f + M_s C_s = 1000\ C$$

where M_f = ml of settled sludge

M_s = ml of supernatant

C = desired concentration

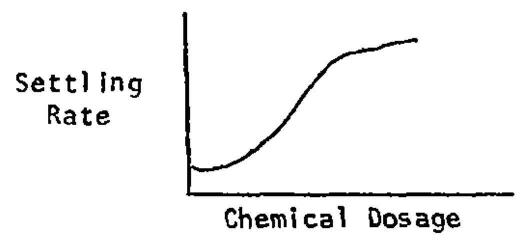
or

$$M_f C_f = 1000\ (C_f - r\ (C_f - C_i))$$

Substituting for C_i and simplifying $M_f = 1000 \left[(1-r) + r\left(\frac{V_f}{V_s + V_f}\right) \right]$

Add M_f ml of settled sludge to a 1 liter graduated cylinder. Fill to the 1000 ml mark using the supernatant. Mix thoroughly, start the stopwatch and record the position of the interface with respect to time. These tests can be run for a shorter period of time because only the initial settling rate is of importance and the later compaction rate is not needed. Repeat for all values of r. After settling, mix thoroughly and obtain a sample for suspended solids.

Gravity Thickening With Chemicals - Chemical addition may improve thickening or sedimentation properties of a sludge by forming a floc and increasing the settling rate. The initial step in testing with chemicals is to screen numerous chemicals for effectiveness. Among chemicals that can be screened are $FeCl_3$, lime, alum, and polyelectrolytes (cationic, nonionic and anionic). Screening tests are normally conducted in 100 ml graduated cylinders using various dosages of chemicals and combinations of chemicals. The test of effectiveness in these screening tests is the visual observation of floc formation. After selection of the chemical or chemicals, settling rate tests are conducted in 1 liter graduated cylinders at a wide range of chemical dosages. A graph of the settling rate versus chemical dosage generally yields a curve of the following form.



The optimum chemical dosage is at or near the break point of the curve, i.e. the point at which additional chemical increases the settling rate only slightly or not at all. A complete set of settling tests as described in the previous section is then conducted using chemicals at the optimum dosage. It should be noted that the chemical dosage used in these tests must be on a weight-weight basis, i.e. gm of chemical per kg of dry sludge solids. Correct amounts of chemical (in mg/l) to use at the various sludge dilutions can be determined using the following equation:

$$D = D_I \left(\frac{M_f}{1000}\right)\left(\frac{V_f + V_s}{V_f}\right)$$

where D = chemical dosage at the test sludge concentration mg/l

D_I = optimum chemical dosage with sludge at the initial concentration, mg/l

The dosages calculated in the above manner are those that are used on the sludge samples after mixing the settled sludge with the supernatant. Chemicals are added after the sludge is mixed to the desired concentration. The chemical is mixed with the sludge, flocculated if necessary and settled as described previously. The same mix time and flocculation time must be used for the entire series.

Data Analysis -

1. Plot the data obtained from the settling tests, i.e. position of the interface in ml versus time in minutes. Each graph will have the following configuration:

The settling rate is the linear portion of the curve. Determine the settling rate in ml/min and convert to meters/hr using the following:

$$S_1 = 6.67 \times 10^{-4} LS_2$$

where S_1 = settling rate, m/hr

L = distance between 100 and 1000 ml mark, cm

S_2 = settling rate, ml/min (slope of the settling curve linear section)

2. Plot the settling rate (m/hr) versus the sludge concentration (mg/l) on graph paper if necessary.

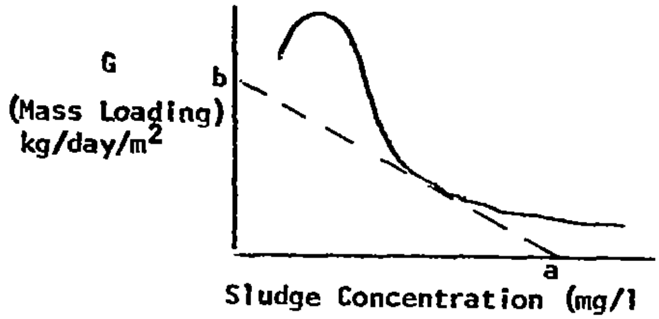
3. Construct a flux concentration curve from the settling rate curve i.e. mass loading in kg/day/sq m versus mg/l suspended solids

$$G = 0.024 \ (S_1) \quad (C)$$

where G = mass loading, kg/day/sq m

S_1 = settling rate, at the tested concentration m/hr

C = sludge concentration, mg/l



Construction of a tangent to the curve from the desired underflow concentration (point a) will intersect the Y axis at the maximum mass loading (point b).

4. From the mass loading rate obtained above the minimum required surface area for thickening may be determined

$$A = 1.44 \times 10^{-3} \ C_i Q_i / G$$

where A = surface area required for thickening, sq m
C_i = feed sludge concentration, mg/l suspended solids
Q_i = feed sludge flow rate, l/min
G = design solids loading, kg/day/sq m

5. The surface area for clarification must also be checked to see which process is limiting - clarification or thickening. The underflow rate is determined first.

$$Q_u = \frac{C_i}{C_f} Q_i$$

where Qu = underflow flow rate, l/min
Q_i = feed sludge flow rate, l/min
C_i = feed sludge suspended solids concentration, mg/l
C_f = underflow sludge suspended solids concentration, mg/l

The effluent flow rate for design of clarification is then obtained by difference.

$$Qe = Qi - Qu$$

where Qe = effluent flow rate, l/min

The minimum surface area required for clarification is then:

$$A = \frac{0.06 \ Qe}{S_i}$$

where A = surface area required for clarification, sq m

Q_e = effluent flow rate, l/min

S_I = settling rate at the feed sludge concentration, m/hr

DISSOLVED-AIR FLOTATION SLUDGE THICKENING

It has been indicated that dissolved-air flotation may be used as a method of thickening sludge to a higher solids concentration in relatively shorter periods of time than other gravity thickening methods. Flotation may be applied to the concentration of sewage plant sludges as well as industrial waste sludges.

Bench scale studies are invaluable in determining the amenability of dissolved-air flotation to sludge thickening and in obtaining certain basic process and equipment design data. Set forth below is a test procedure for conducting sludge thickening tests using dissolved-air flotation (53).

Final effluent or primary effluent should be used as a source of pressurized flow. If another source is used as pressurized flow, the source should be indicated.

The rate of solids separation will be obtained by performing actual tests using the appropriate experimental apparatus. As a part of these tests, the following data should be obtained:

a. Floated sludge volume
b. Settled sludge volume
c. Flotation detention time
d. Volume of waste sludge used
e. Volume of pressurized flow used
f. Concentration of combined flow

The test conducted to obtain the above data should be performed in one liter graduates. Obtain the vertical distance between the 100 ml mark and the 1,000 ml mark in inches or other convenient units and record.

Experimental Procedure

1. Rate of solids separation test:

   The rate of solids separation of the major portion of the waste sludge solids is obtained by observing the solids-liquid interface during flotation and recording its upward travel with time. This test should be performed in a one-liter graduate.

2. Waste sludge volume:

   The amount of waste sludge to be placed into the one-liter graduate for thickening will vary with the initial waste sludge solids concentration and with the ratio of pressurized flow volume/waste sludge volume to be used

Let the amount of waste sludge to be placed into the one-liter graduate for the test be calculated as follows:

$$X = \frac{V}{2Y + 1}$$

where X = volume of waste sludge to be placed in graduate, ml
Y = percentage waste sludge solids concentration
V = total volume of waste sludge and pressurized flow (usually 1000 ml)

For example, assume the waste sludge to be thickened has a solids concentration of 1%. From the equation above, the amount of waste sludge to be placed in the graduate is 333 ml, when V = 1000 ml.

The weight of the sludge in the graduate should be obtained and recorded. The weight of the sludge may be obtained by first determining the graduate tare (weight of empty graduate) on a laboratory beam balance. Record the graduate tare. Then, similarly obtain the weight of graduate containing the sludge to be thickened. Obtain the sludge weight by difference and record. The sludge in the graduate is now ready for the addition of pressurized flow.

3. Pressurized flow

The flotation pressure cell is filled approximately three-quarters full with relatively solids-free water. The cell cover is secured, and air is injected into the cell using compressed air or a tire pump until a pressure of 40 psig is attained. The cell is then shaken vigorously for about 30 seconds to facilitate solution of air in the pressurized flow source. Open the discharge valve located on the pressure cell and fill the attached rubber tubing with air-charged flow. Check the quality of the air bubbles formed. The rubber tubing is then inserted into the graduate (all the way down to the bottom of the graduate) containing the waste sludge to be thickened. The pet-cock on the pressure cell is again opened and the pressurized flow is allowed to enter the graduate at the bottom and mix with the waste sludge. Pressurized flow is added until the combined volume is 1000 ml. Move the tubing up and down in the cylinder to assure complete mixing. It is important that the pressure of 40 psig be maintained during the release of pressurized flow into the graduate.

Determine the total weight of the contents of the graduate and record it. Also determine weight of pressurized flow used by calculation and record it.

4. Rate of solids separation data

At the beginning of the test, the solids-liquid interface is at the bottom of the graduate or at zero volume. As flotation progresses, the solids-liquid interface moves progressively up the height of the graduate. The rate of rise of the major portion of the solids is recorded.

At times the solids-liquid interface may be vague and good judgment may have to be exercised in following this interface. Care should be taken to avoid following the interface formed by the air bubbles alone. In general, this interface lags behind the solids-liquid interface.

The form which may be used in obtaining the rate of separation is suggested by the following example. The flotation detention time should be 60 minutes.

Time (min)	Volume (ml)	POI (Position of Interface) (ft)
0	0	0
0.5	170	0.207
1.0	320	0.379
1.5	430	0.504
2.0	540	0.628
3.0	620	0.718
4.0	655	0.756
5.0	680	0.784
10.0	750	0.865
15.0	780	0.889
20.0	795	0.917
30.0	810	0.934
40.0	850	0.980
50.0	865	0.995
60.0	870	1.000

The ultimate data desired is the position of the interface at various time intervals throughout the test. The column above labeled "Volume" is used as a convenient means of obtaining the position of the interface at any given time. For example, in the hypothetical case shown above, the position of the interface at any given time may be conveniently obtained using the appropriate graduation mark on the liter cylinder as a reference. After the flotation test, the graduation marks may be converted to meters of height by actual measurement.

5. Analyses of data

The data derived from the bench testing is then used to estimate the scum concentration at various mass loading rates. This data is then graphically plotted. Optimum overflow rates are then selected from this plot for the design of dissolved-air flotation thickeners.

CENTRIFUGE TEST PROCEDURE

The purpose of this test is to determine the dewatering characteristics of sludge by centrifugation. Data obtained include the effects of centrifugal force, the effect of residence time, estimates of solids recovery, sludge concentration and sludge consistency. Procedures were developed by Vesilind (54).

Procedure

Approximately 2-4 liters of sludge are required to run a complete test series. If the sludge contains large or stringy materials it should be prescreened on a coarse screen to avoid erroneous results.

1. Mix the screened sludge well and obtain a sample.

2. Place 75 ml of sludge into each of the centrifuge tubes. NOTE: It is important that balanced amounts of samples be placed in opposite centrifuge tubes. Sample sizes other than 75 ml may be used but the amount must be the same in opposing centrifuge tubes.

3. Place in the centrifuge and spin for a predetermined time at the required centrifugal force. Suggestions for spin time are 30 seconds, 60 seconds, 90 seconds and 120 seconds. Suggested centrifugal forces are 400 g, 600 g, 800 g and 1000 g. The step by step procedure for this test using the Dynac (manufacturer of the centrifuge) Model CT-1360 centrifuge is as follows:

    a. Place the filled centrifuge tubes in the head.

    b. Turn the timer dial clockwise to the "hold" setting.

    c. Determine the rpm required to obtain the desired centrifugal force using Figure B-1.

    d. From Figure B-2 determine the setting on the speed control which will yield the required rpm with the number of centrifuge tubes used.

    e. Close and lock the centrifuge cover.

    f. Quickly turn the speed control knob clockwise to the required setting simultaneously starting the stopwatch.

    g. At the end of the predetermined spin time turn the speed control knob counter-clockwise to zero and immediately apply the brake until the head stops.

4. Record the sludge depth on a data sheet.

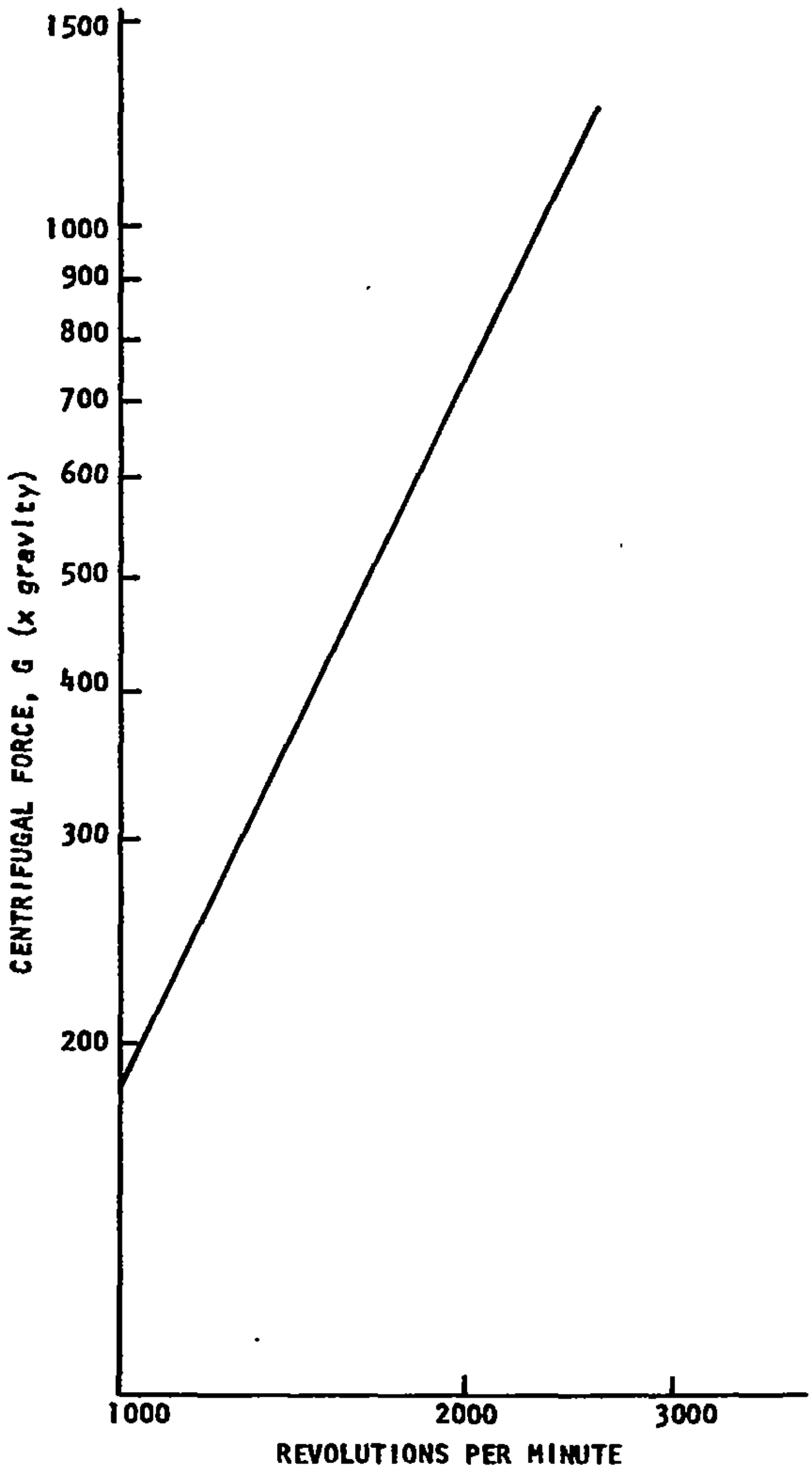


Figure B-1. Centrifugal force vs. RPM for Dynac Model CT-1360 centrifuge

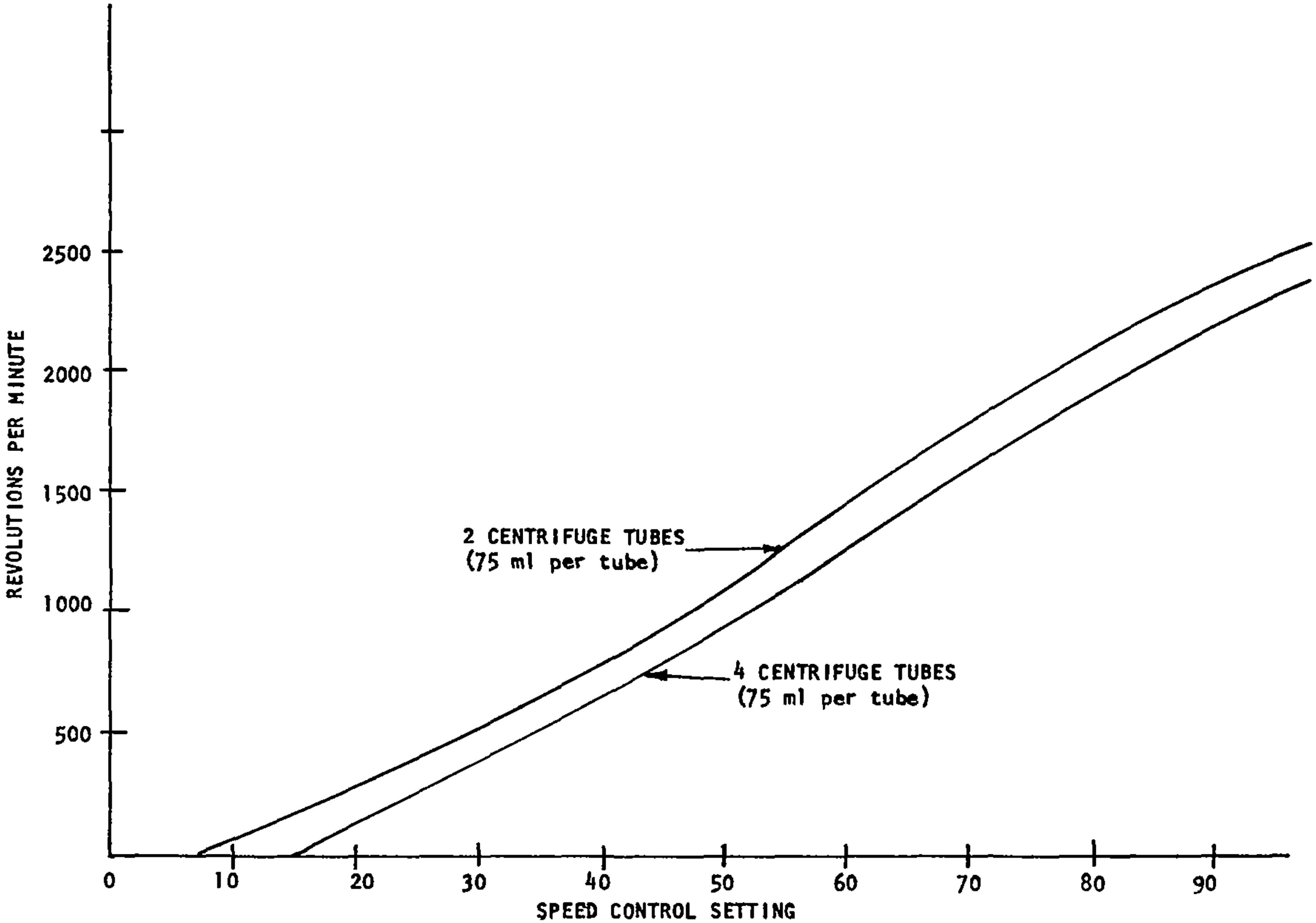


Figure B-2. RPM vs. speed control setting

5. Pour off the centrate from the tubes into a graduated cylinder. Record the centrate appearance and the total volume. Mix well and obtain a sample of the centrate.

6. Determine the consistency of the sludge using the glass rod (4 mm x 40 mm, 13 gm weight). Position the tip of the rod at the sludge surface. Drop the rod from this position, measure and record the depth which is penetrates.

7. Repeat steps 2 through 6 for all test conditions.

8. If chemical conditioning is desired, determine a suitable chemical dosage for floc formation. Dose each sludge sample with the same chemical dosage immediately prior to each centrifugation condition utilizing the same mixing time, degree of agitation and holding time for each test. Repeat steps 2 through 7 for these tests.

Data Analysis

1. Estimate the percent solids recovery for each test utilizing the following equation:

$$\% \text{ Recovery} = \frac{C_f - C_c \times 100}{C_f},$$

where C_f = suspended solids concentration in the feed sludge (mg/l)

C_c = suspended solids concentration in the centrate (mg/l)

2. Estimate the sludge solids concentration using the following equation:

$$C_s = \frac{V_f C_f - V_c C_c}{V_f - V_c}$$

where C_s = final sludge suspended solids concentration (mg/l)

C_f = feed sludge suspended solids concentration (mg/l)

C_c = suspended solids concentration in the centrate (mg/l)

V_f = total feed sludge volume centrifuged (ml)

V_c = total volume of centrate decanted (ml)

This parameter is only an indicator of the relative compactability of the feed sludge at various operating conditions.

3. Calculate the sludge penetrability to determine a correction factor for solids recovery using:

$$P = \frac{d_s - d_p}{d_s} \times 100$$

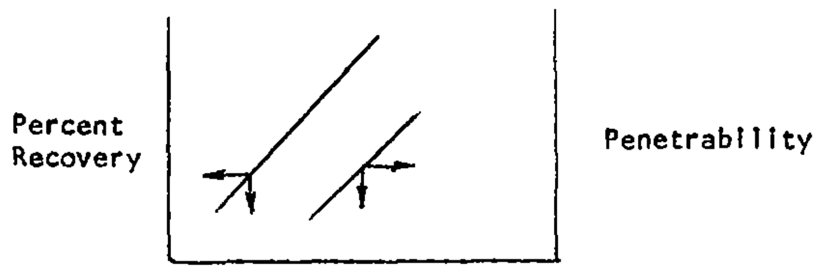
where P = sludge penetrability

d_s = depth of sludge after centrifuging

d_p = depth of penetration of the glass rod

The factor P is the percentage of the total sludge depth not penetrated by the glass rod.

4. Plot the recovery and penetrability versus the centrifugal force (x gravity) at constant spin times on log probability paper as below:



The data should plot as straight lines.

Estimate of Prototype Operation

At a constant centrifugal force read the recovery at one of the spin times. Also read the penetrability at the same spin time. An estimate of the recovery is then determined from the following equation.

$$\text{Recovery in Percent} = \left(\frac{C_f - C_s}{C_f}\right) \cdot \left(\frac{P}{100}\right)^{0.1} \times 100$$

VACUUM FILTRATION TESTS

Buchner Funnel Test Procedure

The Buchner funnel test is conducted to determine the optimum chemical dosage for filter leaf tests (55).

1. Moisten filter paper (Whatman #4) and place it in the Buchner Funnel. Apply a vacuum to obtain a seal. Empty water collected in filtrate receiver.

2. Analyze the sludge to be filtered for solids content.

3. Measure a volume of sludge that will provide a 3 mm to 6 mm thick cake.

4. Select the conditioning chemicals to be utilized and add a predetermined amount to the sludge to be conditioned. This should be reported as kg chemical/ton sludge dry solids.

5. Agitate the volumetric flask vigorously and allow the sludge to sit two minutes. Always agitate the sludge approximately the same amount for any one test series.

6. Add the sludge to the funnel and quickly apply vacuum. As soon as vacuum is applied, start the stopwatch. A vacuum reservoir may be needed to hold a constant vacuum.

7. Take filtrate volume readings with respect to time.

8. Continue the test until the cake cracks, or no filtrate is deposited for a one minute interval. Usually five minutes is sufficient. Be sure the cake edges do not shrink from the sides of the Buchner funnel. If it does, tap the edges of the cake to maintain a seal.

9. Sample cake for total solids.

10. Record filtrate temperature, vacuum level, and cake thickness.

11. Plot a curve of time/volume filtrate vs. volume filtrate and record the slope of the curve. The slope recorded should include only the linear portion of the curve.

$$a = 2PA^2b/\mu\omega$$

where a = specific resistance in sec^2/gm
P = vacuum level in gm/sq cm
A = area of Buchner funnel in sq cm
b = slope of t/v vs. v curve in sec/cm^6
μ = viscosity in Poise
$\omega = 1/[Ci/(100-Ci)) - (Cf/(100-Cf))]$

Ci - initial sludge moisture (%)
Cf = moisture concentration in cake (%)

12. Repeat steps 1 through 12 for several dosages of the same chemical.

13. Plot specific resistance vs. chemical dosage. The minimum point obtained on the curve is the optimum chemical dosage for the chemical tested.

Filter Media Selection Test Procedure

1. Select a cloth for testing in accordance with information available on chemical and physical conditions, sludge type and properties, and parameter qualities desired.

2. Moisten the cloth and place it in a Buchner funnel. Apply a vacuum to obtain a seal.

3. Analyze sludge sample for solids content.

4. Measure a volume of sludge equivalent to a cake thickness of 3 mm to 6 mm.

5. Condition the sludge with the optimum chemical dosage determined from the Buchner Funnel test as described in that test procedure.

6. Add the sludge to the Buchner Funnel. Apply a vacuum of about 50 cm Hg and start the stopwatch.

7. Measure the time to collect 100 cc of filtrate, 150 cc of filtrate, and 200 cc of filtrate. Discontinue test after 5 minutes.

8. Remove the cloth and measure cake thickness.

9. Note cake release as follows:

   excellent - cake peels off medium in pieces with slight amount of spatula aid.

   fair - cake must be taken off medium piece by piece with spatula.

   poor - cake will not come off medium even with maximum spatula use. Some solids left on medium.

10. Analyze the cake for solids content and the filtrate for suspended solids.

11. Wash the filter cloth on both sides with an intense water spray for 5 seconds.

12. Determine if any solids are deposited in the cloth interstices by eye or microscopic evaluation.

13. Repeat steps 1 to 12 three times utilizing the same sample medium.

14. Run a standard test on the sludge at optimum chemical dosage using #4 Whatman filter paper and a 50 cm Hg vacuum.

Vacuum Filter Leaf Test Procedure

1. Condition approximately 20 liters of sludge according to Buchner Funnel test results.

2. Place cloth selected from media screening test on the filter leaf and attach leaf hose to filtrate receiver.

3. Crimp the hose connecting the leaf to the vacuum source and set vacuum to desired level with the bleeder valve.

4. Immerse the leaf in the sludge so that the surface of the leaf is two to three inches below the sludge level. Release the hose and start the stopwatch simultaneously.

5. Keep the leaf submerged for a predetermined pickup time obtained from preliminary tests. For thin sludges, move the leaf slowly in a horizontal plane with a circular wrist movement at a rate of approximately 6 rpm. In thick sludges, the leaf should remain stationary. Keep thin sludges mixed with a small mixer. Thick sludges should be thoroughly mixed prior to the test.

6. At the end of the pickup time, the leaf is rotated out of the bucket.

7. The leaf is then held with the cake upward for the duration of the drying cycle. At the end of this time, vacuum is released. Adjust the vacuum as much as needed during the dry time to maintain vacuum level. Allow all filtrate to drain from the hose to the filtrate receiver.

8. Remove the cake from the filter leaf by blowing into leaf hose and dislodging it with a spatula. Analyze the cake for total solids. Note cake discharge and thickness.

9. Analyze filtrate for suspended solids, and record the filtrate volume.

10. Analyze solids content of remaining sludge. Two to four tests may be run on the same sample.

Preliminary Testing - In initial test, submerge test leafs for various periods of time and note at what time cake sloughing takes place, i.e. sludge will no longer build up uniformly, but falls off when leaf is removed from bucket. This is the maximum pickup time. The minimum pickup time is the time required to produce a cake thick enough to discharge.

Utilizing the maximum pickup time determined above, perform a leaf test and allow the cake to dry until it cracks or shrinks away from the edges of the leaf. This represents the maximum drying time. Run the remainder of the leaf tests according to steps 1-11 in the range of these established pickup and drying times.

Flocculation Test Procedure

1. Measure 50 ml to 100 ml into a 100 ml graduated cylinder and add a predetermined dosage of the chemical selected.

2. Invert the cylinder three times, keeping the palm on the top of the cylinder. (This is rapid mix.)

3. Add any additional chemicals in the order desired and repeat step 2.

4. Gently swirl the graduated cylinder with the wrist for a predetermined time interval. Observe the floc formation.

5. Repeat steps 1 to 4 for various chemical dosages, and compare the graduated cylinders visually to determine optimum chemical dosage. Floc size, supernatant clarity, and rate of floc formation all help in determining the optimum chemical dosage.

6. Utilize any other chemicals desirable.

APPENDIX C. COST DATA

Table C-1. ASSUMPTIONS FOR DEVELOPMENT OF COST DATA

1. Use a maximum sludge treatment time of 24 hours.

2. Assume 50 combined sewer overflows per year.

3. Capital costs for flotation thickening, centrifugation and vacuum filtration include \$3,000 for a pump. Gravity flow assumed for gravity thickeners.

4. Power costs - assume motors running at 75% of full load current. Use 3¢/KWH.

5. Assume \$6,000 for chemical feed system.

6. Chemical costs - polymer : \$1.75/lb.
   lime : \$9.00/100 lbs.
   ferric chloride: \$6.5/100 lbs.

7. Assume 3% of initial capital investment for vacuum filters to be the annual maintenance required. Also assume 0.5 man hours per shift for operator attention.

8. Area estimates are for equipment only.

9. Assume \$0.10 per gallon for hauling costs.

10. Labor costs based on \$6 per man hour.

11. All costs are based on December, 1974 prices.

Table C-2. HUMBOLDT AVENUE - SUMMARY OF PERFORMANCE, COST AND SPACE REQUIREMENTS

Initial residual sludge volume: 34,700 gal.

Initial residual sludge concentration: 1.74% solids

Dewatering[a] process	Performance: Sludge % solids	Performance: Process effluent mg/l	Residual volume: Sludge gal.	Residual volume: Process effluent gal.	Cost: Capital $	Cost: Operating $/year	Dewatered sludge hauling cost $/year	Total annual cost[b] $/year	Area sq ft
Gravity thickening	6.0	870[c]	10,063	24,637	57,000	590	50,315	57,600	707
Flotation thickening	14.0	522[d]	4,313	30,387	111,000	4,960	21,565	39,563	450
Centrifugation	32.4	84	1,864	32,836	65,000	4,360	9,350	21,345	35
Vacuum filtration[e]	30.0	870	2,013	32,687	68,000	8,650	10,065	26,702	143

a. Bench tests done on the basis of sedimentation prior to dewatering. To convert storage basin into settling basin would be a capital expenditure of $516,000; $3,096 operating cost for a total annual amortized cost of $63,705.

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Based on 95% removal.

d. Based on 97% removal.

e. Estimated values based on vacuum filter performance under similar conditions found in this study (3#/ft/hr, 95% recovery).

Table C-3. DETAILS OF OPERATING COST ESTIMATES
FOR HUMBOLDT AVENUE, MILWAUKEE, WI

Dewatering Method	Operating Labor	Operating Costs ($/Year) Maintenance	Chemical Costs	Power Costs	Total
Gravity Thickening	0	570	0	20	590
Flotation Thickening	1,800	2,220	0	940	4,960
Centrifugation	1,200	1,300	1,520	340	4,360
Vacuum Filtration	2,400	2,040	4,000	210	8,650

Table C-4. CAMBRIDGE, MA - SUMMARY OF PERFORMANCE, COST AND SPACE REQUIREMENTS

Initial residual sludge volume: 17,850 gal.[a]

Initial residual sludge concentration: 4.4% solids and 11% solids

Dewatering process	Performance		Residual volume		Cost		Dewatered sludge hauling cost $/year	Total annual cost[b] $/year	Area sq ft
	Sludge % solids	Process effluent mg/l	Sludge gal.	Process effluent gal.	Capital $	Operating $/year			
Gravity thickening[a]	14.0	2,200[d]	5,610	12,240	77,100	801	28,050	37,907	1,256
Flotation thickening	7.2	1,320[e]	10,908	6,942	109,000	4,935	54,540	72,278	370
Centrifugation	34.2	610	2,424	15,426	65,000	2,955	12,120	22,710	35
Vacuum filtration[f]	30.0	2,200	2,618	15,232	68,000	9,954	13,090	31,031	143

a. Based on mass balance of average conditions.

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Performed on a grab sample from Storm 1 at 11% solids.

d. Assume 95% capture.

e. Based on 97% caputre.

f. Estimated values based on vacuum filter perofrmance under similar conditions found in this study ($3\#/ft^2/hr$; 95% recovery).

Table C-5. DETAILS OF OPERATING COST ESTIMATES FOR CAMBRIDGE. MA

Dewatering Method	Operating Labor	Operating Costs ($/Year) Maintenance	Chemical Costs	Power Costs	Total
Gravity Thickening	0	771	0	30	801
Flotation Thickening	1,800	2,060	325	750	4,935
Centrifugation	1,200	1,300	115	340	2,955
Vacuum Filtration	3,600	2,040	4,000	314	9,954

Table C-6. RACINE, WI - SUMMARY OF PERFORMANCE COST AND SPACE REQUIREMENTS

Initial residual sludge volume: 121,000 gal.[a]

Initial residual sludge concentration: 8,430 mg/l

Dewatering process	Performance: Sludge % solids	Performance: Process effluent, mg/l	Residual volume: Sludge, gal.	Residual volume: Process effluent, gal.	Cost: Capital, $	Cost: Operating, $/year	Dewatered sludge hauling cost, $/year	Total annual cost[b], $/year	Area, sq ft
Gravity thickening	19	421[c]	10,200	110,800	29,300	313	51,000	54,755	177
Centrifugation[d]	20	--	5,100	115,900	158,000	12,790	25,500	56,849	200
Gravity thickening & centrifugation	32.9	1,321	3,100	117,900	105,300	4,544	15,500	32,413	205
Gravity thickening & vacuum filt.	23.2	1,821	4,397	116,603	97,300	10,663	21,985	44,077	320
Gravity thickening & flotation thickening	13.2	676	7,728	113,272	162,700	6,064	38,640	63,815	1,404

a. Based on a mass balance of average conditions.

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Assume 95% removal.

d. Basket centrifuge recommended since sludge not scrolable.

e. Assume 97% removal.

Table C-7. DETAILS OF OPERATING COST ESTIMATES FOR RACINE, WI

Dewatering Method	Operating Labor	Operating Costs ($/Year) Maintenance	Chemical Costs	Power Costs	Total
Gravity Thickening	0	293	0	20	313
Centrifugation	7,200	3,160	0	2,430	12,790
Gravity Thickening and Centrifugation	1,800	1,813	0	931	4,544
Gravity Thickening and Vaccum Filtration	3,600	2,333	4,396	334	10,663
Gravity Thickening and Flotation Thickening	1,800	2,961	372	931	6,064

Table C-8. HAWLEY ROAD, MILWAUKEE, WI - SUMMARY OF PERFORMANCE, COST AND SPACE REQUIREMENTS

Initial residual sludge volume: 36,675 gal.[a]

Initial residual sludge concentration: 3.65% solids

Dewatering process	Performance		Residual volume		Capital, $	Operating, $/year	Dewatered sludge hauling cost, $/year	Total annual cost[b] $/year	Area,[c] sq ft
	Sludge % solids	Process effluent, mg/l	Sludge, gal.	Process effluent, gal.					
Gravity thickening	10	1,825[d]	13,386	23,289	35,600	376	66,930	71,489	314
Flotation thickening	13	1,095[e]	10,297	26,378	102,300	5,682	51,485	69,183	796
Centrifugation	23.4	134	5,721	30,954	65,000	3,606	28,605	39,856	20
Gravity thickening & vacuum filtration	35.7	2,056	3,750	32,925	103,600	10,333	18,750	41,252	457
Gravity thickening & centrifugation	30.3	2,123	4,418	32,257	100,600	4,179	22,090	38,085	349

a. Scaled to entire outfall volume.

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Dewatering units sized based on treating entire outfall CSO of 36,675 GPD.

d. Assume 95% removal.

e. Use 97% removal.

Table C-9. DETAILS OF OPERATING COST ESTIMATES FOR HAWLEY ROAD, MILWAUKEE, WI

Dewatering Method	Operating Labor	Operating Costs ($/Year) Maintenance	Chemical Costs	Power Costs	Total
Gravity Thickening	0	356	0	20	376
Flotation Thickening	1,800	2,046	1,026	810	5,682
Centrifugation	1,800	1,300	0	506	3,606
Gravity Thickening and Vacuum Filtration	3,600	2,596	4,003	334	10,333
Gravity Thickening and Centrifugation	1,800	1,656	197	526	4,179

Table C-10. SAN FRANCISCO, CA - SUMMARY OF PERFORMANCE, COST AND SPACE REQUIREMENTS

Initial residual sludge volume: 14,550 gal.[a]

Initial residual sludge concentration: 2.25% solids

Dewatering[a] process	Performance: Sludge, % solids	Performance: Process effluent, mg/l	Residual volume: Sludge, gal.	Residual volume: effluent, gal.	Cost: Capital, $	Cost: Operating, $/year	Dewatered sludge hauling cost, $/year	Total annual cost,[b] $/year	Area, sq ft
Gravity thickening	4.5	1,125[c]	7,275	7,275	67,500	735	36,375	45,039	1,963
Flotation thickening	6.1	675[d]	5,367	9,183	85,000	3,728	26,835	40,547	170
Centrifugation	11.1	33	2,949	11,601	65,000	2,196	14,745	24,576	35
Vacuum filtration	18.2	123	1,699	12,751	62,000	7,600	8,995	23,878	128

a. Based on mass balance.

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Assume 95% removal.

d. Based on 97% removal.

Table C-11. DETAILS OF OPERATING COST ESTIMATES FOR SAN FRANCISCO, CA

Dewatering Methods	Operating Costs ($/Year)				
	Operating Labor	Maintenance	Chemical Costs	Power Costs	Total
Gravity Thickening	0	675	0	60	735
Flotation Thickening	1,800	1,580	64	284	3,728
Centrifugation	600	1,300	127	169	2,196
Vacuum Filtration	1,800	1,860	3,731	209	7,600

Table C-12. KENOSHA, WI - SUMMARY OF PERFORMANCE, COST AND SPACE REQUIREMENTS

Initial residual sludge volume: 122,500 gal.[a]

Initial residual sludge concentration: 8,300 mg/l

Dewatering[a] process	Performance: Sludge % solids	Performance: Process effluent mg/l	Residual volume: Sludge gal.	Residual volume: Process effluent gal.	Cost: Capital $	Cost: Operating $/year	Dewatering sludge hauling cost $/year	Total annual cost[b], $/year	Area sq ft
Gravity thickening	1.0	--	101,675	20,825	87,700	2,010	508,375	520,686	1,590
Flotation thickening	3.1	249[c]	32,798	89,702	117,000	8,843	163,990	186,576	465
Centrifugation	8.9	54	11,424	111,076	170,000	13,030	57,120	90,118	200
Flotation thickening & centrifugation	6.6	356	15,405	107,095	182,000	17,116	77,025	115,401	500
Flotation thickening & vacuum filtration	15.2	331	6,689	115,811	185,000	24,631	33,445	79,806	608

a. Based on a mass balance.

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Based on 97% removal.

d. Based on basket centrifuge since zero corrected recovery indicates that the cake is not scrollable.

Table C-13. DETAILS OF OPERATING COST ESTIMATES FOR KENOSHA, WI

Dewatering Method	Operating Costs ($/Year) Operating Labor	Maintenance	Chemical Costs	Power Costs	Total
Gravity Thickening	0	877	1,073	60	2,010
Flotation Thickening	1,800	2,320	4,014	709	8,843
Centrifugation	7,200	3,400	0	2,430	13,030
Flotation Thickening and Centrifugation	2,700	3,560	9,809	1,047	17,116
Flotation Thickening and Vacuum Filtration	5,400	4,750	13,458	1,023	24,631

Table C-14. NEW PROVIDENCE, NJ - SUMMARY OF PERFORMANCE, COST AND SPACE REQUIREMENTS

Wet-Weather, Primary Clarifier Sludge

Initial residual sludge volume: 195,000 gal.[a]

Initial residual sludge concentration: 0.12% solids

Dewatering process	Performance: Sludge % solids	Performance: Process effluent	Residual volume: Sludge gal.	Residual volume: Process effluent, gal.	Cost: Capital $	Cost: Operating $/year	Dewatering sludge hauling cost, $/year	Total annual cost[b], $/year	Area, sq ft
Gravity thickening[d]	8.0	2,000[c]	3,000	192,000	41,300	1,273	15,000	21,124	177
Flotation thickening	5.9	1,200[d]	3,970	191,000	76,000	3,624	20,000	32,500	150
Gravity thickening & centrifugation	13.0[e]	170	1,750	193,250	100,300	3,737	8,750	24,268	200
Gravity thickening & vacuum filtration	27.5	2,082	85[f]	195,000	109,300	5,298	425	18,561	320

a. Based on mass balance.

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Assume 95% removal.

d. Based on 97% removal.

e. Assume prethickening to 4% solids prior to assumed centrifuge performance based on dry weather sludge data.

f. Done on 1% sample.

Table C-15. DETAILS OF OPERATING COST ESTIMATES
FOR NEW PROVIDENCE, NJ
Wet Weather Primary Clarifier Sludge

Dewatering Method	Operating Labor	Operating Costs ($/Year) Maintenance	Chemical Costs	Power Costs	Total
Gravity Thickening	0	413	840	20	1,273
Flotation Thickening	1,800	1,520	0	304	3,624
Gravity Thickening and Centrifugation	1,200	1,593	840	104	3,737
Gravity Thickening and Vacuum Filtration	1,200	2,453	1,573	72	5,298

Table C-16. NEW PROVIDENCE, NJ - SUMMARY OF PERFORMANCE, COST AND SPACE REQUIREMENTS

Wet-Weather, Final Clarifier Sludge

Initial residual sludge volume: 15,995 gal.[a]

Initial residual sludge concentration: 2.5% solids

Dewatering process	Performance: Sludge % solids	Performance: Process effluent mg/l	Residual volume: Sludge gal.	Residual volume: Process effluent, gal.	Capital $	Operating $	Dewatered sludge hauling cost $/year	Total annual cost[b], $/year	Area, sq ft
Gravity thickening	4.0	1,250[c]	9,997	5,998	69,000	1,848	49,985	59,938	737
Flotation thickening[d]	4.6	750[e]	8,693	7,302	99,300	4,512	43,465	59,721	780
Centrifugation	7.5	169	5,332	10,663	71,000	4,297	26,660	39,297	50
Gravity thickening & vacuum filtration	18.5	1,481	2,161	13,834	121,000	10,299	10,805	35,317	586

a. Based on mass balance

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Assume 95% removal.

d. Feed solids to flotation thickener - 32,300 mg/l suspended solids.

e. Use 97% removal.

Table C-17. DETAILS OF OPERATING COST ESTIMATES FOR NEW PROVIDENCE, NJ

Wet-Weather - Final Clarifier Sludge

	Operating costs				
Dewatering method	Operating man-hours required at $6/hr	Maintenance	Chemical cost	Power cost	Total cost
Flotation thickening	1,800	1,986	0	806	4,592
Gravity thickening	0	690	1,148	10	1,848
Centrifugation	1,200	1,420	1,341	336	4,297
Gravity thickening and vacuum filtration	1,200	2,570	6,422	107	10,299