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FLOCCULATION-FLOTATION AIDS FOR TREATMENT OF COMBINED SEWER OVERFLOWS

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FLOCCULATION-FLOTATION AIDS FOR TREATMENT OF COMBINED SEWER OVERFLOWS

by

N. F. Stanley and P. R. Evans
Hercules Incorporated
Allegany Ballistics Laboratory
Cumberland, Maryland 21502

Contract No. 14-12-855

Project Officers

Clifford Risley, Jr.
U.S. Environmental Protection Agency
Region V
Chicago, Illinois 60606

Richard Field
Storm and Combined Sewer Section
Wastewater Research Division
Municipal Environmental Research Laboratory (Cincinnati)
Edison, New Jersey 08817

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

FOREWORD

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

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the 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.

Many metropolitan areas of the United States are served by combined storm and sanitary sewer systems, which result in stream pollution when their capacity is exceeded by severe runoff. This study reports the investigation of one approach to the problem of economically retrofitting existing facilities with an adequate pollutant removal process for peak flow periods.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

ABSTRACT

The objectives of this study were to investigate the flocculation/flotation characteristics of combined sewer overflow through laboratory and field testing. The concept involves the introduction of chemicals and buoyant flotation aids into the overflow and the subsequent coflocculation of the suspended sewage solids about the aids which rise to the surface from where they may be removed by skimming.

Laboratory parametric studies of three flotation aids and numerous coagulants and flocculants resulted in the batch demonstration of 70 to 100 percent suspended solids removal with 100 mg/l of the polystrene flotation aid Dylex KCD-340, 100 mg/l of the coagulant $FeCl_3$ and 1 mg/l of the flocculant Hercofloc 810.

Subsequent field evaluation in the Rexnord, Inc.-USEPA pilot flotation facility in Milwaukee, Wisconsin, of the combination of chemicals and aids selected in the laboratory tests was beset with difficulties including decreased flocculant strength due to long storage times and flotation aids with poor buoyancy characteristics. Three field tests were devoted to solving these problems. One final field test was achieved with most of the identified problems rectified and resulted in suspended sewage solids removal of 67 to 87 percent. An air flotation test conducted in the same facility for comparison resulted in 50 to 77 percent suspended solids removal.

Recovery, cleaning and reuse of the flotation aids was judged essential to economic feasibility for the flocculation/flotation process. Subsequent testing of recovered used aids indicated a disparity in requirements. When the bonding, or coflocculation, of suspended sewage solids to the fresh aid surface was sufficiently strong to provide a high degree of suspended solids removal, subsequent efforts to clean or remove the solids in anticipation of aid reuse were unsuccessful. This deficiency, coupled with the overall mechanical complexity of the process, resulted in the investigation concluding that the flocculation/flotation process is not as promising for broad field application to the storm overflow problem as the similar dissolved air flotation process. No further investigation of the flocculation/flotation process is recommended.

This report was submitted in fulfillment of Contract No. 14-12-855, under the sponsorship of the Office of Research and Development, US Environmental Protection Agency. Work was completed as of January 1972.

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LIST OF ABBREVIATIONS AND SYMBOLS

BGWTP	Bowling Green Waste Treatment Plant
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
D	Diameter (feet)
Effluent	Treated flow
fpm	feet per minute
fps	feet per second
gpm	gallons per minute
Influent	Raw (untreated) flow
MGD	Million gallons per day
ppm	parts per million
Re	Reynolds Number ($DV\rho/\mu$)
SS	Suspended Solids
TOC	Total Organic Carbon
TS	Total Solids
TVS	Total Volatile Solids
V	Velocity (ft/sec)
VSS	Volatile Suspended Solids
ρ	Density, lb/ft^3
μ	Viscosity, lb/ft-sec

LIST OF ABBREVIATIONS AND SYMBOLS (CONT'D)

cp	centipoise
%	percent
¢	cents
$\gtrsim$	greater than approximately
$\geq$	greater than or equal
$\leq$	less than or equal
$\sim$	approximately equal to
mg/l	milligrams per liter
=	equal to
@	at
min	minutes
hp	horsepower

ACKNOWLEDGMENTS

Technical specialists within Hercules, Rexnord, Inc., and Koppers Company have been consulted during the program.

Initially, Hercules Research Center, Wilmington, Delaware, was visited to discuss flocculation, flotation, and waste water treatment techniques. with Dr. D. Monagle, Dr. C. Smith, Dr. S. Pearson, and Mrs. P. Gilby. Discussions concentrated on: (1) coagulant and flocculant candidates to be evaluated in the program, (2) laboratory flocculation and flotation test techniques, (3) probable coagulant and flocculant dosage effects, (4) comparative laboratory data on dissolved-air flotation and (5) the effect of phosphate content on floc formation. Polyionic flocculants (Hercules, Dow, and Calgon products) were supplied for evaluation.

Messrs. D. Mason and M. Guptu of Rexnord, Inc., Envirex Division, Milwaukee, Wisconsin,were consulted to review their subcontract, the pilot-scale facility modifications and laboratory results. Equipment modifications required for the field tests were defined in these consultations.

Dylex beads are under development at Koppers Technical Center, Monroeville, Pennsylvania. This facility was visited to review processing and supply of the material for field tests. Dr. A. Ingram, head of the Kopper's Expandable Polymers Group, supplied samples for evaluation. Mr. T. Altares, Senior Research Scientist, provided valuable consultation services during the field testing phase.

The support and guidance of the following United States Environmental Protection Agency personnel are acknowledged:

Richard Field, Chief
Richard P. Traver, Staff Engineer
USEPA
Storm and Combined Sewer Section
Municipal Environmental Research Laboratory
Edison, NJ 08817

Stephen Poloncik
USEPA
REGION V
Chicago, IL 60604

SECTION 1

CONCLUSIONS

1. Laboratory testing of the flocculation/flotation process was sufficiently successful to demonstrate the technical feasibility of the concept, but field testing conducted by the Envirex Div. of Rexnord, Inc., at the modified Rexnord-USEPA pilot-scale flotation facility located at Hawley Road, Milwaukee, Wisconsin, revealed numerous operating difficulties of sufficient severity to render that particular embodiment of the process impractical.

2. Laboratory open tank tests of dry weather ordinary sewage from four different sources exhibiting influent suspended solids loadings from 8 mg/l to 1200 mg/l yielded highly variable removal rates, 0 to 100 percent, in parametric tests of three flotation aids and numerous coagulants and flocculants. Consistently good suspended solids removal rates, 70 to 100 percent, were achieved with Koppers Co. Dylex KCD-340 heat-expanded polystyrene flotation aid at a dose rate of 100 mg/l coupled with 100 mg/l of $FeCl_3$ coagulant and 1 mg/l of Hercules Incorporated Hercofloc 810 flocculant.

3. A suspended solids removal level of 67 to 87 percent was demonstrated in the last of five field tests at the Rexnord-USEPA pilot-scale flotation facility. Overall performance of the process in the initial three field tests was poor; numerous process startup difficulties were experienced by Rexnord including mixed flocculant strength degradation under storage, and poor flotation aid expansion/flotation. The suspended solids removal levels achieved in the last field test are comparable to those achieved in test number 71-4 with air flotation, 50-77 percent.

4. The economics of the flocculation/flotation process dictate recovery and reuse of the flotation aids (4 to 7¢ per 1000 gallons of overflow with 90 percent flotation aid reuse versus 20 to 35¢ per 1000 gallons, for 100 percent new aids). The key element in flotation aid reusability is the removal of coflocculated sewage solids from the aid surface so that a relatively clean aid is available for subsequent reuse. Laboratory tests qualitatively indicated that suspended solids could be readily separated from the flotation aid by a high shear mixing operation. However, suspended solids removal tests on float cake (used flotation aids with coflocculated sewage solids) from the last field test showed a high degree of resistance to removal, with 70 to 90 percent solids retention being typical after vigorous agitation. It was concluded that coflocculation adequate to ensure high rates of suspended solids removal is probably inconsistent with flotation aid recovery, placing the economics of the flocculation/flotation process in serious question.

5. The mechanical flocculation/flotation process is considerably more cumbersome and complex than air flotation and is judged to have less potential for broad application.

6. The concept of introducing a mass of highly attracting artificial coflocculation sites into storm overflow to enhance a rapid separation of suspended sewage solids remains intriguing, particularly if the operation can be conducted in situ in the sewer lines. However, many technological breakthroughs in flotation aids, aid recovery and processing will be required to achieve worthwhile results.

SECTION 2

RECOMMENDATION

No further experimental evaluation of the flocculation/flotation concept discussed in this study is recommended.

SECTION 3

INTRODUCTION

BACKGROUND

Pollution from storm and combined sewers is recognized as a significant pollution problem. The magnitude of this source of pollution is indicated in a recent study by the U. S. Environmental Protection Agency (1) which reported that combined sewerage systems serve 29 percent of the total sewered population of the United States.

Polluting substances discharge from combined storm and sanitary sewers during wet-weather periods when the carrying capacity of the sewers is exceeded because of the excessive amounts of storm water entering them. The capacity of the interceptor sewers largely determines the maximum flow to a sewage treatment plant. Since the wet-weather flow from a combined sewer system may be as much as 50 times the normal dry-weather flow, the cost of providing treatment facilities and interceptor sewers capable of handling the entire flow from combined collection sewers is prohibitive. Economical methods for treatment of excess combined sewer flow are being sought. One significant aspect of the problem is to rapidly separate dilute slurries, suspensions, and colloidal dispersions of solids from large volumes of water in an efficient, practical and inexpensive manner.

Hercules Incorporated offered to investigate a process believed to have significant potential for the removal of suspended solids from combined sewer overflow. The process involves the use of chemical flocculants to agglomerate sewage solids about buoyant solid flotation aids which rise to the surface of the waste stream where they can be removed.

CONCEPT DESCRIPTION

In conventional sewage treatment processes, chemical coagulants and flocculants are commonly used to promote rapid solids separation. Both efficiency and degree of separation generally must be defined for each waste and treatment process because of the diversity of waste characteristics. Regardless of the application, however, the function of the chemicals is to condition the solids suspension so that the particles attach to each other. The attachment is achieved by reducing coulombic (van der Walls) forces between particles, by modifying surface properties of the solids or by adding agents which bridge the solids. In the concept studied in this program, a low-density solid flotation agent and chemicals were used to attach waste solids to the flotation agent. The resulting low-density flocs float to the surface for separation.

In the concept (Figure 1), a coagulant, a flocculant and a solid flotation aid are admixed with combined sewer overflow to effect a high-rate flotation of the suspended solids. Economic feasibility of the process clearly depends upon the chemical dosages required plus recovery and reuse of the low-density solids employed as flotation aids. The essence of this program was an assessment of the concept by laboratory investigation of the process parameters and pilot-scale investigation and evaluation under actual combined sewer overflow conditions.

Although various aspects of flocculation have been studied (2), flow effects are not well defined for flocculation/flotation processes. Therefore, to develop the concept for combined sewer overflow, the effect of flow turbulence on flocculation and flotation was studied. In these studies, an in-line flow turbulence concept was evaluated.

OBJECTIVES

The objectives of this investigation were (1) Phase I, to evaluate the flocculation/flotation properties of combined sewage overflow, (2) Phase II, to demonstrate a high-rate flocculation/flotation concept for suspended solids separation under field conditions in combined sewer systems by utilizing existing USEPA-Rexnord pilot-scale flotation equipment installed at Hawley Road, Milwaukee, Wisconsin, and (3) Phase III, to conduct an engineering analysis and evaluation with a preliminary plant design.

Specific objectives of Phase I were to evaluate selected chemical coagulants, flocculants, flotation aids and experimental techniques; to establish equipment modifications required for field testing in the USEPA-Rexnord pilot-scale facility; and to assess a nonmechanical flow-turbulence, flocculation/flotation concept as an alternative to the conventional mechanical process.

The specific objectives of Phase II were to evaluate the best combination of coagulant, flocculant, and flotation aid discovered in Phase I in the USEPA-Rexnord pilot flotation facility and to assess the feasibility of recovering and reusing flotation aids in the field.

Alteration of Scope

During the startup and early test run portions of the field test program, several significant and costly alterations in testing technique were required. These were primarily associated with the proper preparation and addition of flocculant and flotation aid. As a result, the work scope was altered to maximize the amount of field test work possible without increasing the overall contract cost. A planned Phase III, engineering evaluation and preliminary plant design, was deleted, and the field test scope was reduced from a planned 20 storm events to 5 storm events. The sixth scheduled field test was not completed because of the arrival of winter and shutdown of the test facility.

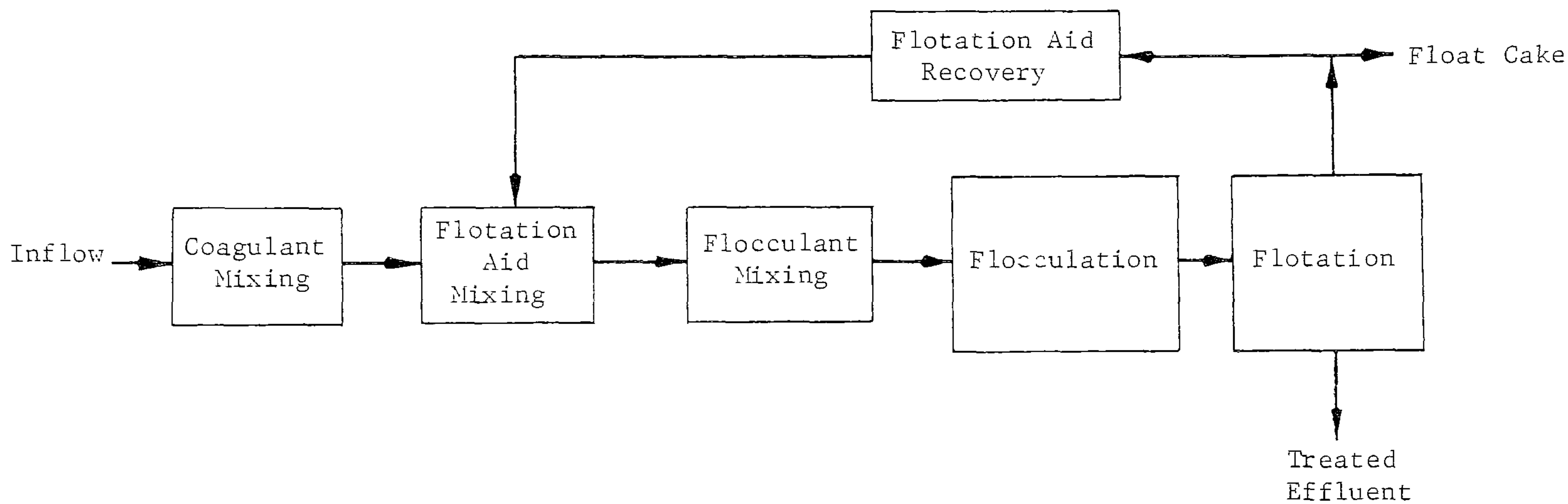

Figure 1. Concept schematic.

SECTION 4

LABORATORY TESTS

INTRODUCTION

The experimental approach, methods, laboratory-scale results and discussion are presented in this section.

APPROACH

The experimental approach consisted of conducting preliminary experiments at the Hercules/Allegany Ballistics Laboratory (ABL) facility, Cumberland, Maryland, in preparation for pilot-scale tests in the Rexnord, Inc., Envirex Division, flotation pilot plant in Milwaukee, Wisconsin. Preliminary experiments were conducted on dry-weather raw sewage at both the Hercules facility and at the nearby Bowling Green, Maryland, domestic sewage treatment plant. Actual combined sewer overflows were subsequently examined only in tests at the Rexnord facility in Milwaukee.

In this discussion, the laboratory scale tests in Maryland are described first. Experimental results and interpretation of results are then considered, following a brief review of the experimental methods. The following review of experimental methods illustrates the types of tests performed to identify flotation-aid and chemical dosages for actual storm flow testing in Milwaukee, Wisconsin.

EXPERIMENTAL METHODS

Domestic sewage and, especially, combined sewer overflows vary significantly in the nature of solids, solids concentrations and chemical characteristics. Experimental investigations were therefore required to select treatment chemicals, dosages and the sequence of addition to wastewater in a treatment system. Suspended solids, chemical oxygen demand (COD), pH, phosphate and total solids were measured to establish initial field test conditions. In addition to the above analytical tests, laboratory tests were developed to screen chemical coagulants, flocculants and flotation aids for the field tests.

The tests employed were those given in Standard Methods for the Examination of Water and Waste Water, 12 Ed. except as described below. Visual observation of the flocculation and flotation characteristics in batch tests provided the basis for laboratory-scale flow test techniques which were developed to establish the initial flow effects. These techniques are also considered in this section.

Flocculant Preparation

To prepare stock flocculant solutions for the laboratory tests, ½ percent anionic and 1 percent cationic solutions were prepared. Solution preparation consisted of stirring 0.25 or 0.50 g dry flocculant into 500 cc of distilled water with sufficient agitation to create a vortex. Dry flocculant was added slowly to the shoulder of the vortex, and the stirring was continued for 45-60 minutes or longer, when required, to effect solution of the flocculant.

Batch Flotation Tests

In the batch flotation tests, chemical coagulants, flocculants, and flotation aids were added to 500-ml sewage samples contained in 1000 ml beakers in the commercial six-station Phipps and Bird stirrer shown in Figure 2. The mixing operation consisted of (1) agitation at 60-80 rpm for 1-2 min to suspend the solids, (2) addition of 1 percent chemical coagulant solution while agitating at 5 rpm for 2 min, (3) addition of ½ or 1 percent flocculant solution while agitating at 5-10 rpm for 2 min, and (4) addition of flotation aid. Following addition of all chemicals, the mixture was either tumbled in a 500-ml graduated cylinder or stirred vigorously to effect coflocculation of solids.

The flotation rate was estimated by timing separation of the flocs and clarified liquid. The clarified phase was then sampled for chemical analysis.

Suspended Solids, COD and pH Measurements

Suspended solids were determined initially by the Gooch crucible asbestos filter method and subsequently by the Millipore filter method. In the latter tests, 100-ml samples were filtered through fiberglass filter paper (934 AH which retains solids greater than 0.45 micrometer) and dried at 103°C for one hour.

The dichromate reflux method was used for COD analyses as specified in Standard Methods for Examination of Water and Waste Water, 12 Ed. (1965).

The glass electrode method was used to measure pH. A commercial Beckman pH meter was employed.

Phosphate Determination

Essentially, the phosphate determination method used was that described in Standard Methods for Examination of Water and Waste Water, 12 Ed. (1965). The method selected was the aminonaphtholsulfonic acid method for orthophosphate by colorimetric comparison of samples with standard solutions of known phosphate content. A colorimetric with a red filter was used for the comparisons.

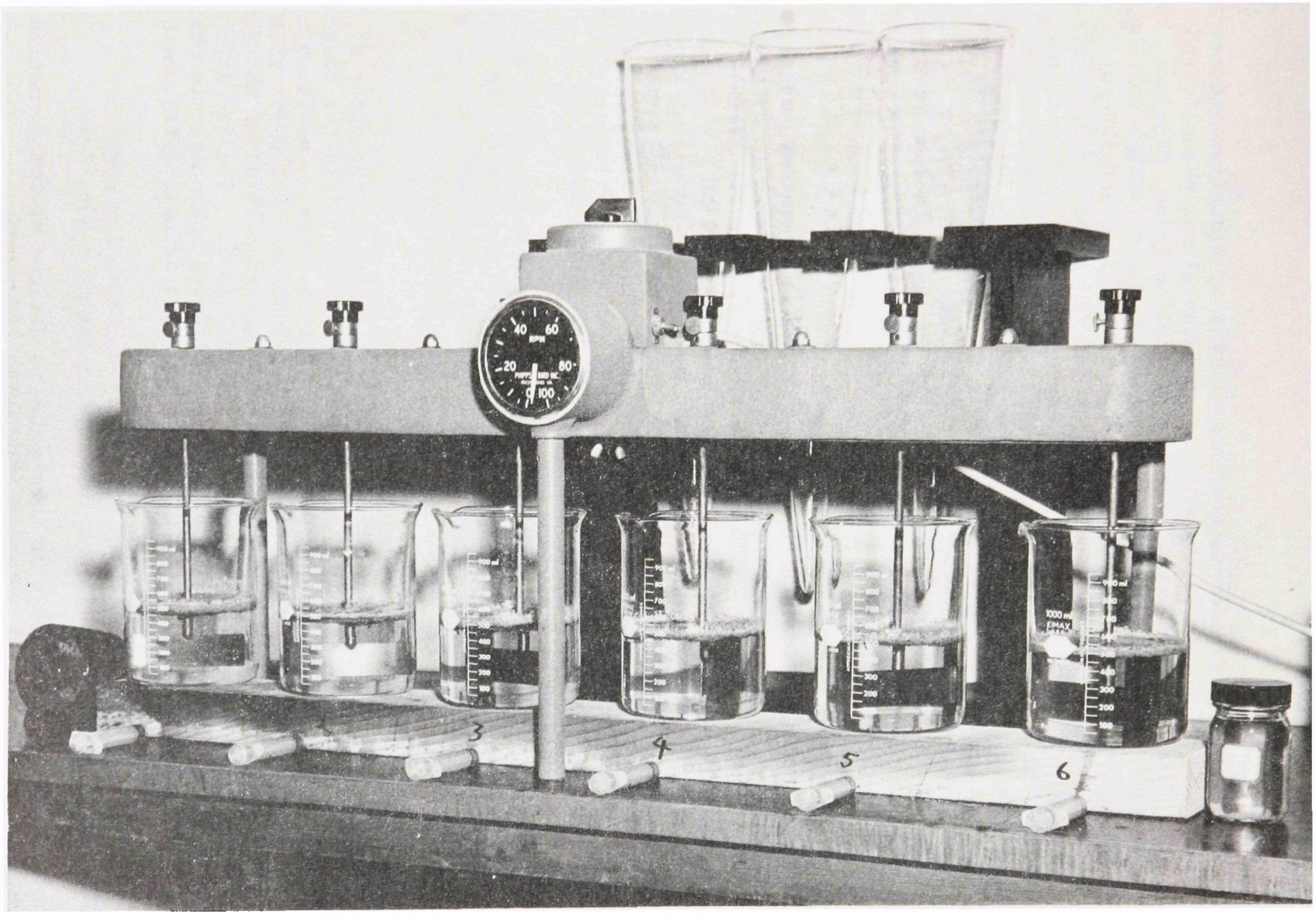

Figure 2. Photograph of Phipps and Bird mixer test.

LABORATORY SCALE RESULTS

Qualitative Batch Tests

Flotation Aid Tests

Screening studies were conducted on a variety of flotation aid candidates (Table 1). Materials of composition included glass, phenolic and polystyrene. The test medium was a sample of Bowling Green, Maryland, domestic dry-weather sewage. Candidates were accepted for further testing, or rejected, based on visual inspection of flotation rate and the coflocculation* propensity. Coagulant, flocculant and flotation-aid dose rates covered the ranges of 25-100 mg/l, 0.4-1.0 mg/l and 10-100 mg/l, respectively. Selected for further evaluation using quantitative tests were the heat-expandable polystyrene Dylex KCD-340, glass Eccospheres IG-101 and FT-102 and phenolic microballoons BJO-0840 and BJO-0930, the other materials listed in Table 1 giving markedly poorer performance. Physical property and cost data for the acceptable flotation aids are given in Table 2. Photomicrographs of these materials (Figure 3) are indicative of their geometry, size distribution, and surface textures.

Coagulant Tests

In addition to the tests with ferric chloride, comparative tests employing alum ($Al_2(SO_4)_3 \cdot 18\ H_2O$) as the coagulant were conducted. Both Dylex KCD-340 beads and glass microballoons were tested as flotation aids with a variety of flocculants. Flocculant dosages tested were 1 mg/l with alum dosages of 25 mg/l and 100 mg/l for all flocculants. Although the tests showed good visual flocculation for all chemical combinations, there was only limited visual suspended solids coflocculation on the flotation aids. Because of this difficulty, flocs settled while the relatively clean flotation aid floated. The tests with alum were therefore discontinued.

Experiments with lime as coagulant gave similar results; i.e., floc growth without significant coflocculation. Consequently, tests with lime were also discontinued and $FeCl_3$ was selected as the coagulant for all subsequent testing.

Treatment Chemical Sequencing

The batch tests included qualitative investigation of the order of coagulant and flocculant additions. Addition of flocculant before the coagulant appeared to have an adverse effect on floc formation, whereas addition of coagulant before the flocculant promoted floc formation. The order of flotation aid addition, on the contrary, did not significantly alter the flocculation or subsequent flotation rate of resultant flocs. The flotation aid sequence tests included tests with glass microballoons, phenolic microballoons and Dylex beads. All materials could be added before, after, or with the ferric chloride coagulant or flocculant.

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*Coflocculation in the context of this study is defined as the formation of flocculating sewage solids about the flotation aid.

TABLE 1. FLOTATION AID SCREENING TEST RESULTS

Flotation Aid	Results[a,b]
Dylex KCD-340[c]	Very fast flotation rate and good coflocculation.
Dylex Superfine[c]	Unacceptably slow flotation rate.
Dylex (> 400 micron)[c]	Unacceptable coflocculation.
Polystyrene PYF-2921[c]	Unacceptably slow flotation rate.
Eccospheres IG-101[d]	Fast flotation rate and good coflocculation.
Eccospheres FT-102[d]	Fast flotation rate and good coflocculation.
Bakelite BJO-0840[e]	Fast flotation rate and good coflocculation.
Bakelite BJO-0930[e]	Fast flocculation and good coflocculation.

NOTES: [a]Results were visual in nature and qualitative only, with no flotation aid rise velocities or sewage solids removal tests made. Coagulants, flocculants and flotation aid dosages were started low and progressively increased for each aid investigated.

[b]Coagulants employed were $FeCl_3$, alum and lime in doses of 25 and 100 mg/l. Flocculants were polyionic Hercules Incorporated products used in doses of 0.5 and 1.0 mg/l. Flotation aid doses were 10 and 100 mg/l.

[c]Polystyrene microballoon, product of Koppers Co., Inc., Pittsburgh, Pennsylvania.

[d]Glass microballoon, product of Emerson and Cumings, Inc., Canton, Massachusetts.

[e]Phenolic microballoon, product of Union Carbide Corp., New York, New York.

[f]Sample was domestic dry weather sewage from Bowling Green, Maryland with a suspended solids level of about 100 mg/l.

TABLE 2. FLOTATION AID PROPERTIES AND COSTS

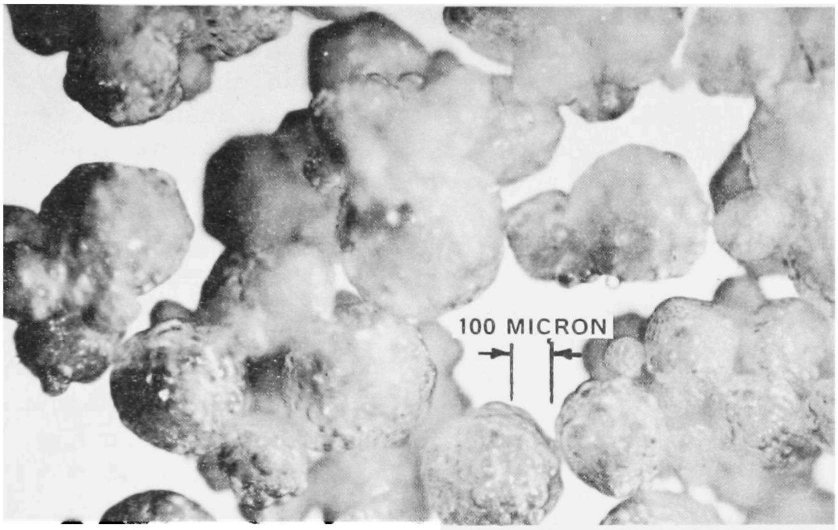
Flotation Aid	Bouyant Density gm/cc	Nominal Diameter Microns	Cost,[d] $/lb
Eccospheres (glass)[a]			
IG-101	0.34	250	0.69
FT-102	0.26	10-250	2.00
Bakelite Spheres (phenolic)[b]			
BJO-0840	0.25-0.35	10-150	0.86
BJO-0930	0.25	10-150	0.95
Dylex Beads (heat expandable polystyrene)[c]			
KCD-340	0.02	200-300	0.40

NOTES: [a]Emerson and Cumings, Inc., Canton, Massachusetts.

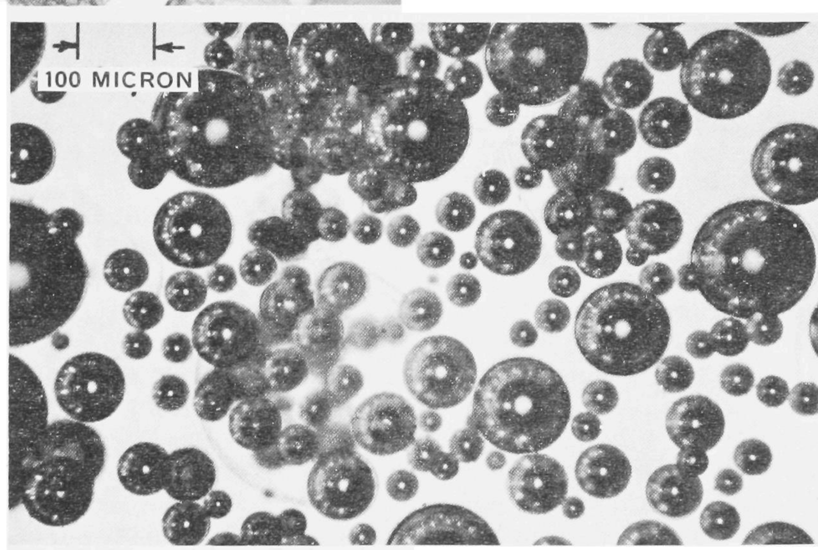
[b]Union Carbide Corp. New York, New York.

[c]Koppers Co., Inc., Pittsburgh, Pennsylvania.

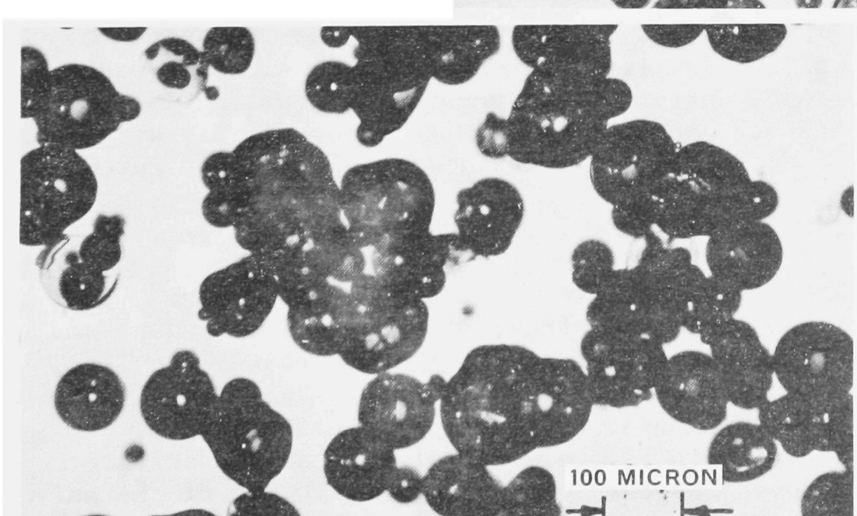
[d]Prices based on 100 ton quantities.



Dylex KCD 340 Beads (50X)
Lot 296.01



Glass Microballoons (100X)
Lot IG 101



Bakelite Microballoons
(100X)
Lot BJO 0930

Figure 3. Photomicrographs of flotation aids.

Mixing Condition Effects

Qualitative tests were also conducted to assess the effects of coagulant and flocculant mixing times with evaluation of effects attributable to changes in sample properties such as pH, suspended solids and chemical oxygen demand. These experiments were qualitative rather than quantitative because observation of floc growth revealed that visual appearance of floc was prerequisite for coflocculation of sewage solids and flotation aid. Initial vigorous agitation prevented floc growth whereas gentle agitation promoted floc growth without affecting the coflocculation of floc and flotation aid. Accordingly, it was necessary to gently agitate the system to promote floc growth and then increase the agitation (or shaking) to effect coflocculation of sewage solids and solid flotation aid. Further, these tests suggested (qualitatively) that the coagulation/flocculation operation is a kinetic process affected by both the coagulant and flocculant concentrations; that is, higher chemical concentrations enhanced the visual coagulation and flocculation rates. Since it was not the purpose of this study to define such kinetic effects in a simulated system, mixing time and action which seemed adequate for the desired coflocculation were selected for subsequent testing.

Quantitative Batch Tests

Flotation Aid Tests

A series of tests were conducted to determine the quantitative effects on suspended solids removal of flotation aid dose, flocculant type, coagulant and flocculant dosages and raw sewage screening. All tests employed batch samples less than 8 hours old to minimize aging effects.

Table 3 reports the suspended solids removal efficiencies of the various candidate flotation aids using 100 mg/l of $FeCl_3$ and 1 mg/l of Hercofloc 810, a cationic flocculant. Results were quite variable, with removal percentages ranging from 0 to 100 percent suspended solids. Dylex polystyrene and Eccosphere glass flotation aids performed best with suspended solid removals ranging from 52 to 100 percent. Phenolic/Bakelite flotation aids resulted in markedly poorer performance. The low suspended solids content, 8-24 mg/l, of the Bowling Green domestic dry-weather sanitary sewage was considered to be unrepresentative of highly solids laden storm overflow material. Its use was discontinued in favor of grab samples from the Frostburg, Maryland, municipal treatment plant influent for further testing.

Flocculants

A broad range of commercially available flocculants was screened using Koppers Co. polystyrene KCD-340 flotation aid, 100 mg/l $FeCl_3$ coagulant and ordinary dry-weather sanitary sewage influent from the Frostburg, Maryland, sewage treatment plant. Flocculant dosages were 1 mg/l in all cases. Results are presented in Table 4. In these tests, removal efficiencies were similar for many cationic and anionic flocculants but some of the anionic candidates clearly showed reduced suspended solids removal. Two of the anionic flocculants showed essentially no suspended solids removal (Calgon ST269 and Nalco 2066). On the basis of these results, the cationic flocculants, as a group, were better than the anionic flocculants. However,

TABLE 3. RESULTS OF QUANTITATIVE PRELIMINARY LABORATORY FLOTATION AND TESTS[a]

Flotation Aid	Dosage mg/l	S/F[b]	Raw Sewage[c] SS mg/l	Treated Sewage SS mg/l	Removal %
	10	2/1	21	9	57
	10	1/1	11	0	100
Dylex (KCD-340)	20	1/1	21	10	52
	100	1/5	21	6	71
	100	1/4	24	7	71
Eccospheres (IG-101)	10	1/1	21	1	95
	100	1/10	8	3	62
Bakelite Spheres (BJO-0930)	10	1/1	8	8	0
	100	1/10	8	4	50

NOTES: [a]Tested with 100 mg/l $FeCl_3$ and 1 mg/l Hercofloc 810.

[b]S/F - Suspended Solids/Flotation Aid Ratio.

[c]Bowling Green Waste Treatment Plant dry-weather domestic sanitary influent.

TABLE 4. FLOCCULANT SCREENING TESTS[a,b]

Flocculant	Post Treatment Suspended Solids mg/l	Percent Removal	Post Treatment COD mg/l	Removal %
Cationic				
Hercofloc 810[c]	34	97	224	80
Dow 1629.1[d]	77	93	291	74
Nalco 610[e]	38	97	-	-
Betz 1260[f]	58	95	267	76
Anionic				
Hercofloc 816[c]	491	57		
Hercofloc 822[c]	387	66		
Dow A-23[d]	54	95		
Calgon ST269[g]	1205	0		
Nalco 2066[e]	1164	0		
Hercofloc X8-1[c]	56	95	300	73
Hercofloc X8-2[g]	72	94	333	70
Hercofloc X8-3[c]	45	96	275	75
Hercofloc X8-4[c]	30	98	262	76

NOTES: [a]All samples treated with 100 mg/l $FeCl_3$, 100 mg/l Koppers Co. Dylex KCD-340 flotation aid and 1 mg/l flocculant.

[b]Test medium was a grab sample of dry-weather ordinary domestic sewage taken from the influent lines of the Frostburg, Maryland, municipal sewage treatment plant. The suspended solids level was 1134 mg/l and COD was 1104 mg/l.

[c]Product of Hercules Incorporated, Wilmington, Delaware.

[d]Product of Dow Chemical Co., Midland, Michigan.

[e]Product of Nalco Chemical Co., Oak Brook, Illinois.

[f]Product of Betz Laboratories, Trevose, Pennsylvania.

[g]Product of Calgon Corp., Pittsburgh, Pennsylvania.

because of the inconsistency in the results, additional tests were conducted with the apparently best candidates. In these tests, reported in Tables 5 and 6, all three candidate flotation aid materials were utilized, and both high and low coagulant and flocculant dosages were investigated. Comparison of Table 5 with Table 6 shows (1) that the lower chemical dosages were as effective as the higher dosages and (2) that the cationic flocculants were generally better than the anionic flocculants, particularly for the Dylex bead flotation system.

Purifloc C-31, a cationic flocculant, has been employed successfully in dissolved-air flotation tests to promote solids removal efficiency so this flocculant was also tested here. Purifloc C-31 and Nalco 607-C were substituted for Hercofloc 810 during one phase of the bench Dylex flotation tests on Milwaukee combined sewage to assess the sensitivity of the Milwaukee sewage to coflocculation with different flocculants. Results were visual qualitative only and are shown in Table 7. In all cases, an excellent floc was fomed but no coflocculation occurred with the Nalco 607-C or the Purifloc C-31 while good coflocculation occurred with the Hercofloc at 1 mg/l. The floc was less lightly coflocculated to the flotation aid for this sewage than had been the case with the dry-weather Frostburg, Maryland, sewage.

Based on these initial laboratory tests, Hercofloc 810 was selected as the field test flocculant.

Screening

The effects of screening the raw sewage influent were briefly investigated using Frostburg, Maryland, dry-weather domestic sewage. Tests representative of both high and low suspended solids concentrations were conducted. Results, reported in Table 8, indicate that removal efficiency by the flocculation/flotation method is relatively insensitive to screening.

Batch Test Flotation Aid Recovery Tests

From both sludge handling and chemical cost viewpoints, recovery of flotation aid is desirable and probably essential. Preliminary qualitative tests showed that flotation aid can be recovered by high-shear agitation of the float cake. In these tests, a commercial Waring blender was used to promote the separation. Flotation aid separated from the coflocculates sewage solids and floated whereas most of the sewage solids settled.

Float cake samples for the Waring blender experiments were prepared by treating 500 cc of Bowling Green, Maryland, dry-weather municipal waste with (0.01 gm) 20 mg/l Dylex KCD-340 flotation aid, 100 mg/l $FeCl_3$ (0.05 gm) and 1 mg/l Hercofloc 810 flocculant. The "recovered" flotation aid plus residual solids were dried to a constant weight of 0.017 gm which confirmed that there were residual solids which did not separate from the flotation aid. The settled solids were also filtered and dried. However, a material balance on these small sample tests could not be achieved so tests to define recovery efficiency were deferred until larger open tank flow test samples could be obtained.

TABLE 5. FLOCCULANT DOSAGE TESTS (LOW CHEMICAL DOSAGES)[a, b]

	Suspended Solids in Effluent					
	Dylex KCD-340		Glass IG-101		Phenolic BJO-0930	
Flocculant	SS mg/l	Removal %	SS mg/l	Removal %	SS mg/l	Removal %
Cationic						
Hercofloc 810	25	91	41	85	29	89
Nalco 610	37	86	49	82	42	85
Betz 1260	38	86	58	79	52	81
Anionic						
Dow A23	49	82	228	16	80	71
Hercoflox X8-4	41	85	71	74	65	76
Hercofloc 822	-	Neg.	-	Neg.	101	63

NOTES: [a]All samples tested with 100 mg/l flotation aid, 25 mg/l $FeCl_3$ and 0.5 mg/l flocculant.

[b]Treatment medium was a grab sample of dry-weather ordinary sanitary sewage from the Frostburg, Maryland, municipal treatment plant with a raw sewage suspended solids level of 271 mg/l.

TABLE 6. FLOCCULANT DOSAGE TESTS (HIGH CHEMICAL DOSAGES)[a,b]

	Suspended Solids in Effluent					
	Dylex KCD-340		Eccospheres IG-101		Bakelite BJO-0930	
Flocculant	SS mg/l	Removal %	SS mg/l	Removal %	SS mg/l	Removal %
<u>Cationic</u>						
Hercofloc 810	3	87	8	67	4	83
Nalco 610	5	79	6	75	5	79
Betz 1260	5	79	8	67	8	67
<u>Anionic</u>						
Dow A23	No Cofloccula-tion		3	87	3	87
Hercofloc X8-4	"	"	2	92	5	79
Hercofloc 822	"	"	0	100	5	79

NOTES: [a]All samples tested with 100 mg/l flotation aid, 100 mg/l $FeCl_3$ and 1.0 mg/l flocculant.

[b]Treatment medium was a grab sample of dry weather ordinary sanitary sewage from the Frostburg, Maryland, municipal treatment plant with a raw sewage suspended solids level of 241 mg/l.

TABLE 7. LABORATORY BENCH SCALE FLOCCULATION/ FLOTATION TESTS ON MILWAUKEE, WISCONSIN, COMBINED SEWAGE OVERFLOW[a]

Flocculant	Flocculant Concentration (mg/l)	Results
Purifloc C-31	1.0	Good[b] flocculation - no co-flocculation
	2.0	Good flocculation - no co-flocculation
	4.0	Excellent flocculation - no coflocculation
Nalco 607-C	4.0	Good flocculation - no co-flocculation
	6.0	Good flocculation - no co-flocculation
Hercofloc 810	0.5	Good flocculation - fair co-flocculation
	1.0	Excellent flocculation - good coflocculation[c]
	2.0	Excellent flocculation - good coflocculation

NOTES: [a]Tests conducted on a raw Milwaukee, Wisconsin, combined sewer overflow sample collected on 6/8/71 and stored under refrigeration until testing on 7/8/71. $FeCl_3$ was added to each test sample (40 mg/l) and agitated before addition of the flocculant and Dylex flotation aid (100 mg/l).

[b]"Good flocculation" in the context of this investigation means that suspended solids formed quickly into large, tightly knitted flocs capable of rapid settlement.

[c]"Good coflocculation" in the context of this investigation means that flocculation occurred about the flotation aid as a nucleation site and was sufficiently tightly bound to the aid to rise to the liquid surface with it while the liquid was being vigorously agitated.

TABLE 8. EFFECTS OF SCREENING LABORATORY BATCH TREATMENT TESTS[a]

High Suspended Solids Test[b]

Dylex KCD-340 Dosage (mg/l)	Screened Sewage[c] SS (mg/l)	Screened Sewage[c] Removal (%)	Raw Sewage SS (mg/l)	Raw Sewage Removal (%)
100	52	97	133	94
50	83	95	116	95
10	167	89	74	97
	Avg.	94	Avg.	95

Low Suspended Solids Test[d]

Dylex KCD-340 Dosage (mg/l)	Screened Sewage[c] SS (mg/l)	Screened Sewage[c] Removal (%)	Raw Sewage SS (mg/l)	Raw Sewage Removal (%)
100	40	72	43	80
50	33	77	39	82
10	58	60	45	79
	Avg.	70	Avg.	80

NOTES: [a]Chemical dosages were Hercofloc 810 at 0.5 mg/l and $FeCl_3$ at 25 mg/l.

[b]Dry-weather ordinary domestic raw sewage from the Frostburg, Maryland, treatment plant with an unscreened raw sewage suspended solids level of 2345 mg/l and a screened suspended solids level of 1584 mg/l.

[c]Screened sewage was passed through a U.S. Standard No. 50 screen (297 micron openings).

[d]Dry-weather ordinary domestic raw sewage from the Frostburg, Maryland, treatment plant with an unscreened raw sewage suspended solids sewage level of 218 mg/l and a screened suspended solids level of 145 mg/l.

Open Tank Tests

A series of laboratory-scale open tank flow tests were performed to evaluate flow effects on the mechanical flocculation/flotation process and to relate laboratory batch test results to field condition.

Test Apparatus

The open tank laboratory test apparatus is described by a schematic, (Figure 4) and photographs (Figures 5 and 6).

Experimental Plan

The experimental plan consisted of seeking a chemical dosage optimization by varying the flotation retention (by varying the flow rate through the apparatus) from 2.5 to 10 min., the $FeCl_3$, coagulant dosage from 0 to 125 mg/l, and the suspended solids influent loading. The baseline flotation aid, Dylex KCD-340, was slated for all tests except a check using one other aid. Flotation aid dosage was 100 mg/l for all tests. The effects of screening versus nonscreening were to be evaluated.

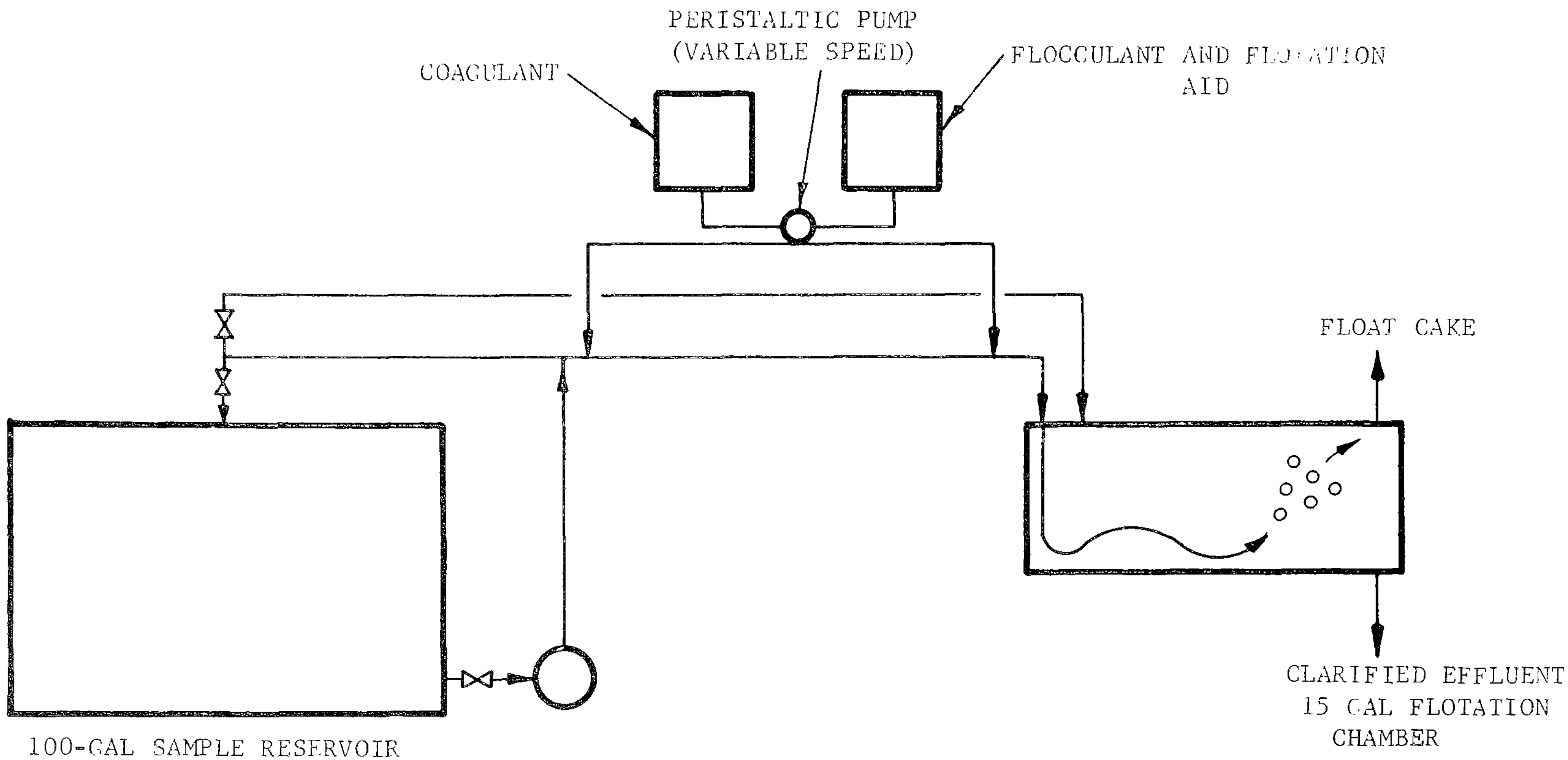
Test Results

Preliminary laboratory-scale open tank flow tests of the flocculation/flotation concept and laboratory apparatus were conducted on samples of dry-weather ordinary domestic sewage from the influent to the sewage treatment plant for Hercules Incorporated/Allegany Ballistics Laboratory (ABL) located near Cumberland, Maryland, and from the influent line for the Bowling Green, Maryland, municipal treatment facility. The unit was tested first at Allegany Ballistics Laboratory (ABL) in 1-hour tests of about 50-gallon sewage samples. Table 9 gives the preliminary flow test results for the ABL experiments. Excellent removal efficiencies (equal to or greater than 95 percent) were obtained in these short tests.

Results of the tests on Bowling Green sewage (Table 10) were less successful with suspended solids removals of 39-60 percent. Ranges of $FeCl_3$ coagulant dosages (0-50 mg/l) and retention times (0.1 to 0.4 min) were tested on the low suspended solids laden samples (91 to 183 mg/SS). In Tests 4-8, an estimated 25 percent of the inflow was diverted and treated with the chemicals before combining this side stream/fraction with the balance of the inflow to simulate anticipated operations at the USEPA-Rexnord Milwaukee pilot facility installation. The split flow operation did not markedly affect suspended solids removal (based on comparison of Test 3 with Tests 6 and 7).

Representative flow proportioning was complicated by rapid changes in the character of the flow during the tests. Some inflow samples contained large amounts of grit and particulate solids, whereas other samples were relatively clean or contained significantly more fibrous material. The reported results are for composite samples obtained by mixing discrete samples taken about every 15 minutes during a flow test and, therefore, may not precisely reflect changes in flow or waste characteristics during a test.

A series of open tank flow tests were conducted on line at the Bowling Green, Maryland, sewage plant, including two tests on combined sewer overflow. The



OPERATING CHARACTERISTICS

FLOW RATE	1-3 GPM
SURFACE LOADING	0.5-1.5 GPM/FT^2
HORIZONTAL VELOCITY	0.1-0.4 FPM
RISE RATE	$\sim$ 5 FPM
RETENTION	1-10 MIN

Figure 4. Laboratory open tank flow test apparatus.

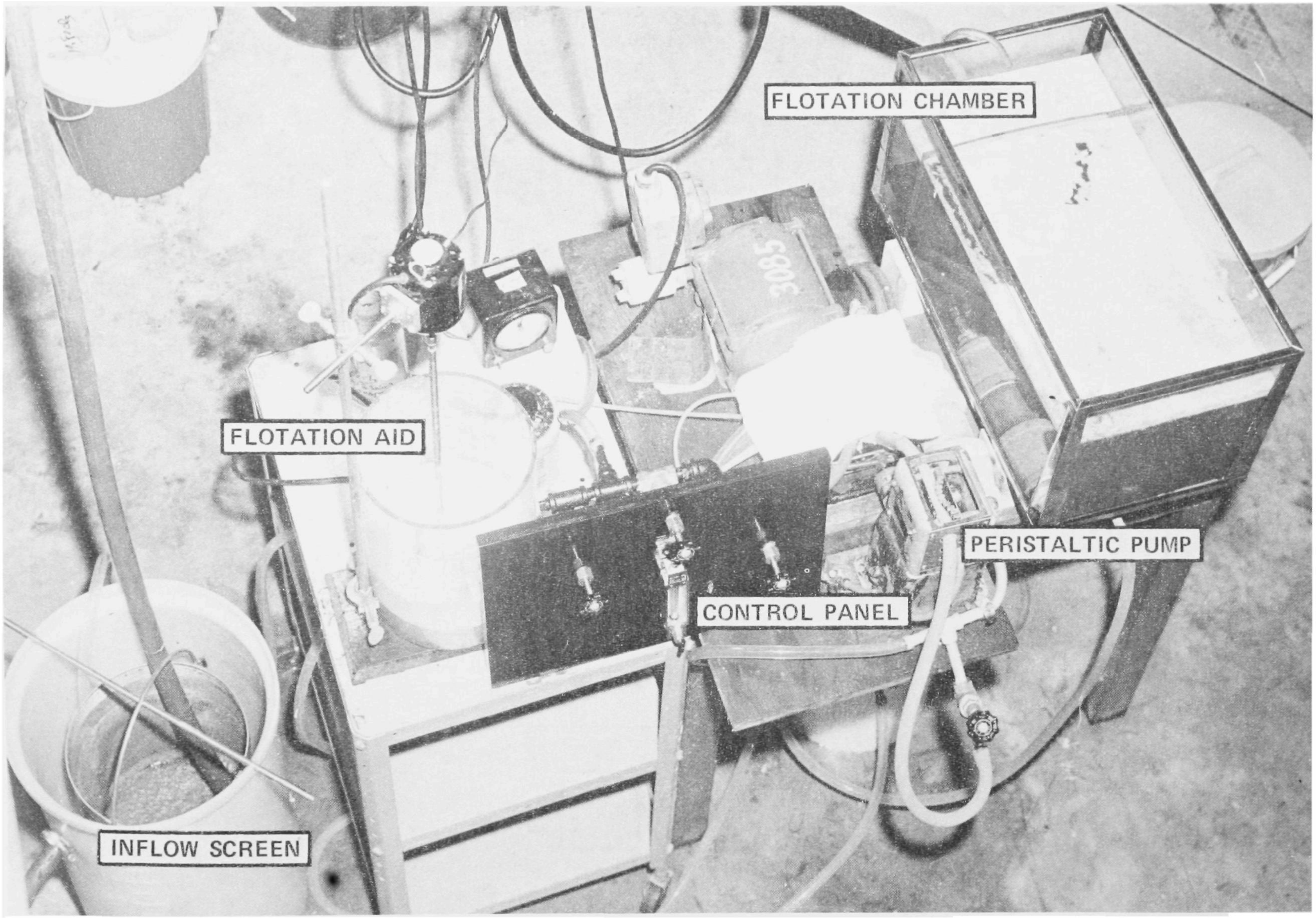


Figure 5. Photograph of open tank flow test apparatus.

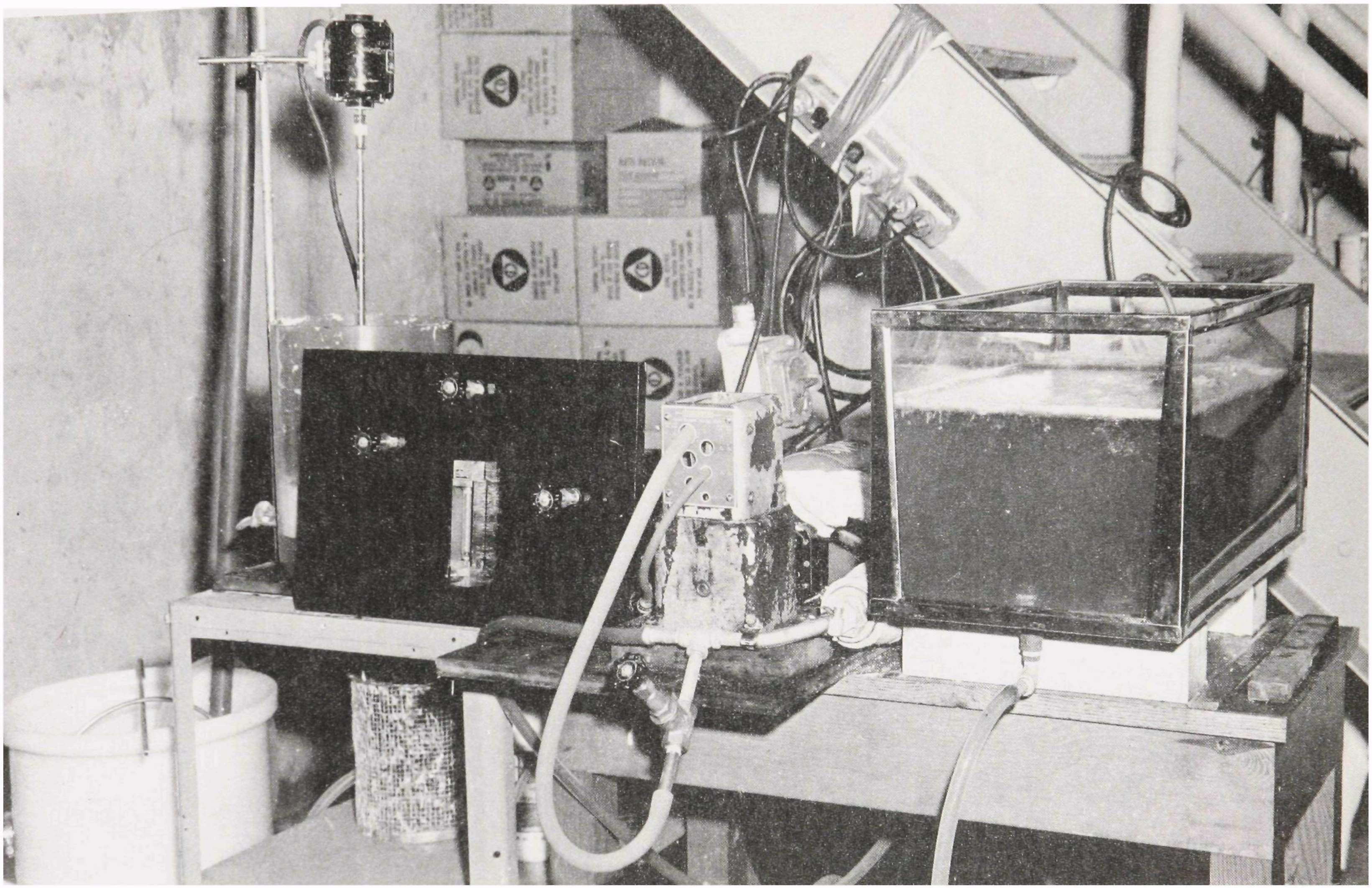


Figure 6. Photograph of open tank flow test apparatus.

TABLE 9. PRELIMINARY OPEN TANK FLOW TESTS, ALLEGANY BALLISTICS LABORATORY SEWAGE[a,b]

Test No.	$FeCl_3$ (mg/l)	Flotation Retention[c] (min)	Suspended Solids Raw (mg/l)	Suspended Solids Treated (mg/l)	Suspended Solids Removal (%)
1	125	5	378	18	95
2	45	10	378	12	97
3	50	5	1170	53	95
4	50	10	1170	55	95

NOTES: [a]Test medium was grab samples of dry weather ordinary sanitary sewage taken from the influent line of the treatment plant for Hercules Incorporated/Allegany Ballistics Laboratory, near Cumberland, Maryland.

[b]Dosages were 100 mg/l of Dylex KCD-340 flotation aids and 1 mg/l of Hercofloc 810 flocculant. Flow rate was 1 gal/min.

[c]Flotation retention is defined as average residence time after addition of flocculant.

TABLE 10. PRELIMINARY OPEN TANK FLOW TESTS, BOWLING GREEN, MARYLAND, MUNICIPAL SEWAGE[a,b]

Test No.	Flow (gpm)	Ferric Chloride Dosage (mg/1)	Ferric Chloride Retention[c] (min)	Flotation Retention[d] (min)	Suspended Solids Raw (mg/1)	Suspended Solids Treated (mg/1)	Suspended Solids Removal (%)
1	1	25	0.2	5	91	55	40
2	1	50	0.2	5	155	61	60
3	2	25	0.1	5	155	75	52
4	2 (split)	25	0.4	2.5	172	105	39
5	2 (split)	50	0.4	2.5	172	79	54
6	2 (split)	25	0.4	5	123	72	41
7	2 (split)	25	0.4	5	183	100	45
8	2 (split)	0	-	5	124	83	33

NOTES: [a]Test medium was grab samples of dry weather ordinary domestic raw sewage from the Bowling Green, Maryland, municipal treatment facility.

[b]Dosages were 100 mg/1 of Dylex KCD-340 flotation aids and 1 mg/1 of Hercofloc 810.

[c]$FeCl_3$ retention is defined as average retention time before flocculant addition.

[d]Flotation retention is defined as average retention time after flocculant addition.

results of the on-line, dry-weather flow are summarized in Table 11. In these tests, removal efficiencies varied between 0 and 88 percent. Lower suspended solids removals were obtained in tests without coagulant. Selected tests (Tests 4-8) were conducted with an estimated 25 percent of the inflow treated with chemicals before combining this "slip stream" fraction with the balance of the inflow to simulate the Milwaukee pilot facility installation. The split flow operation did not adversely affect suspended solids removal.

The results obtained suggest that flow effects are significant. Although a coagulant was generally required to effect coflocculation of sewage solids with the flotation aids in the batch tests, significant amounts of suspended solids were removed with and without ferric chloride as coagulant in the flow tests.

Chemical dosages appeared to affect suspended solids removal efficiency. When the flocculant dosage was reduced to less than 1 ppm (Tests 22 and 23), solids removal decreased. In Test 21, with 4 ppm flocculant, suspended solids removal improved slightly. In Test 26, solids removal increased to 76 percent with relatively large dosages of both coagulant (100 mg/l) and flocculant (7 mg/l). In Test 27, flocculant dosage was halved to 2 mg/l with the same coagulant dosage and solids removal decreased to 65 percent. These results indicate that relatively large chemical dosages, particularly coagulant dosages, are probably required to achieve high removal efficiencies for municipal sewage.

The results of two tests conducted on combined sewer overflow are summarized in Table 12. Raw sewage was screened through a U.S. No. 50 screen in both tests. Suspended solids removal was 79 percent in the first test using Bakelite/phenolic microballoons as the flotation aid. Suspended solids removal on the second test decreased 28 percent. Dylex KCD-340 polystyrene flotation aids were used for this test. The reduced suspended solids removal efficiency is attributed in part to the change in influent solids rather than to the flotation aid replacement. These results are interpreted as suggesting that the initial flush is more easily flocculated and more easily treated than the subsequent flow because of higher suspended solid concentrations.

Reproducibility of the Test Results

Reproducibility of the flow test results was determined (Tests 17-20, Table 13) to provide a basis for statistical interpretation of results. Analysis of the data reproducibility permits interpretation of process variable relationships in terms of statistical significance. Significance of indicated effects was determined by comparing the estimated variance of grouped data with the estimated experimental variance via the statistical "F" tests (3-4). These data show a variance of 260 (standard deviation = 16.1).

Another useful statistical parameter for characterizing test reproducibility is the statistical coefficient of variation (C_V = standard deviation/mean x 100). For these experiments, C_V is about 11 percent which means that

TABLE 11. OPEN TANK FLOW TEST RESULTS ON LINE AT BOWLING GREEN, MARYLAND, MUNICIPAL TREATMENT PLANT

Test No.	Flotation Aid	Hercofloc 810 Dosage (mg/1)	Ferric Chloride Dosage (mg/1)	Suspended Solids Raw (mg/1)	Screened (mg/1)	Removal (%)	Treated (mg/1)	Removal (%)
16	Dylex,KCD-340	1	50	-	295	-	36	88
17	Dylex,KCD-340	1	0	-	295	-	123	58
18	Dylex,KCD-340	1	0	-	295	-	152	48
19	Dylex,KCD-340	1	0	-	295	-	159	46
20	Dylex,KCD-340	1	0	-	295	-	134	55
21	Dylex,KCD-340	4	0	-	295	-	112	62
25	Dylex,KCD-340	1	25	-	199	-	146	27
26	Dylex,KCD-340	4	100	-	199	-	48	76
27	Dylex,KCD-340	2	100	-	199	-	70	65
11	Phenolic,0930	1	25	-	123	-	90	29
12	Phenolic,0930	1	25	-	259	-	215	17
13	Phenolic,0930	1	50	-	212	-	151	29
14	Phenolic,0930	1	0	-	227	-	153	33
22	Phenolic,0930	0.5	0	-	98	-	86	10
23	Phenolic,0930	0.25	0	-	98	-	98	0

NOTES: [a]Test medium was in-line flow of dry weather, ordinary domestic sewage from the Bowling Green, Maryland, municipal treatment plant.

[b]Flotation aid dosage was 100 mg/1.

[c]Flotation tank retention time was 5 min.

[d]Hydraulic loading was 1 gpm/ft^2.

TABLE 12. OPEN TANK FLOW TEST RESULTS, BOWLING GREEN, MARYLAND, STORM OVERFLOW

Test No.	Flotation Aid	Hercofloc 810 Dosage (mg/l)	Ferric Chloride Dosage (mg/l)	Suspended Solids Raw (mg/l)	Suspended Solids Screened (mg/l)	Suspended Solids Removal (%)	Suspended Solids Treated (mg/l)	Suspended Solids Removal (%)
1	Phenolic, 0930	1	25	282	177	37	37	79
2	Dylex, KCD-340	1	25	112	79	29	57	28

NOTES: [a]Flotation aid dosage was 100 mg/l.

[b]Flotation tank retention time was 5 min.

[c]Hydraulic loading was 1 gpm/ft^2.

TABLE 13. FLOW TEST REPRODUCIBILITY

Test No.	Effluent Suspended Solids 1	2	Avg.
17	120	125	123
18	154	149	152
19	168	149	159
20	135	133	134
		Avg.	142

[a]Composite influent sample for all four tests contained 295 mg/l suspended solids.

[b]Suspended solids tests were run in duplicate.

[c]Experimental conditions were 100 mg/l Dylex KCD-340 flotation aid, 1 mg/l Hercofloc 810 flocculant and no coagulant. Flow was 1 gpm with flotation chamber retention of 5 min.

the experimental values presented are reproducible within about 11 percent.

Float Cake Tests

Float cake from the Bowling Green storm overflow tests was characterized. Results of the float cake tests are given in Table 14. The samples tested were skimmed from the flotation tank, weighed, filtered and dried. Float cake and filter cake densities were similar for both Dylex and phenolic flotation-aid systems, but the former dewatered in less than one half the time.

In-Line Tests

In the flow-turbulence concept for in-line concentration of suspended solids sewage, flocculation and flotation unit operations are performed in a pipeline by flow turbulence. As in the mechanical process, the concentrated flow is then passed to the treatment plant while the clarified effluent flows to the river.

Test Apparatus

Two flow-turbulence modules were built and tested. Essentially, investigation of the concept consisted of operating the units with various flow conditions and chemical treatment combinations. The flow-turbulence concentrator design first tested is shown in Figure 7. The unit, made of cellulose acetate, was designed to permit visual observation of flocculation and flotation at various levels of flow turbulence. The unit was designed to allow both laminar and turbulent flow conditions to be investigated. The second flow turbulence module (Figure 8) was designed with a smooth surface and tapered chamber to promote float cake flow and separation. Also, the module design was selected on the basis of geometric similitude to keep similar Reynolds numbers for use in scaling the laboratory module from 30 gpm to a reasonable demonstration scale module (0.5 MGD capacity). In scale-up operations of this nature, it is of course desirable to maintain complete geometric similarity but this is not possible here since retention time may also be important. For a fixed liquid flow system (i.e., constant liquid density and viscosity), Reynolds number varies inversely with the module diameter and residence time varies directly with the module volume. In a truncated conical module, volume varies with length and diameter squared; volume = $\pi/12\ (D_1^2 + D_1D_2 + D_2^2)$. Therefore, as a diameter is increased to maintain the Reynolds number in higher capacity modules, the length similitude cannot be maintained (Figure 9).

Test Results and Discussion

The results of the in-line flow-turbulence tests are summarized in Tables 15, 16, and 17.

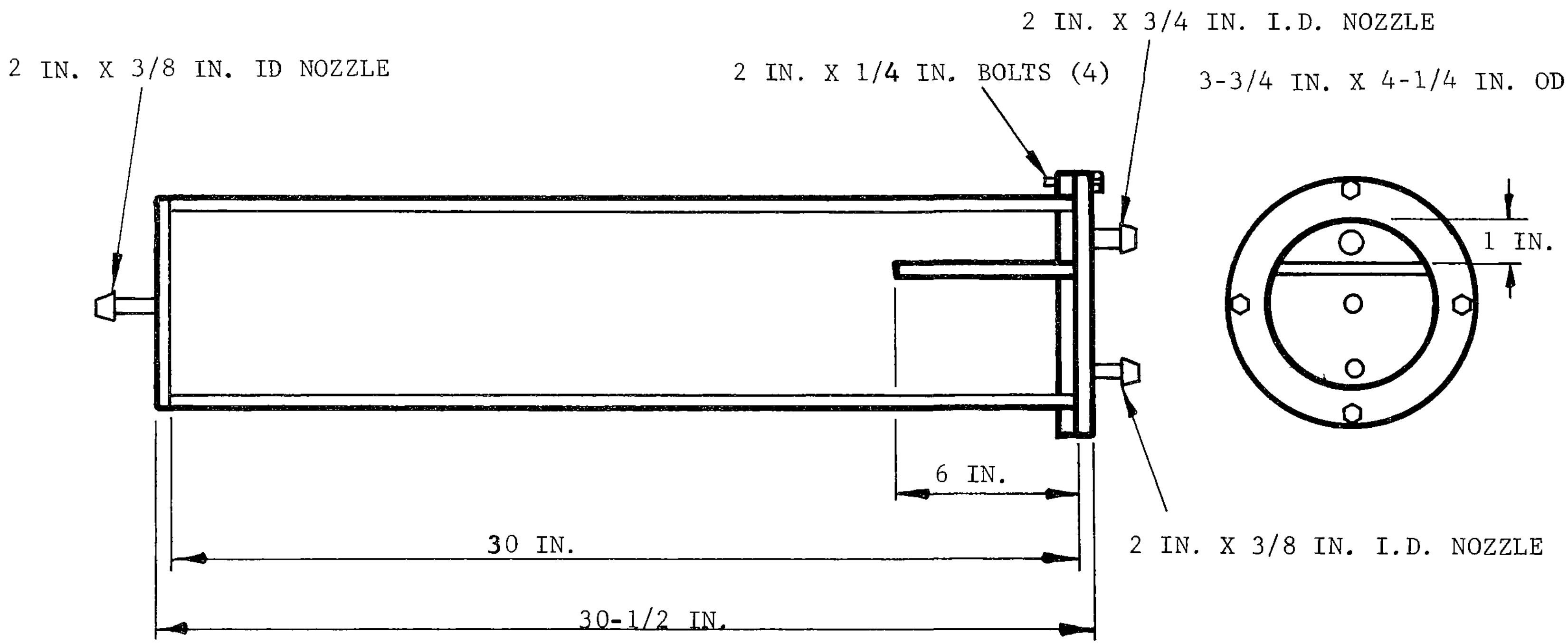
Table 15 shows that both solids and phosphate removal efficiencies improve as the coagulant dosage increases. From a practical standpoint, optimum removals were obtained with the 100 mg/l ferric chloride dosage. About 90 percent removal of suspended solids and 70 percent phosphate removal were obtained at this dosage level. As expected, effluent pH

TABLE 14. FLOAT CAKE TEST RESULTS

Parameter	Value	
Flotation Aid	Dylex KCD-340	Bakelite 0930
Dosage, mg/l	100	100
Coagulant	$FeCl_3$	$FeCl_3$
Test Flow, gpm	2	2
Float Cake Bulk Density, gm/cc	0.9	0.9
Float Cake Moisture (%)	95	96
Filtration Time,[a] min.	2	5
Filter Cake Bulk Density,[b] gm/cc	0.7	0.8
Filter Cake Moisture (%)	86	87

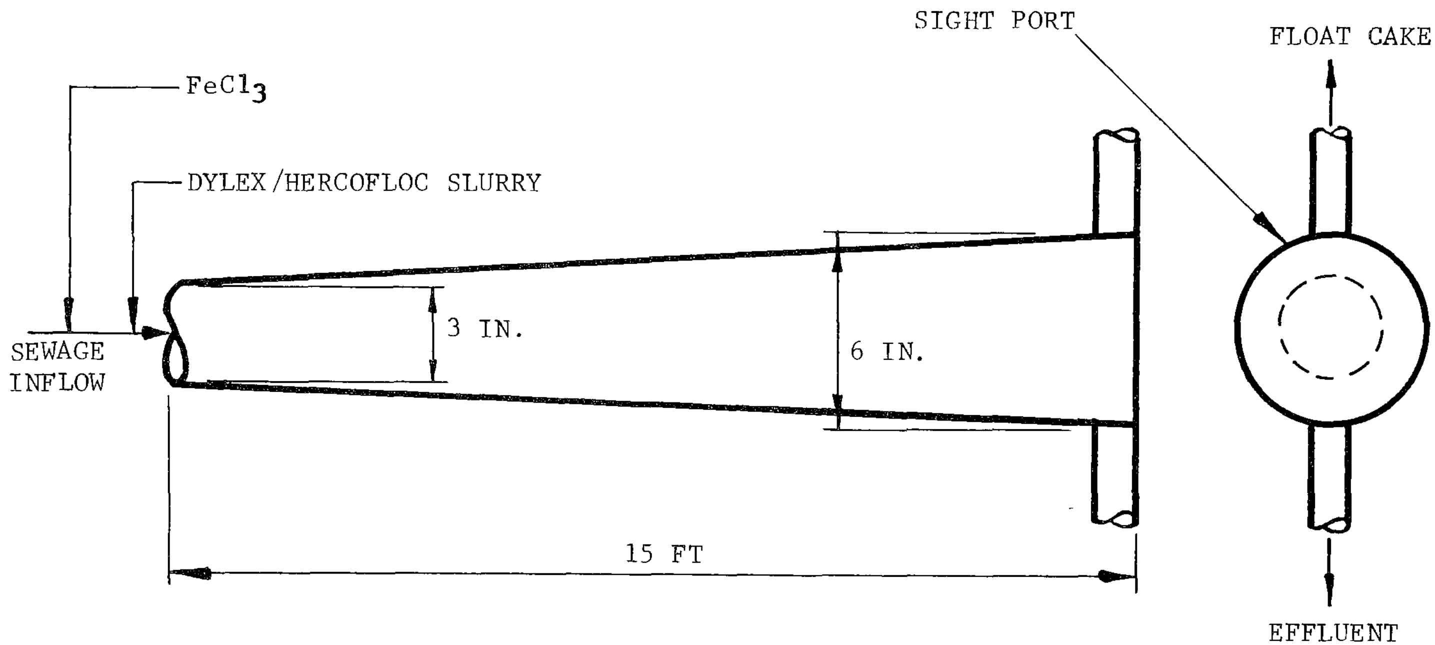
NOTES: [a]Filtration time to dewater 100 cc float cake through a Watman No. 5 filter paper in a standard Millipore suspended solids apparatus.

[b]Difficult measurement with small sample, tests repeated once and averaged.



NOTE: MATERIAL - 1/4 IN. THICK CELLULOSE ACETATE.

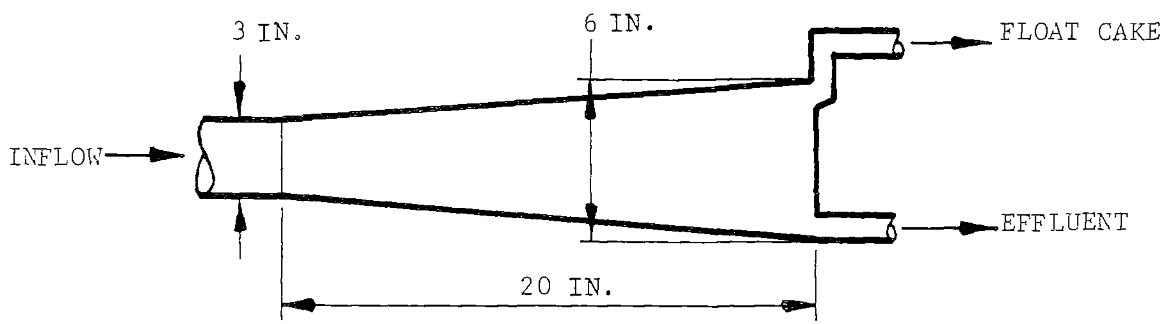
Figure 7. Sketch of first in-line concentrations.



OPERATING CHARACTERISTICS

MAXIMUM FLOW (GPM)	20
REYNOLDS NUMBER	20,000 → 10,400
MAXIMUM VELOCITY (FPM)	54

Figure 8. Sketch of second in-line test module.



OPERATING CHARACTERISTICS

	LABORATORY MODULE	DEMONSTRATION MODULE
FLOW (GPM)	30	350 (0.5 MGD)
REYNOLDS NO. (MIN.)	15,000	15,000
MAJOR DIAMETER	6 IN.	6 FT
MINOR DIAMETER	3 IN.	3 FT
LENGTH (FT)	15	20
RETENTION (MIN.)	0.4	7

Figure 9. In-line model design.

TABLE 15. RESULTS OF IN-LINE TESTS - FIRST TEST MODULE

Test No.	Ferric Chloride Dosage (mg/l)	Suspended Solids		Phosphate Removal		
		Effluent	Removal %	mg/l	%	pH
1	0	164	41	14	7	7.3
2	25	275	-	9	40	7.0
3	50	179	36	10	33	6.8
4	100	33	88	5	67	6.7
5	100	29	90	4	73	6.5
6	200	23	92	3	80	6.3
7	100	256	8	6	60	7.1

NOTES: [a]Flow = 1 gpm, Re = 800, V = 1.75 fpm, Retention = 17 min.

[b]Flocculant - Hercofloc 810 at 1 mg/l.

[c]Flotation aid - Dylex KCD-340 at 100 mg/l.

[d]Raw sewage properties: SS = 552 mg/l, Phosphate = 19 mg/l, ph = 7.2.

[e]Screened sewage properties: SS = 279 mg/l, Phosphate = 15 mg/l, pH = 7.3.

[f]Test No. 5 employed 30 minutes batch retention for influent sample in Test No. 4.

[g]Test No. 7 employed batch remix of Test 5 float cake with fresh sewage.

TABLE 16. ADDITIONAL RESULTS OF IN-LINE TESTS - FIRST TEST MODULE

Test No.	Flow (gpm)	Reynolds Number	Velocity (fpm)	Suspended Solids[a] Effluent (mg/l)	Suspended Solids[a] Removal (%)
8	10	8,400	17	No separation	-
9	7½	6,300	13	89	45
11[b]	7½	6,300	13	112	31
12[c]	7½	6,300	13	38	77
10	5	4,200	9	86	47

NOTES: [a]Except as noted,
Inflow suspended solids = 163 mg/l.
Flotation aid = Dylex KCD-340 at 100 mg/l.
Ferric chloride at 100 mg/l.
Hercofloc at 1 mg/l.

[b]Phenolic microballoons as flotation aid at 100 mg/l.

[c]Flocculant-Hercofloc 810 at 4 mg/l.

TABLE 17. RESULTS OF IN-LINE TESTS - SECOND TEST MODULE

Flow (gpm)	Flocculant Dosage (mg/l)	Reynolds Number	Maximum Velocity (fpm)	Suspended Solids	
				Effluent (mg/l)	Removal (%)
10	1	10,400 → 5,200	27	337	20
10	1	10,400 → 5,200	27	256	39
10	2	10,400 → 5,200	27	288	32
10	3	10,400 → 5,200	27	205	51
(Batch)	3	10,400 → 5,200	-	38	91
(Batch)	3	10,400 → 5,200	-	16	96
20	2	20,800 → 10,400	54	235	36
20	2	20,800 → 10,400	54	288	21

NOTES: [a]Inflow suspended solids = 422 mg/l for 10 gpm tests, 366 mg/l for 20 gpm tests.

[b]Flotation aid - Dylex KCD-340 at 100 mg/l.

[c]Ferric chloride at 100 mg/l.

[d]Flocculant - Hercofloc 810.

decreased as ferric chloride dosage increased. The maximum pH change was about 1 with 200 mg/l ferric chloride.

Tests 5 and 7 were included to determine (1) the effect of increased retention time and (2) float cake reuse potential, respectively. The increased (batch) retention time in Test No. 5 did not significantly affect suspended solids removal (92 percent suspended solids removal versus 90 percent at 17 min. retention). Reuse of float cake (Test No. 7) in a batch experiment resulted in poor suspended solids removal (8 percent).

Visual float cake flow properties and settleable material in laminar flow (Re $\sim$ 800, V = 1.75 fpm) were of interest. At this flow condition, float cake did not flow readily and there was a considerable amount of settleable solids which did not scour out of the unit. (Scouring velocities in combined sewer lines are generally 2-3 fps) (5).

Tests were then conducted (Table 16) to define the upper flow limit at which flocculation and flotation could be achieved. Tests at 10 gpm showed visual flocculation but no significant flotation of the resulting flocs. Subsequent tests at 7½ gpm and at 5 gpm showed that flocculation and flotation could be achieved at these flow levels. As in the low flow tests, the degree of suspended solids removal was sensitive to chemical dosage. In Test No. 12, the solids removal efficiency was increased to 77 percent by increasing flocculant dosage to 4 mg/l. Although satisfactory flocculation and flotation were achieved, float cake would not flow significantly even at this flow condition. With a 100 mg/l flotation aid dosage, the float cake appears to be relatively nonflowable.

Since the nominal inlet velocity in the flow-turbulence module was quite high (100 x module velocity), dissipation of this velocity (energy) in the initial portion of the module promoted turbulence not considered in the calculated Reynolds number. The adverse effect of high inlet velocity on flocculation was evident, and module design must consider gross changes in velocity which could affect flocculation and flotation. Reynolds number, flow velocity and retention time appear to be important design criteria.

The second in-line module was designed to alleviate some of the shortcomings of module one. Table 17 gives the test results for the second module. Comparison of these data with the data from the first module shows a marked improvement (20 to 50 percent versus none) in solids removal at the 10 gpm flow rate. This improvement is attributed to an increased residence time in the modified design. Indeed, the best results were obtained for samples which received batch retention following initial flocculation/flotation in the flow system. The excellent suspended solids removal (greater than 90 percent visual clarity) was obtained by an additional 30 min. retention to promote separation of solids from the clarified stream.

Float cake flow difficulties were encountered in these tests as in the earlier tests, but some float cake flow was obtained. Separation of the float cake showed a significant concentration of suspended solids in the float cake stream: 80,000 mg/l vs 422 mg/l in the influent. Both float cake and effluent streams varied significantly during the tests, but the separation was obvious from visual observation through a sight port in the module.

Discussion and Recommendations

Since concentration of sewage suspended solids was achieved at a relatively high velocity (about 1 fps), the concept may have general application for storm flow treatment in sewer lines where long retention time can be achieved by simply adding the treatment chemicals to the system a considerable distance before attempting separation of the concentrated stream. Such a technique is, of course, more general than the present concept in that the flotation could be effected by air as well as by low density solids or separation could be by sedimentation rather than by flotation. As a result of flow control difficulties in this investigation, however, further examination of such a concept should be in an actual combined flow sewer system rather than at the laboratory scale.

Dissolved Air Flotation Tests

Bench-scale batch tests were conducted with Milwaukee combined sewer overflow samples to compare the solid flotation aid system with the dissolved-air flotation system which has been under development (6). Tables 18 to 21 give the results of these tests. The results confirm that a combination of ferric chloride and polyionic flocculant provides excellent flocculation. Chemical dosages tested were 25 mg/l ferric chloride and 0.5-2.0 mg/l flocculant to produce suspended solids removals of greater than 90 percent.

Table 18 gives the results of tests comparing ferric chloride and alum as coagulants. Suspended solids, total COD and soluble COD were measured before and after treatment. Suspended solids removals were similar for both coagulants.

Table 19 gives the results of varying chemical addition methods. In Test No. 1, without a flocculation period, a reduced suspended solids removal efficiency is indicated. Table 20 gives additional data on the effect of varying flocculation time. Although floc rise rates were too fast to measure, the results show that a short flocculation period is beneficial.

Table 21 gives data comparing Hercofloc 810 with Purifloc C-31, the polyionic flocculant which has been utilized previously in dissolved-air flotation field tests. The dosages were selected for comparison on an equal cost basis. Similar suspended solids removal efficiencies were obtained.

In addition to the dissolved-air flotation experiments, a bench test was conducted with the Dylex flotation aid. The results showed a reduction in combined sewer overflow suspended solids from 337 mg/l to 2 mg/l with a Dylex dosage of 75 mg/l (Hercofloc dosage at 1 mg/l and ferric chloride at 25 mg/l). The flotation aid was difficult to disperse in the test beaker, but suspended solids removal was excellent. Since the solid flotation aid is difficult to disperse in batch tests, flow tests are probably required for meaningful comparisons.

TABLE 18. DISSOLVED AIR FLOTATION - BENCH CHEMICAL TREATMENT TESTS

Test No.	1	2
Chemical and Dosage	25 mg/l $FeCl_3$ 2 mg/l Purifloc C31	25 mg/l $Al_2(SO_4)_3 \cdot 18\ H_2O$ 2 mg/l Purifloc C31
Floc Time (min)	1.5	1.5
Recycle Rate (%)	15	15
Retention Time (min)	5	5
Scum Volume (gal/1000 gal)	15	15
Sludge Volume (gal/1000 gal)	Trace	Trace
Effluent:		
Suspended Solids (mg/l)	6	10
Total COD (mg/l)	37	50
Soluble COD (mg/l)	36	42
Raw Waste:		
Suspended Solids (mg/l)	228	203
Total COD (mg/l)	211	193
Soluble COD (mg/l)	73	59
SS Removal (%)	97	95

TABLE 19. DISSOLVED AIR FLOTATION - CHEMICAL ADDITION TECHNIQUE EFFECTS

Test No.	1	2	3	4	5
$FeCl_3$ Dose (mg/l)	25	25	25	25	25
Floc Time (min)	0	0[a]	0	4	3
Purifloc C31 Dose (mg/l)	2[b]	2[c]	2[b]	2[b]	2[c]
Floc Time (min)	0	0	0	0	1
Recycle Rate (%)	15	15	15	15	15
Recycle Pressure (psig)	40	50	50	50	50
Detention Time (min)	5	5	5	5	5
Scum Volume (gal/1000 gal)	15	15	15	12	20
Sludge Volume (gal/1000 gal)	Trace	Trace	Trace	Trace	Trace
Effluent:					
Suspended Solids (mg/l)	54	21	33	59	15
Total COD (mg/l)	138	93	119	112	62
Soluble COD (mg/l)	70	68	63	70	66
Suspended Solids Removal (%)	87	95	92	89	96

NOTES: [a]No flocculation period; however, there was a 20-sec time lapse between chemical additions.

[b]Injected into pressurized flow while adding to cylinder.

[c]Added by pipette to cylinder.

[d]Tests conducted on raw waste. Recycle was raw waste after screening through a 50 mesh screen. SS = 431 mg/l Total COD = 512 mg/l, Soluble COD = 102 mg/l

TABLE 20. DISSOLVED AIR FLOTATION - FLOCCULATION TIME EFFECT

Test No.	1	2	3
$FeCl_3$ Dose (mg/l)	25	25	25
Floc Time	2	0	1
Purifloc C31 Dose (mg/l)	2	2	2
Floc Time (min)	0	2	1
Recycle Rate (%)	15	15	15
Rise Rate (fpm)		Too Fast	
Detention Time (min)	5	5	5
Scum Volume (gal/1000 gal)	15	15	15
Sludge Volume (gal/1000 gal)	None	Trace	Trace
Effluent:			
SS (mg/l)	13	12	8
Total COD (mg/l)	24	24	23
Soluble COD (mg/l)	20	18	20
Suspended Solids Removal (%)	91	92	95

NOTES: [a]Raw waste sample stored 3 days in refrigerator SS = 148 mg/l. Total COD = 168 mg/l, Soluble COD = mg/l.

[b]Pressurized flow - raw waste that had been screened through 50 mesh screen. Pressurized at 50 psig.

TABLE 21. DISSOLVED AIR FLOTATION - FLOCCULANT TYPE EFFECT

Test No.	1	1
Chemical Treatment		
$FeCl_3$ (mg/l)	25	25
Hercofloc 810 (mg/l)	0.5	0
Purifloc C31 (mg/l)	0	2
Floc Time (min)	1	1
Flotation Data		
Recycle Rate (%)	15	15
Rise Rate (fpm)	-	-
Detention Time (min)	8	8
Scum Volume (mg/l)	10	15
Sludge Volume (mg/l)	Trace	Trace
Effluent Quality		
pH	6.6	6.6
Suspended Solids (mg/l)	24	14
Total COD (mg/l)	40	34
Soluble COD (mg/l)	36	26
Suspended Solids Removal (%)	89	94
Raw Waste Properties		
pH	7.1	
Suspended Solids (mg/l)	225	
Total COD (mg/l)	169	
Soluble COD (mg/l)	36	

SECTION 5

FIELD TESTS

DESIGN AND MODIFICATION OF THE DEMONSTRATION FACILITY

Original Demonstration Facility

The original treatment facility available at the Hawley Road site consisted primarily of a screening chamber and a dissolved air flotation basin. Figure 10 shows a schematic flow sheet for the treatment system. A photograph of the overall system is shown in Figure 11.

The screen is an open-end drum into which the raw waste flows after passing through a ½ in. bar rack. The water passes through the screen media into a chamber directly below the drum. The drum rotates and carries the screened solids to the spray water cleaning system where they are flushed from the screen with previously screened water. A 50 mesh screen (297 micrometer openings) is provided on the drum screen. This provides approximately 20-30 percent removal of pollutants and allows high throughput rates (50 gpm/sq ft) at reasonable head losses (up to 12 in. water). The drum screen as installed is an eight-sided drum with a cross-sectional area equivalent to a 7.5 ft diameter circle. Drum length is 6 feet. Total screen area is 144 sq ft. The wetted screen area ranges between 72 and 90 sq ft depending upon the head loss across the screen.

The flotation basin is a rectangular chamber with a surface skimming system to remove floated scum. Screened water is pressurized and saturated with air under pressure in an air solution tank. When the pressure is reduced across a weir-type diaphragm valve, minute air bubbles (less than 100 micrometers) are formed. This air-charged stream is then blended with the remaining screened water flow. The bubbles become attached to the particulate matter in the mixing zone (detention time: approximately 60 sec) shown in Figure 10 and rise to the surface for subsequent removal by skimmer flights. Chemical flocculants may be added to enhance the removal efficiency of finely divided particulates.

The design of the system was such that a wide range of selected variables could be evaluated. The following range of variables was possible with the demonstration system:

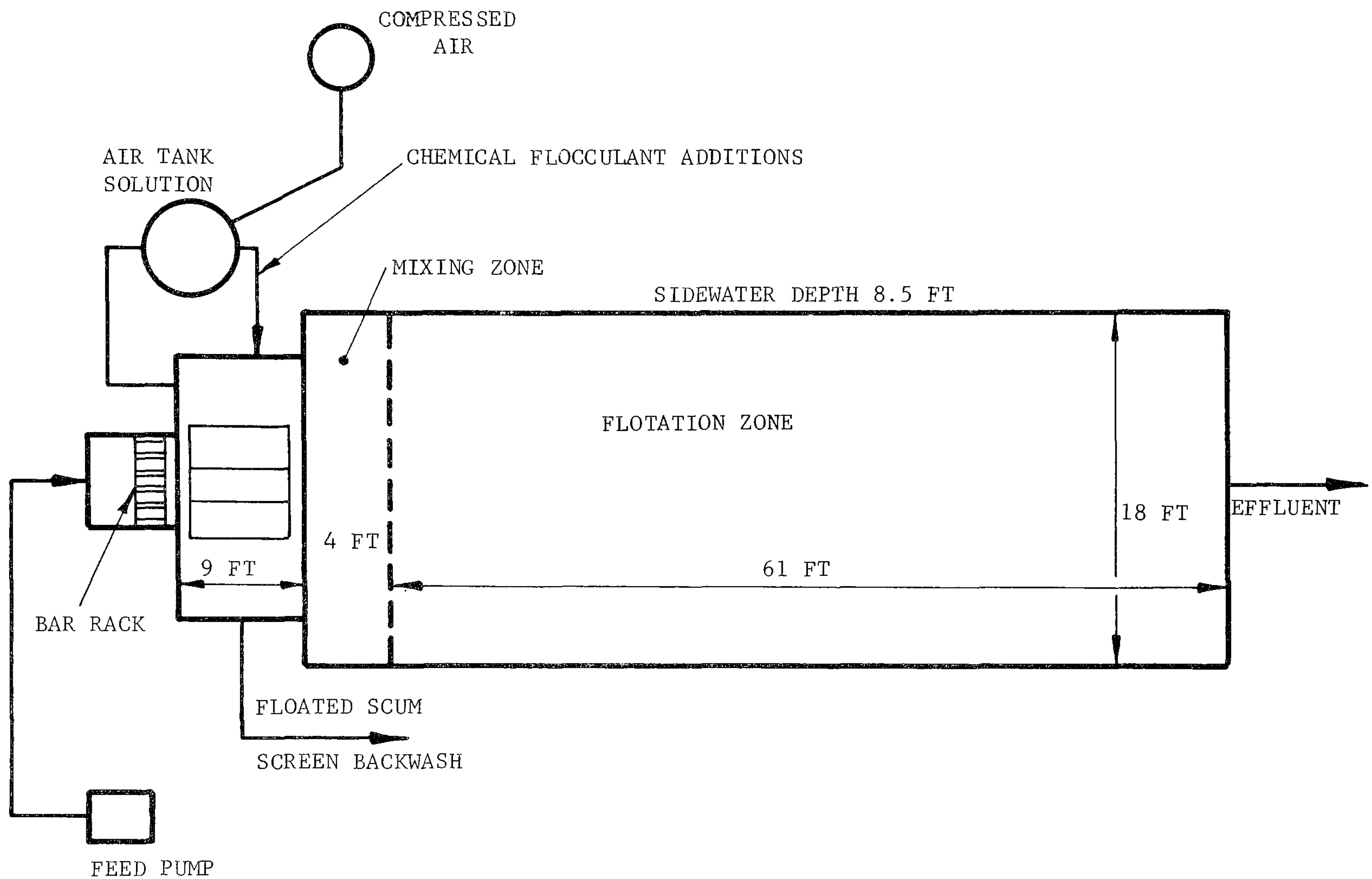


Figure 10. Original Hawley Road treatment facility.

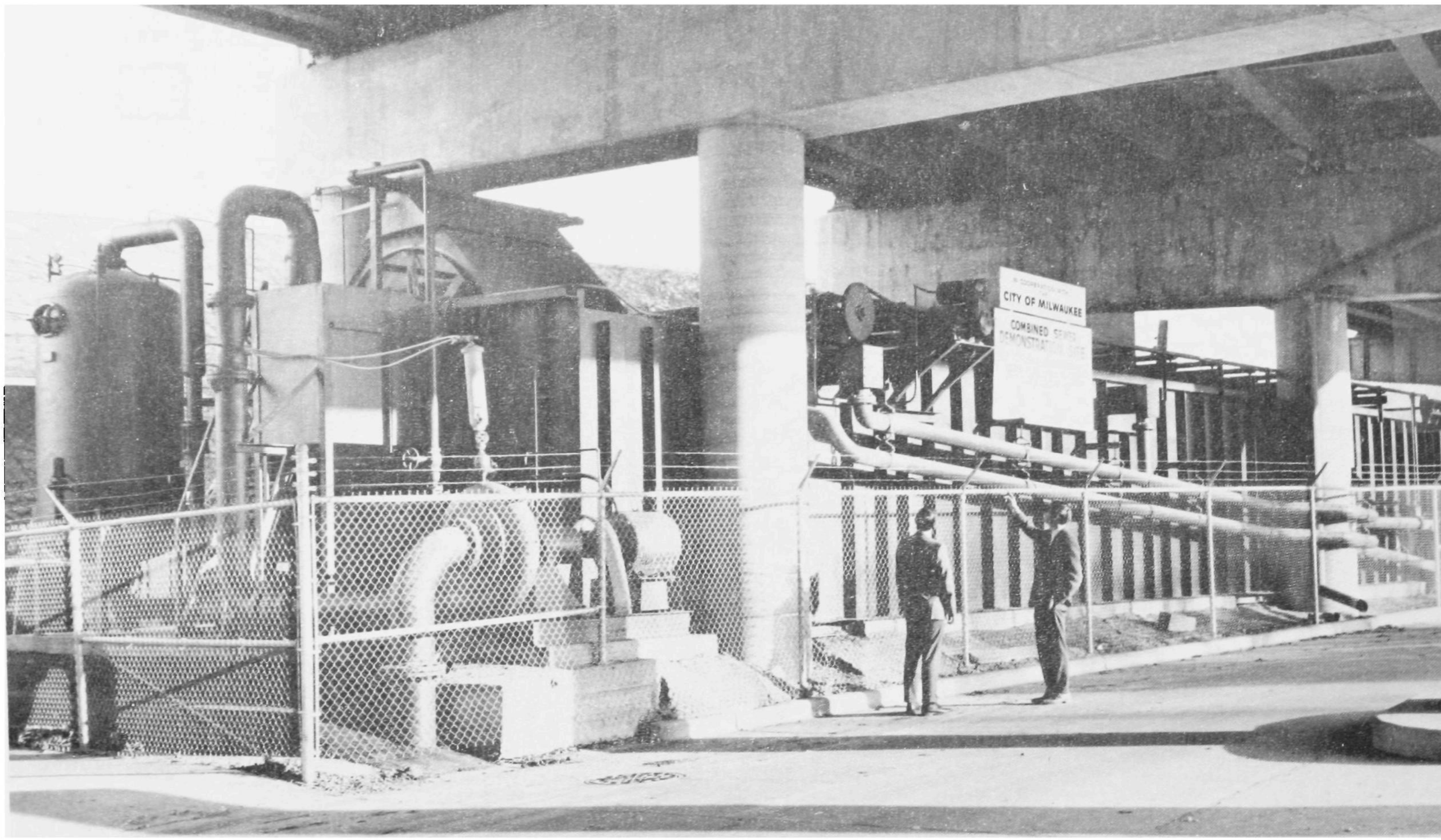


Figure 11. Photographic view of Hawley Road site.

Flow rate	1500 - 4400 gpm
Surface loading	2 - 10 gpm/sq ft
Horizontal velocity	1.30 - 3.75 ft/min
Pressurized flow rate	300 - 1100 gpm
Operating pressure	40 - 70 psig
Detention time	7 - 44 min

As seen in Figure 11, the system is located under an existing highway bridge which provides overhead protection. A dam is provided in the combined sewer to allow impoundment of a limited quantity of overflow for subsequent treatment. Flow metering equipment is provided to measure the influent flow rate, the volume of screen backwash water and the volume of floated scum collected. The raw and screened backwash flows are measured via venturi meters connected to differential pressure gauges which both record and totalize the flows. The floated scum is measured with an open-channel, float-type meter which records and totalizes the flow of floated scum. The electrical control panel provides all necessary controls for 100 percent automatic operation with manual overrides on all systems. A Merchants Police alarm is connected to the system so that personnel will be alerted when the system goes into operation. The system is always (24 hours per day, 7 days per week) ready to operate to allow monitoring of maximum number of overflows.

Modification of the Original Demonstration Facility

Essentially, the modification of the original demonstration system consisted of the following:

(1) Bypassing the existing dissolved air pressure tank.

(2) Installation of a mechanical flocculation capability to the flotation basin.

(3) Addition, mixing, storage and feeding capabilities of the desired amounts of flotation-aid and flocculant chemicals.

The following design criteria were selected for the design of the demonstration system modifications:

(1)	Chemical dosages	100 mg/l $FeCl_3$ 5 mg/l cationic polyelectrolyte 100 mg/l flotation-aid 5% slurry
(2)	Retention time prior to addition of beads	60 sec
(3)	Flocculation time	5 min
(4)	Rise rate	2 to 5 ft/min

Figure 12 shows a flow schematic of the modified treatment facility utilized for the evaluation of the flocculation/flotation aid process.

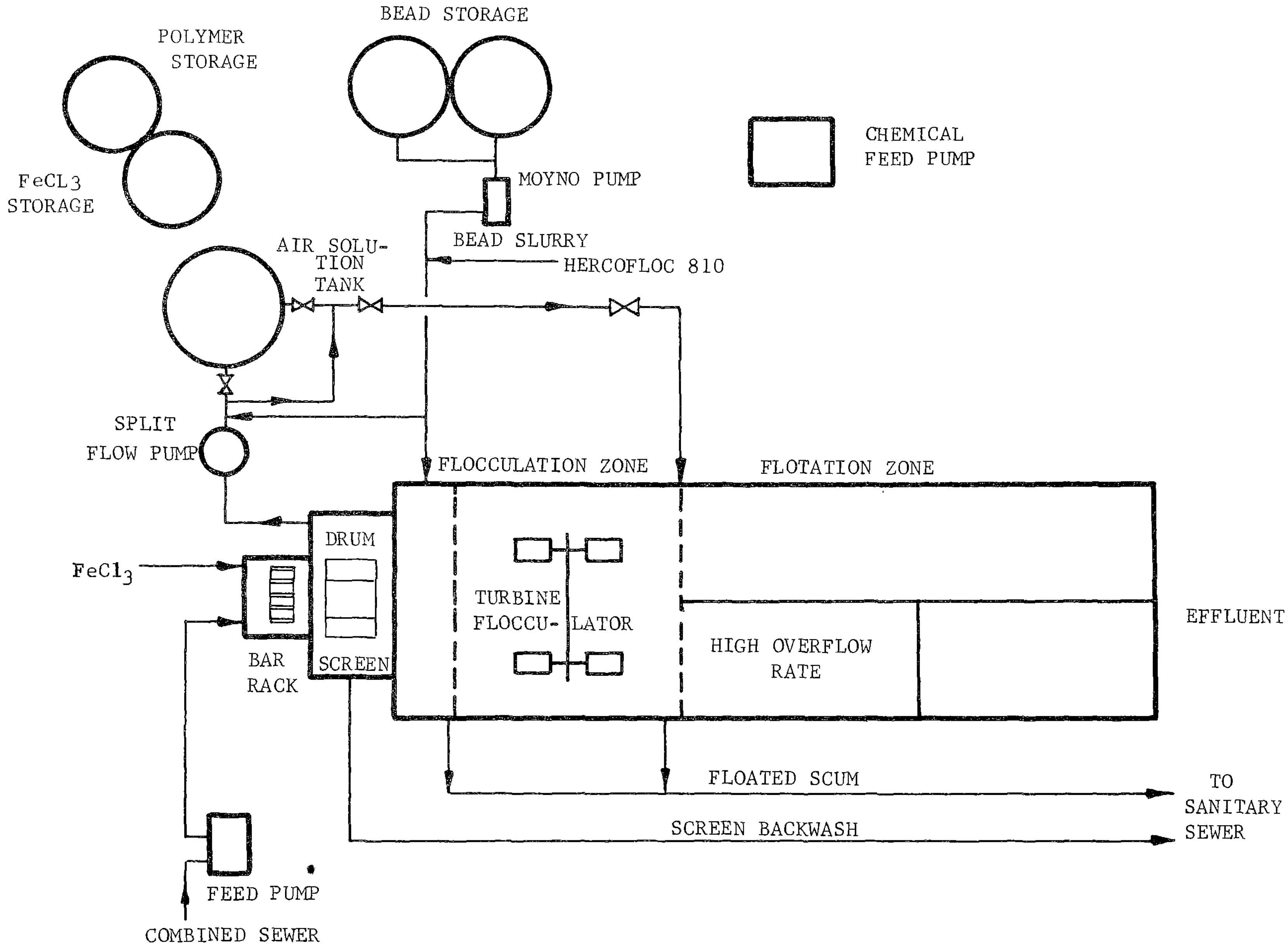


Figure 12. Flow schematic of modified demonstration facility.

Bypassing of the existing dissolved air pressure tank was accomplished by the addition of four butterfly valves. Stock solutions of the chemical flocculants were stored in 400-gallon capacity fiberglass tanks, and the chemicals were injected at the desired locations with a calibrated Triplex chemical feed pump.

Design of the Turbine-Flocculator

It was decided to utilize a turbine-flocculator for the promotion of the coflocculation of the flotation aid and the particulate matter in the combined sewer overflows. The input horsepower requirement and the maintenance of a suitable tip velocity of the turbine blades are the most important design creiteria of a turbine flocculator. A tip velocity of 5 ft/sec was selected, and a power requirement of 3 hp was calculated for the present design. It was decided to utilize two turbines with six blades each. A sketch of the turbine flocculator is shown in Figure 13. A mechanical variable-speed drive with a flexible shaft coupling was provided on the flocculator which permitted variation in the flocculator speeds in the range of 3 to 27 rpm.

Flotation Aid Expansion and Feeding Procedures

It was decided to expand the flotation aids on a batch basis since an on-stream expansion of these aids was beyond the scope of the present test program. It was also decided to feed the flotation aids in the form of a uniform slurry with Milwaukee tap water in a portion of the screened raw waste. This portion of the raw waste and flotation aid slurry were then mixed with the main waste stream and coflocculated with a flocculant.

Expansion of Flotation Aid

Initially, twenty 55-gallons of expanded polystyrene beads (Dylex KCD-340) prepared in an agitated boiling-water batch expander were shipped from Koppers Co. to Rexnord, Inc. After the exhaustion of this shipment, all future beads were expanded in batch systems within the Rexnord premises. The final bead expansion system utilized, as recommended by Koppers, is shown in Figure 14. Initially, the system consisted of putting approximately ½ gal of wet bead cake in approximately 30 gal of boiling water in a 55 gal insulated tank. Then steam was injected through a sparger at the bottom of the tank, and a heating time of 30 to 60 sec was allowed for the expansion of beads. The steam was produced at a pressure of 40 to 70 psi and was fed through a 3/8 in. to 1/2 in. pipe. The expanded beads were taken out of the 55 gal tank and stored separately. There were several changes made in this system as the project progressed. These changes and details of expansion technique will be discussed in later sections of this report.

Mixing of the Flotation Aids

An integral part of the process was to whip the beads and water into a uniformly mixed slurry so that the beads could be metered at a known concentration into the flocculation/flotation chamber. Initially, only one

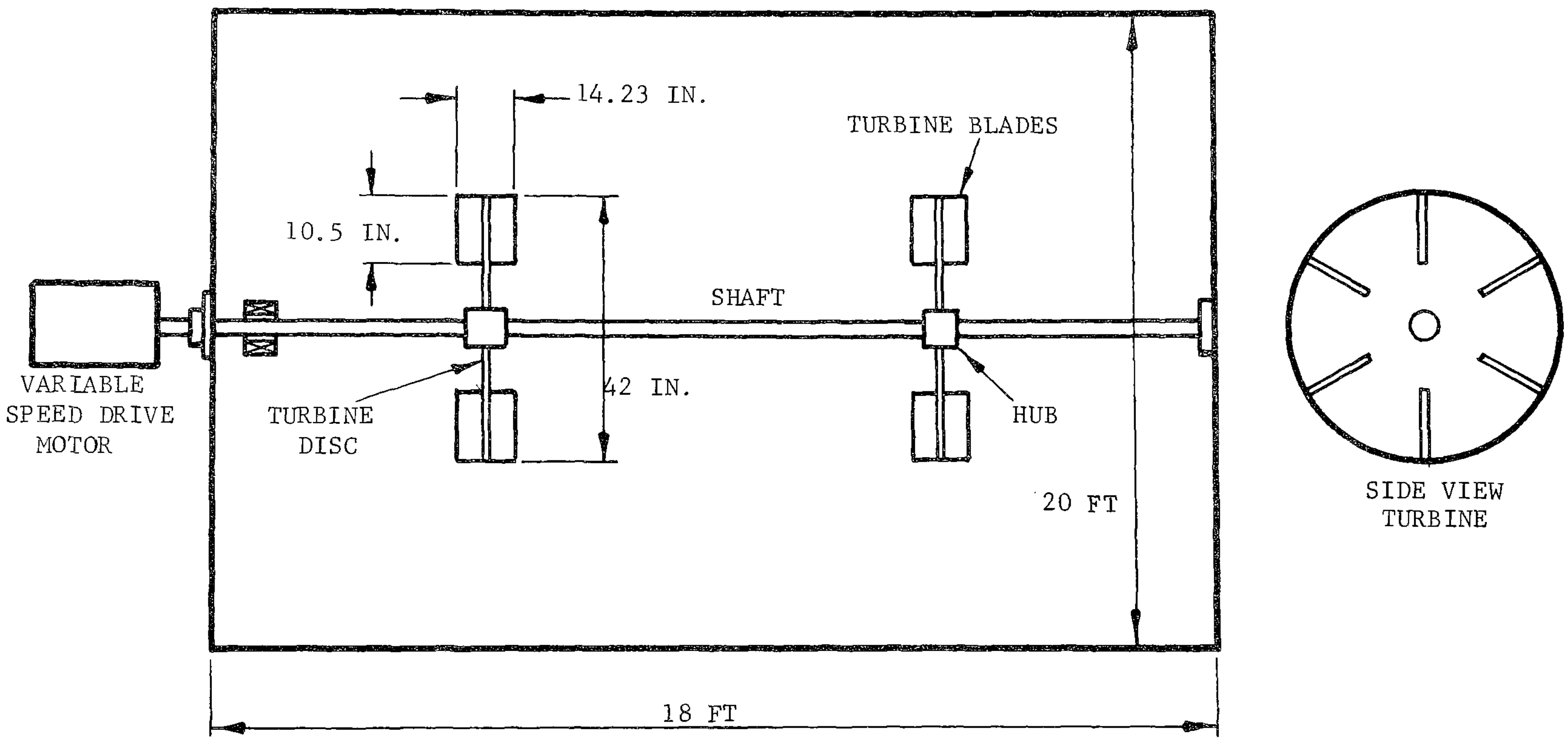


Figure 13. Turbine flocculator.

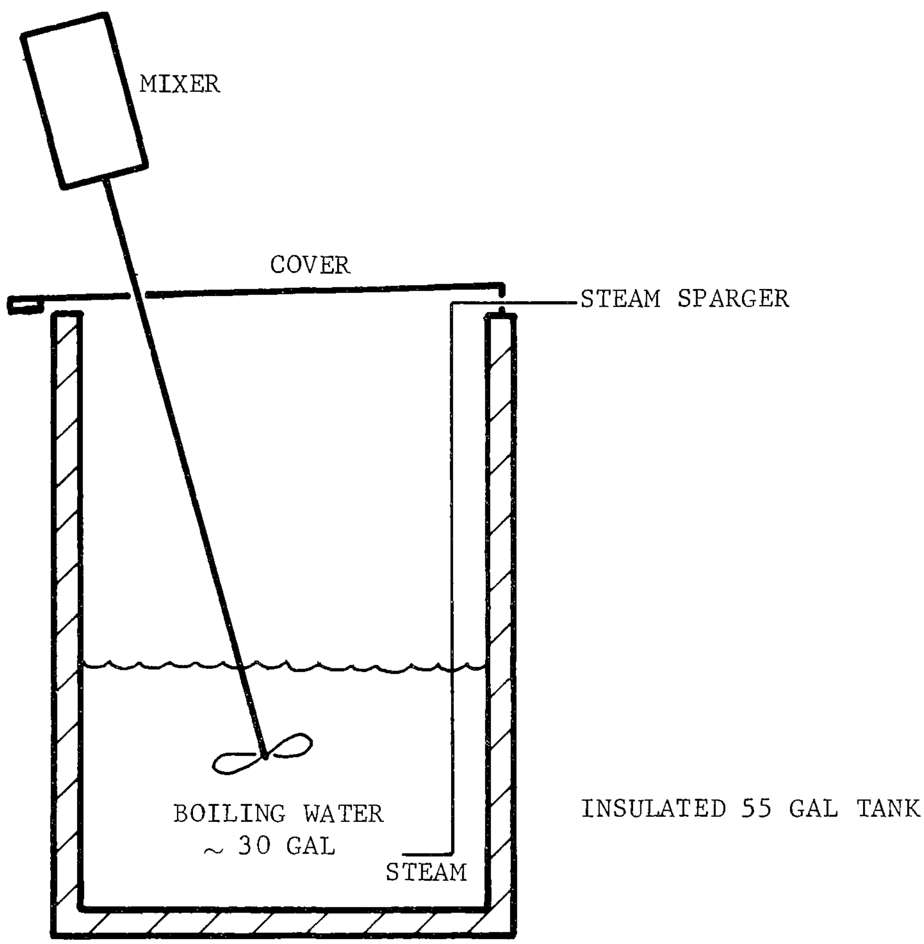


Figure 14. Bead expansion system.

600 gal capacity fiberglass tank was provided for mixing a 5 percent bead slurry with the expanded hollow beads supplied by Koppers Co. However, it was immediately apparent that the 0.5 hp propeller mixer provided for the mixing of the bead slurry was not adequate to keep the beads in suspension. Therefore, the existing mixer was replaced with a 1.5 hp agitator mixer* having two 12-in.-diameter propellers. Although this mixer was almost adequate, it was apparent that it still would not keep a 5 percent bead slurry completely in solution.

To overcome the bead mixing problem, consultations were held with the MIXCO Corp. Samples of beads and Hercofloc 810 were shipped to MIXCO for evaluation of the mixing requirements for the bead slurry. The recommended mixer consisted of three turbine blade propellers and was driven by a 15 hp motor. Because almost adequate suspension could be achieved with only a 1.5 hp mixer, it was felt that the MIXCO recommendation was extremely conservative and expensive.

Additional laboratory experiments were conducted by Rexnord to provide design information leading to a solution of the bead mixing problem. It was determined that a combination of mixing and recirculation pumping would provide sufficient energy to keep a 3 to 6 percent bead slurry in suspension. This was considered sufficient for the present test program and the proposed combination of mixing and recirculation was recommended for field use.

A sketch of the mixing system utilized is shown in Figure 15. The system consisted of two interconnected 600-gal fiberglass tanks, one centrifugal recirculation pump, two 1.5 hp low speed propeller mixers** and two specially designed twin bronze eductors for promoting a vortex in each tank. The twin eductors were submerged beneath the bead-water interface, and were fed by pumping from the bottom of each tank using a 375 gal centrifugal pump. In the process, water and eventually beads were pumped out of the tank bottom and recirculated through the eductor nozzle where the very high velocity exit stream passed through a collar and violent mixing occurred. The continuous mixing by the low speed mixers and the eductors produced a homogeneous slurry which could be maintained homogeneous as long as the mixers and the eductor system were on. The mixed slurry was then pumped into a portion of the raw waste via a Moyno pump equipped with a variable speed drive motor to adjust the required concentration of the flotation aids. The flocculant (Hercofloc 810) was added into the bead slurry before it mixed with the screened split flow stream. The whole setup was automated and the bead mixing system started automatically along with the priming pump when an overflow signal was actuated in the combined sewer.

*1.5 hp open tank, top entering agitator with steel shaft, LIGHTNIN Mixers and Aerators, Milwaukee, Wisconsin.

**LIGHTNIN Mixers and Aerators, Milwaukee, Wisconsin.

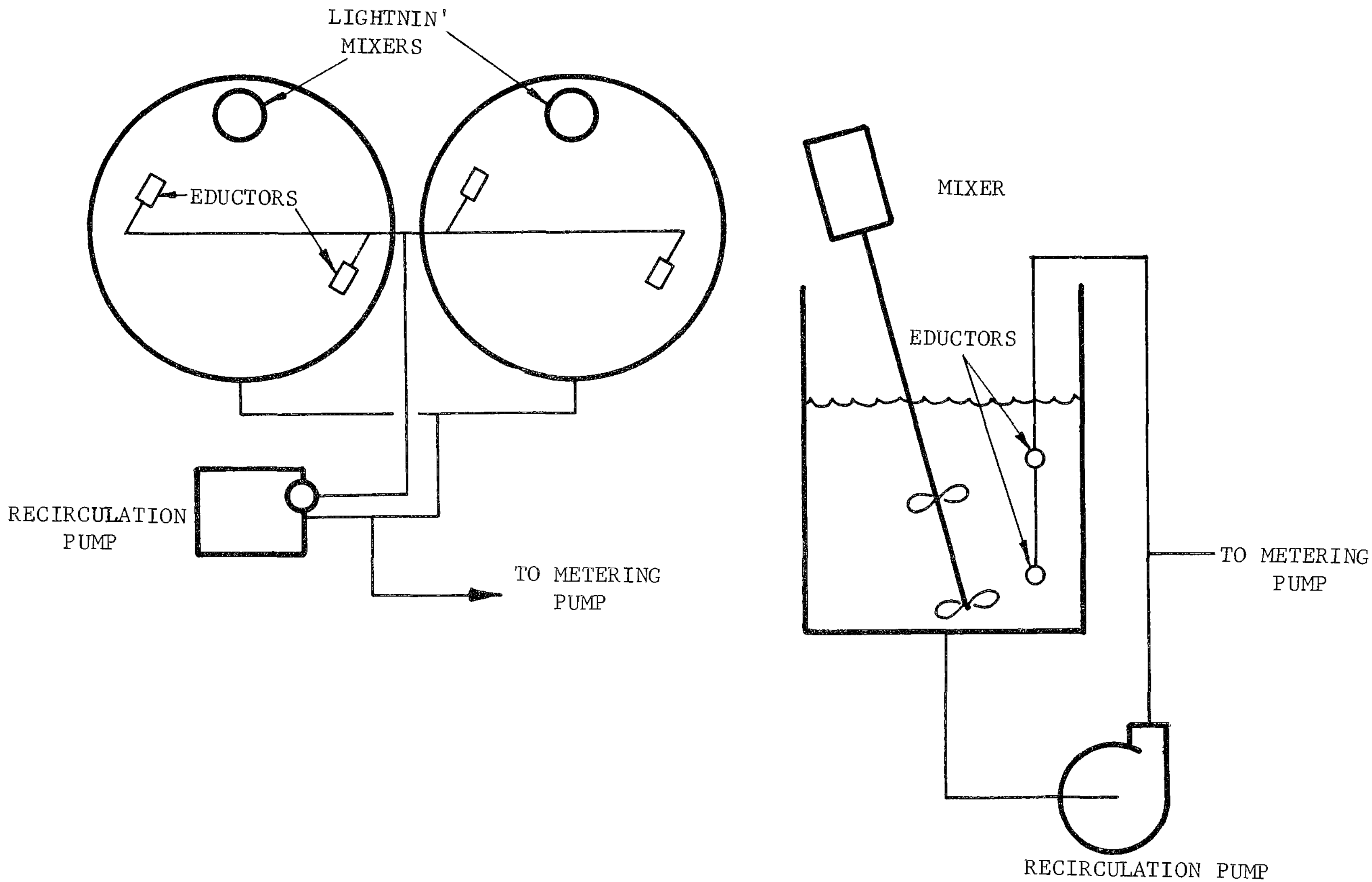


Figure 15. Schematic of bead mixing system.

OPERATION METHODS AND TEST PLAN

Operational Procedures

The demonstration system was put into operation automatically when a float switch in the sewer sensed an overflow. An alarm signal was immediately transmitted to the Merchants Police; the raw feed pump began to prime; and the drum screen, the flocculator and the split flow pump were put into operation.

Along with the priming pump, the bead recycle and mixing system was also started to provide a uniform bead slurry. All runs except No. 71-2 were started with the tank approximately 80 percent full of water. The water in the tank was mostly clean ground water which had been added after draining and flushing out the water from the previous run. The raw feed pump generally primed in about 12-15 min. When primed, the raw pump was activated and the flow meters, bead slurry pump, chemical feeder, skimmers and all other auxiliary equipment were put into operation. At the end of the overflow, the system shut down automatically. All variables were then selected for the next run and the controls positioned. Variables associated with system operation included: raw flow rate, split flow rate and flotation aid and flocculant dosages.

Sampling Procedures

Sampling began when the raw pump primed. Raw waste and screened water sample collection was started immediately. Effluent sample collection was delayed from 20 to 45 min (depending upon raw flow rate) to allow purging of water in the tank. This procedure insured collection of representative effluent samples. Screen backwash and floated scum samples were taken manually during screen backwash and scum removal periods. All other samples were collected via an automatic sampling system. This system consisted of two timers connected through the proper valving to automatically composite the various samples. The first timer controlled the sample-taking frequency (0-30 min). The second timer controlled duration of the sampling time (0-60 sec). The sampling valves are air-operated weir valves. Samples were composited every 5 min with the automatic system, and approximately 2-5 gal of sample was collected per hour. The samples were refrigerated immediately after the run. Analyses were then started within 8 hr.

Test Plan

Process variables associated with the evaluation of the flocculation/flotation aid concept include: hydraulic overflow rate (gpm/sq ft of tank area), split flow rate, flotation aid type and dosage, and flocculant chemicals type and dosage. Based on the promising results shown in the bench scale tests, it was proposed initially to evaluate 20 overflow events (7). A detailed field test plan based on a 2 x 2 factorial design is outlined in Table 22. However, the total field evaluation was limited to only five overflow events after a series of start-up difficulties depleted funds.

TABLE 22. FIELD TEST PLAN

	Process Variable	Level	No. of Storms
1)	Flotation-Aid Type	Dylex, Glass Microballoons	4-6
2)	Flotation-Aid Level	10-100 mg/1	4-6
3)	Overflow Rate	3-9 gpm/ft^2	20
4)	Screening	With, Without	2
5)	Air Flotation	Comparison	3
6)	Flocculation Time	Optimize	-
7)	Flocculation Speed	Optimize	-
8)	Ferric Chloride Dosage	Optimize	-
9)	Flocculant Dosage	Optimize	-

Analytical Test Summary

Analysis	Samples					Total/*
	Raw	Wash	Screened	Scum	Effluent	Storm
pH	1	1	1	1	2	6
Total Solids	1	1	1	1	2	6
Total Solids, Volatile	1	1	1	1	2	6
Suspended Solids	1		1		2	4
Suspended Solids, Volatile	1		1		2	4
TOC	1		1		2	4
COD	1		1		2	4
Nitrogen	1				2	3
Phosphates	1				2	3
Chlorine Demand	1				2	3
Total Coliform	1				2	3

*Total/storm doubles for storms tested to identify treatability of first flush and subsequent flow.

Flotation Aid Recovery Tests

	No. of Storms
Hydrocyclone Experiments	2
High-Shear Mixing Experiments	2
Float Cake Properties	4

The test results at the end of four storms had pointed out two important problem areas which affected the technical feasibility evaluation of the proposed concept. These problem areas and changes in program plan will be discussed in detail in later sections of this report. However, the general range of variables investigated during this field test program was as follows:

Overflow rates	1.9 - 5.6 gpm/sq ft
Split flow rates	600-1100 gpm
Flotation aid type	Dylex beads (polystyrene) KCD-340)
Flotation aid dosage	81 - 113 mg/l
Flocculant chemicals:	
Ferric chloride	30 - 34 mg/l
Hercofloc 810 (cationic)	2.6 - 6.0 gm/l

RESULTS AND DISCUSSION

Raw Wastewater Characterization and Screening Efficiency

A total of five overflow events were monitored during the field test phase. The quality of the raw wastes for these overflows is shown in Table 23. There was a wide variation in the wastewater quality. The suspended solids varied between 179 and 916 mg/l. Four of these overflows (71-1, 71-2, 71-3, 71-5) were float treated with polystyrene beads (Dylex KCD-340) and one overflow (71-4) was float treated with dissolved air. All the five overflows were passed through a 50 mesh (297 micron openings) screen. The screened water quality for these storms is shown in Table 24. Taken as a group, data indicates erratic and poor results. However, bead flotation tests 1, 2 and 3 were severely hampered by start-up difficulties and in no way represent the technical potential of the concept. As a result of these difficulties, many data showed negative removals when compared with the corresponding raw water quality. The reasons for the poor screened water quality may be attributed to possible leakage of the influent raw wastewater through the worn drum seal. However, a lack of efficient screening removals did not influence the evaluation of the flocculation/flotation aid concept, and therefore it will not be considered any further.

Operation of the Flotation System

The bead flotation effluent quality data and overall pollutant removals for Storm Nos. 1, 2 and 3 are shown in Table 25. Results of these tests are reported as a guide to the start-up difficulties encountered and to remedial actions taken, not as being indicative of the technical potential of the concept.

Pollutant removal efficiencies were better for low overflow rates compared with high overflow rates. The removal efficiencies as shown in Table 25 varied over a wide range. Significantly better pollutant removals were obtained for Run 71-1 compared with Runs 71-2 and 71-3. The percent pollutant removals ranged between 65 and 75 percent for Storm No. 71-1 and between 0 and 50 percent for the other two tests. The high removal efficiencies for Run 71-1 would appear to indicate fairly good operation. However, much of the removal accomplished during this test was attributable to settling and not flotation. Upon draining the tank, it was found that approximately 8 in. of settled sludge had resulted from this run. Thus the first startup problem, flotation aids which sink, became apparent. The influent pollutional load for this test was significantly high (Table 23), and this might have facilitated the sedimentation of the particulate matter. Visual observations in the field during the test showed many beads in the flotation effluent which obviously were not effecting any removal of solids.

In Run 71-2, the effluent concentrations of most parameters were found to be higher than the influent concentrations. The reason for these apparent negative removal efficiencies was probably the resuspension of the particulate matter that had settled in the tank during Run 71-1, which was not

TABLE 23. RAW COMBINED SEWER OVERFLOW QUALITY

Overflow No.	pH Units	Total Solids	Total Volatile Solids	Suspended Solids	Volatile Suspended Solids	COD	BOD	TOC	Soluble TOC	Ortho Phosphate as P	Kjeldahl Nitrogen
71-1	6.9	1167	440	916	360	646	-	290	70	1.26	19.0
71-2	7.3	365	242	187	50	120	-	111	18	0.45	3.9
71-3	7.2	753	178	625	200	65	41	22	16	0.03	5.0
71-4	7.4	-	-	179	57	69	25	21	16	-	-
71-5	6.4	351	419	289	101	123	25	37	7	1.46*	3.1
Average	7.0	659	252	439	154	205	30	96	25	0.58	7.8
Range	6.4-7.4	351-1167	149-440	179-916	50-360	65-646	25-41	21-290	7-70	0.03-1.26	3.1-19.0

NOTE: All results in mg/l except where noted otherwise.

*Measured as total phosphates.

TABLE 24. SCREENED COMBINED SEWER OVERFLOW QUALITY

Overflow No.	pH Units	Suspended Solids	Volatile Suspended Solids	COD	BOD	TOC	Soluble TOC
71-1	6.9	1002	216	368	-	160	32
71-2	6.7	323	151	131	-	50	15
71-3	6.8	578	86	140	35	34	-
71-4*							
71-5	6.4	215	80	96	19	35	6

NOTE: All results in mg/l except where noted otherwise.

*Sample lost during handling.

TABLE 25. BEAD FLOTATION EFFLUENT QUALITY

Overflow No.	Overflow Rate gpm/sq ft	Suspended Solids Quality mg/l	Suspended Solids Removal %	Volume Suspended Solids Quality mg/l	Volume Suspended Solids Removal %	COD Quality mg/l	COD Removal %	BOD Quality mg/l	BOD Removal %
Low Overflow Rates									
71-1	2.25	329	64.1	97	73.1	165	74.5	-	-
71-2	2.7	251	-	1.48	-	110	8.3	-	-
71-3	2.8	-	-	-	-	61	6.2	31	24.4
High Overflow Rates									
71-1	4.5	414	54.8	148	58.9	328	49.2	-	-
71-2	5.4	261	-	165	-	143	-	-	-
71-3	5.6	549	12.2	154	23.0	177	-	38	7.3

TABLE 25 (continued)

Overflow No.	Overflow Rate gpm/sq ft	TOC Quality mg/l	TOC Removal %	Soluble TOC Quality mg/l	Soluble TOC Removal %	Ortho Phosphates Quality mg/l	Ortho Phosphates Removal %	Kiehdahl Nitrogen Quality mg/l	Kiehdahl Nitrogen Removal %
Low Overflow Rates									
71-1	2.25	68	76.6	36	48.6	0.05	96.0	8.2	56.8
71-2	2.7	56	49.1	18	0	0.10	77.8	5.9	-
71-3	2.8	25	-	16	0	0.13	-	9.1	-
High Overflow Rates									
71-1	4.5	116	60.0	46	34.3	0.08	93.7	13.2	30.5
71-2	5.4	69	37.5	19	-	0.10	77.8	5.6	-
71-3	5.6	50	-	17	-	0.04	-	9.6	-

removed. In an effort to improve upon the efficiency of the operation, several changes were made in the operating conditions. The actions taken to improve the operating results were as follows:

1. Polyelectrolyte (Hercofloc 810) was added to the bead slurry in an attempt to effectively coat the beads and thereby provide more effective flotation.

2. The amount of split flow volume was increased to the achievable maximum of 1100 gpm.

3. The flocculator speed was increased to maximum to improve upon the coflocculation of beads and solids.

However, these corrective actions did not affect the bead flotation removal efficiencies as shown by the effluent quality for Run 71-3 (Table 25). The removal efficiencies were found to be poor and ranged between 0 and 25 percent for various parameters. The effluent quality again varied over a wide range, and in many cases the data was erratic because of the presence of beads in the effluent samples. The apparent increases in effluent COD, TOC and nitrogen values over the influent concentrations were attributed to the presence of beads. On the other hand, the BOD analysis would not be affected by the presence of beads and did not show an increase in values as did COD, TOC and nitrogen.

The overflow 71-3 had actually been divided in two operational periods. The initial 60 min of operation was conducted with beads and was designated as Run 71-3. The remaining 40 min of operation on the tail end of the same overflow was conducted with dissolved air and designated as Run 71-4. A tabulation of the effluent qualities and the removal efficiencies for that test is shown in Table 26. The results of the air flotation run indicated significantly better pollutant removal efficiencies than the bead flotation results. The range of pollutant removals was 35 to 75 percent for air flotation compared with 0 to 25 percent for bead flotation. It is emphasized that a direct comparison between the two techniques on the basis of these two tests alone is unfair since the air flotation technique is well developed while the bead flotation technique was barely started and was suffering the usual startup difficulties associated with any large pilot plant.

<u>Reevaluation of the Field Test Program Plan</u>

Based on the field data obtained from the above-described four experiments, a meeting was held between USEPA, Hercules and Rexnord to review the field test progress and future program plan of the project. Two major technical problems were indicated to have limited the performance of the flocculation/flotation concept effectiveness. These problems were:

1. Settling of some of the flotation aids instead of flotation.
2. Ineffective coflocculation of the coagulated particulate matter onto the flotation aid.

TABLE 26. RESULTS OF RUN NO. 71-4

Analysis	Raw Waste Water Influent Quality	Overflow Rates,[a] gpm/sq ft			
		1.9		2.8	
		Effluent Quality mg/l	Removal %	Effluent Quality mg/l	Removal %
Suspended Solids	179	42	76.5	88	50.3
Vol. Suspended Solids	-	18	68.4	40	29.8
COD	69	46	33.3	38	44.9
BOD	25	12	52.0	12	52.0
TOC	21	14	33.3	13	38.1
Soluble TOC	16	13	18.8	13	18.8

NOTE: [a]Estimated overflow rates.

The presence of the polystyrene beads had been noticed both in the field test effluents as well as at the bottom of the bead slurry storage tanks. When viewed under a microscope, it was found that the size of most of the expanded beads was in the range of 200 to 300 micrometers. The size of the unexpanded beads ranged between 75 and 100. Several partially expanded beads were observed in the grab samples of the expanded beads under a microscope. These observations indicated that the reason for the sinking of some of the beads might be non-expansion or insufficient expansion due to the short heating time (20 to 60 sec) employed during the expansion technique.

It was also indicated that the principal reason for the inadequate coflocculation of the beads and suspended matter was the deterioration of the flocculant (Hercofloc 810) strength due to its long storage time during dry weather periods. Spot viscosity checks of the field-prepared Hercofloc solution showed a value of 15-20 cp for a 0.5 percent solution in Milwaukee tap water compared with 290 cp for a laboratory solution in distilled water at corresponding strength. The shelf life of a 0.5 percent Hercofloc solution was indicated to be of the order of 2 days only.

The use of a different liquid polyelectrolyte would have greatly simplified matters, but a series of laboratory tests with Milwaukee sewage and such liquid flocculants as Dow D-31 and Nalco 607 as well as Hercofloc 810 (all cationic polyelectrolytes) showed that all would build a good floc but only the Hercofloc would promote the coflocculation of this floc to the Dylex flotation aid.

A preliminary comparison of the operating costs for the bead and dissolved air flotation concepts showed that the cost of treatment with beads was high even when a bead recovery factor of 90 percent was utilized. The chemical costs alone were calculated to be 6.7¢/1000 gal for bead flotation. In comparison, Rexnord estimates 2.5¢/1000 gal for air flotation, based on two years operation at the Hawley Road site. The costs for the bead flotation were based on the following:

	¢/1000 gal
Flotation-aid (Dylex KCD-340 @ $0.40/lb)- 100 mg/l assuming 90% recovery	3.75
Hercofloc 810 - 2 mg/l @ $1.35/lb	2.2
Ferric Chloride - 20 mg/l @ $90/ton	0.75
	6.7

The above considerations clearly demonstrated the need of a solution to several technical problems before a realistic evaluation of the technical feasibility of the bead flotation concept in the field could be made. It was mutually decided that the further evaluation of the technical feasibility of the flocculation/flotation concept in field would be limited to only one or two additional tests after the above-mentioned problems were satisfactorily solved.

Solution of the Major Technical Problems

Bead Settling Problem

Since it has been indicated that a shorter time (approximately 30 to 60 sec) was insufficient for the proper expansion of beads, the heating time was increased to 2 min. A quality control check was also instituted during the expansion of beads to insure proper expansion. Grab samples of expanded beads were viewed under the microscope and were added to water to observe their floatability. No sinking characteristics were shown in the expanded beads immediately after expansion. However, after the beads were mixed at the site and stored during dry weather, the beads started to exhibit some settling characteristics. When viewed under a microscope, these settled beads were found to be properly expanded (200 to 300 micrometer). A sample of such beads was also put in boiling water for 10 min in an attempt to refloat them, but the results were negative.

The problem of sinker beads was then conveyed to Koppers Co., the manufacturer of the beads, for further evaluation. Samples of unexpanded, expanded but settling, and expanded and floatable beads were shipped to the manufacturer. At the same time, bench scale tests were undertaken by Hercules to find the cause of the problem by reproducing the bead settling characteristics in the laboratory.

It was thought that the method of expansion of the beads might be responsible for the sinkers. The improper expansion of beads could impart excessive heat to the bead cells, causing the cell walls to blow out and leaving the beads with an open network of capillaries which would gradually fill with water and sink. Based on suggestions by Koppers Co., it was decided that the following modifications in the bead expansion technique might be desirable.

1. An increase in the heating time for bead expansion from 2 min to 5 min.

2. Installation of a mixer on the bead expansion tank to provide uniform heating.

3. Use of a covered expansion tank to avoid a sudden exposure of the heated beads to the ambient atmosphere.

Bench scale tests conducted both at Koppers and Hercules did not produce any sinkers in the laboratory by soaking the expanded beads in water for prolonged durations up to 3-4 weeks. Any effects of long storage on the expandability potential of the Dylex beads were discounted by Koppers after examining the density of the wet cake. Short time (approximately 30 to 60 sec) mixing of the beads with water in a Waring blender did not produce any sinkers in the laboratory. However, when a 5 min blending period was provided to the bead water mixture, some sinker beads were noticed. After two 5-min blending periods, more sinkers were observed. After three 5-min blending periods and an overnight settling period, 60-65 percent of the beads were on the bottom of the jar as sinkers. Microscopic examination showed that the blender-treated beads had been physically sheared or chopped. Although the samples of sinker beads from Hawley Road site did not exhibit strong shearing under microscopic examination, it was felt that the essential source of sinker beads in field was due to their exposure to the high shear fields in the eductor system which could have caused bead damage. Therefore, the most optimum solution under the present circumstances would be to expand a fresh batch of Dylex beads under best possible conditions and use the bead mixing system as sparingly as possible prior to the actual field operation.

Preparation of Hercofloc 810 Solution

Since the reason for the deterioration of the Hercofloc solution was concluded to be its aging, it was decided to check the viscosity of a newly prepared batch at various time intervals and feed the polymer at a proportionately higher rate according to its strength. (Note: This polyer is shipped in a dry powdered form and is ordinarily mixed and immediately used via chemical metering systems.) A 0.5 percent solution of the Hercofloc 810 was prepared in Milwaukee tap water available at the site. It was found that a large number of fisheyes, globules of undissolved flocculant, remained in the 400 gal tank. To get the fisheyes in solution, the contents were mixed over night. A viscosity check next morning revealed a very low viscosity of the solution compared with the standard viscosity vs solution strength curves available from Hercules Incorporated. The viscosity of the field prepared solution was only 33 cp compared with the 290 cp for a standard 0.5 percent solution in distilled water. Solutions made in the laboratory with distilled water confirmed the correctness of the standard curves.

Assistance was sought from Hercules sales-services field personnel associated with the application of Hercofloc solutions. It was indicated that the water flow rate and pressures available at the site were not sufficient to provide the required vacuum needed through the eductor which was utilized for mixing the polymer. Alternate solutions such as the use of a smaller eductor, higher flow rate and substitution of another polymer were considered.

Smaller ejectors* were obtained and tried in the laboratory. None of the above models produced any encouraging results.

Alternatives open for providing higher flow rates at the site were: either to tap a 1 in. to 1½ in. line into the municipal main or to temporarily rent the fire hydrant across the road. Both of these solutions involved extra expense and neither of them provided a sure solution to the problem. Therefore, a centrifugal pump was borrowed from Rexnord stock supplies. Using a throttling valve and the pump, sufficient water pressure was generated and polymer was mixed in solution. However, several smaller fisheyes still remained in solution and an additional one-hour mixing with a lightning mixer was needed in the 400 gal tank. The viscosity of this solution was found to be 150 cp which can be considered to be quite close to the desired value because of the lowering effect on viscosity due to the increased pH of the tap water (7.4) as compared with distilled water (5.5).

*Models 62A and 63A, Pen-Berthy Mfg. Co.

It was found that the viscosity of the Hercofloc solution was very sensitive to increases in mixing time as shown below:

Mixing time, hrs	Viscosity of 0.5% Hercofloc Solution - cp
1	150
4	120
24	30

A new version of Hercofloc 810, termed 810.3, having the same polymeric properties as 810 but a different powder texture, was easier to handle. Therefore, in order to document the effect of pH and Hercofloc type and their respective deterioration with time, solutions of 810 and 810.3 were made in tap water at a pH of 5.5 and 7.5. The pH of the tap water (normally 7.4) was lowered to 5.5 with sulfuric acid for the appropriate solutions. Another solution of Hercofloc 810 was made in distilled water for comparison. A minimum of mixing time ranging from 25 to 60 min was allowed in the laboratory, and the initial viscosities of the various solutions were recorded. Table 27 shows the viscosity data at various time intervals for the various solutions.

It can be seen from this table that the viscosity decreased with time for all solutions. Although the solution was most stable in distilled water, it would have been impractical to make a 400 gal batch in the field. The Hercofloc 810.3 did not show any significant ease of mixing and handling and its viscosity decreased more rapidly than that of 810 at a solution pH of 5.5. Therefore, it was decided that the best solution to the problem was to make a Hercofloc 810 solution at a pH of 5.5, which could be stored up to 7 to 10 days and polymer pumpage be controlled according to its strength at the time of use. (For actual plant use, of course, an automated system to mix the polymer on call would be installed.)

Operation & Evaluation of the Final Bead Flotation Test

A fully satisfactory solution of the bead settling problem would have been to install an on-stream continuous bead expansion facility and feed them dry to the raw waste stream. Since such an installation was obviously beyond the scope of the present project, it was mutually decided between Hercules, USEPA and Rexnord that at least one additional field test be conducted with most optimum operation conditions to demonstrate the technical feasibility of the flocculation-flotation concept. The suitable conditions for bead expansion were a heating time of 5 min, and the use of a mixer and insulated lid over the 55 gal. tank as suggested by Koppers Co. Sufficient beads were expanded under these conditions for one test realizing that some bead damage would still result from the slurrying system. A fresh batch of 400 gal of Hercofloc 810 at a pH of 5.5 was prepared in field with Milwaukee tap water under conditions recommended previously, and its viscosity was monitored closely with time. The flow schematic utilized during this test is shown in Figure 16. Nearly all of the test flow was routed through the split flow system and through a relatively long pipe run after the injection of the flocculant and flotation aid. This was done to provide the maximum retention time possible in the test unit for the turbulent

TABLE 27. VISCOSITY DATA FOR VARIOUS HERCOFLOC SOLUTIONS WITH TIME

Storage Time Hours	Hercofloc Solution Viscosities - Centipoise[a]				
	Hercofloc 810 in Tap Water		Hercofloc 810 in Distilled Water	Hercofloc 810.3 in Tap Water	
	pH 7.4	pH 5.5	pH 5.4	pH 7.4	pH 5.5
0	111	132	295	122	160
24	18	123	280	23	127
53	16	112	268	14	91
148	18	93	240	15	38
200	18	93	240	15	38

[a]All viscosities taken with a Brookfield Viscometer at 60 rpm and at room temperature.

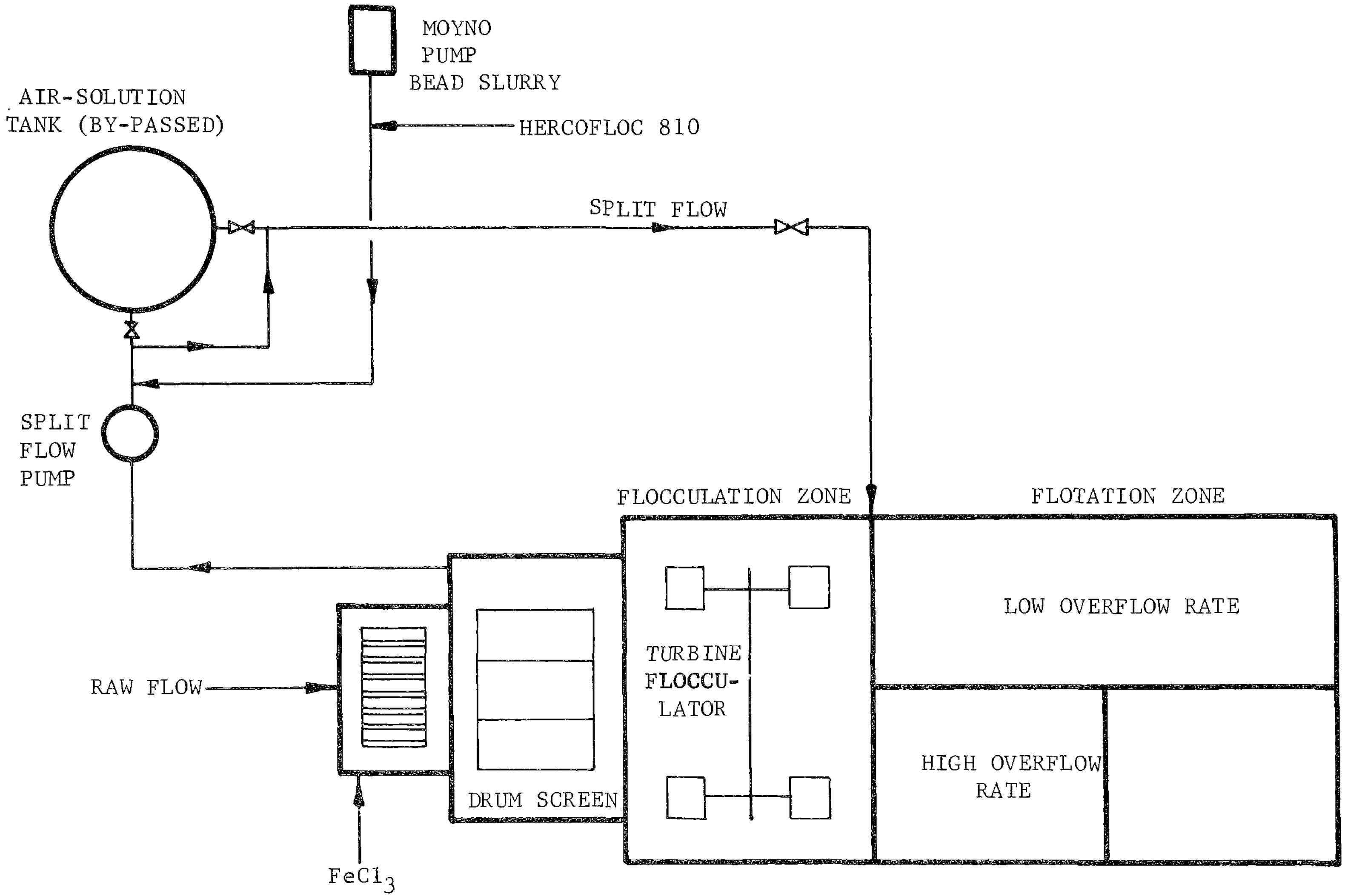


Figure 16. Process schematic for head flotation test no. 5.

mixing of coagulated sewage, flocculant and flotation aid, it having been noted in the Phase I laboratory tests that such extended agitation greatly promoted coflocculation. The overflow rates were low since only a limited flow could be so routed. The operating conditions utilized during this test were as follows:

Raw flow rate, gpm	1500
Split flow rate, gpm	930 - 950
Overflow rates, gpm/sq ft	High 3.8: Low 1.9
Bead dosage, mg/l	110
Hercofloc 810 dosage, mg/l	6.0 @ 80 cp for 0.5% Solution (equivalent to 1.65 mg/l at 290 cp)
Ferric chloride dosage, mg/l	30

Note that the viscosity of the flocculant and hence its strength had decayed significantly and the amount added was increased proportionately. On the basis of 290 cp representing full strength:

$$\frac{290}{80} = 3.62 \text{ times as weak}$$

$$\frac{6.0}{3.62} = 1.65 \text{ mg/l equivalent}$$

The effluent qualities and pollutant removal efficiencies for this test are shown in Table 28. The overall pollutant removal efficiencies for most parameters ranged between 50 and 85 percent. The removals were generally higher by 10-20 percent for the low overflow rate of 1.9 gpm/sq ft compared with the higher overflow rate of 3.8 gpm/sq ft, reflecting the process sensitivity to coflocculation time. Particulate removals as shown by suspended solids and volatile suspended solids were relatively higher (15 to 25 percent) compared with the removals for BOD, COD and TOC. Removals of 75 and 84 percent were achieved for total phosphates. Nitrogen removals were 12 and 23 percent.

Mechanically, the system worked very smoothly and no problems were encountered during the testing period. The amount of the sludge build-up at the bottom of the flotation tank was estimated to be insignificant as observed by draining out the tank at the end of the run. The pollutant removals achieved during this test were generally comparable to that expected via dissolved air flotation although the overflow rates utilized were considerably lower for this test. Some sinker beads were noticed in the composite as well as the grab samples obtained during this test, indicating that the flotation aid slurrying system was causing some bead damage even when operated for a minimum period of time.

Flotation Aid Recovery Reuse Tests

The objective of this experiment was to define the separability characteristics of the coflocculated sewage solids and flotation aids. No efforts could be made to define the quantities of coflocculated flotation

TABLE 28. BEAD FLOTATION EFFLUENT QUALITY

Analysis	Overflow Rates, gpm/sq ft 1.9 Quality mg/l	1.9 Removal %	3.8 Quality mg/l	3.8 Removal %
pH, units	6.1	-	6.2	-
Suspended Solids	39	86.5	96	66.8
Vol. Suspended Solids	15	85.1	43	57.4
COD	42	65.9	56	54.5
BOD	10	60.0	12	52.0
TOC	14	62.2	17	54.1
Soluble TOC	8	-	7	0
Total Phosphate as P	0.23	84.2	0.37	74.7
Kjeldahl Nitrogen	2.38	23.2	2.72	12.3

aid which were recovered as a percentage of those introduced into the overflow. Following run 71-1, six batch flotation aid recovery experiments were conducted with 60 gal of scum collected during the storm. The tests employed a high-shear Cowles mixer and the hydrocyclone shown in Figure 17. Analysis of solids in the scum (control sample) and a material balance on the test setup showed that most of the sewage solids in the scum could be readily separated from the flotation aid. Since coflocculation of flotation aid and sewage solids was inadequate, separation and recovery of the flotation aid was probably less difficult (required less energy) than would be the case for better coflocculated solids. Although not reflected in the results, most of the sewage solids in the scum were so loosely attached to the flotation aid that simply handling the scum caused significant separation and sedimentation of the sewage solids.

Results summarized in Table 29 show that a cyclone can be employed to separate loosely attached sewage solids from flotation aid. The higher flow rate in Bead Recovery Test 2 improved sewage solids removal slightly, from 15 percent to 25 percent. The scum sample used in Test 2 was subjected to high-shear agitation in bead recovery Tests 3 and 4 to determine if additional solids could be removed from the flotation aid. The results show only 0-1 percent additional solids removal.

Bead recovery Tests 5 and 6 were conducted to determine separation capability of the mixer-cyclone combination. Results of these two tests (11 percent and 28 percent removal of sewage solids) were not significantly different from the results in Tests 1 and 2 without high-shear agitation. Recirculation of the water plus flotation aid stream (Test No. 6) improved solids removal but overall removal remained poor.

In addition to the flotation aid recovery experiments, samples of scum were tested for viscosity, density and filtration characteristics, and recovered flotation aid was tested in batch flotation tests to assess flotation aid recycle potential.

Scum viscosity was 708 cp (Brookfield No. 1 spindle at 30 rpm) and scum density approached that of water (samples were approximately 98.5 percent water). Scum filtration time (No. 5 Watman filter paper) was quite variable but was generally longer than 5 min for a 250 cc sample.

Some tests for reusability of the partially cleaned flotation aids for Test 2 were conducted. Recovered flotation aid remixed with ferric chloride, Hercofloc 810 and Milwaukee overflow sewage verified preliminary laboratory results with Bowling Green, Maryland municipal (domestic sanitary dry-weather) sewage which showed that recovered flotation aid is reusable. Comparative batch flotation (clarification) tests with fresh and recovered flotation aid showed: (1) flotation rate is sensitive to solids coflocculation, and (2) flotation rate of the recovered material is lower than that of unused flotation aid. Clarification time for a 250 cc sample, although difficult to measure quantitatively, was about 1/3 min for unused flotation aid versus 2/3 min for the recovered material. When chemical dosage was increased to promote solids coflocculation, clarification time increased to 1-1/2 minutes.

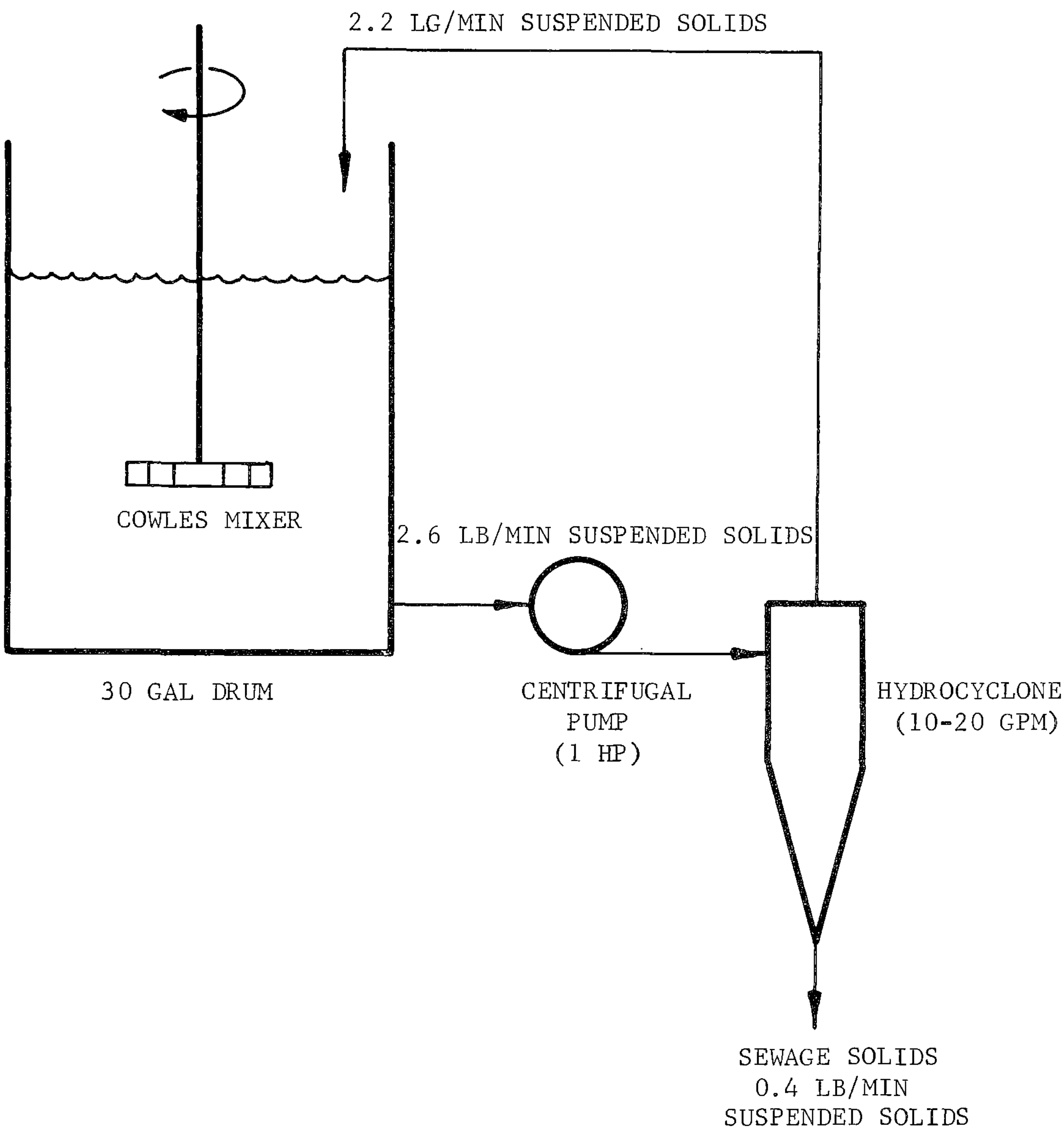


Figure 17. Schematic diagram of Dylex recovery test.

TABLE 29. FLOTATION-AID RECOVERY RESULTS

Test No.	Method	Time (min)	Flow (gpm)	Solids Removal (%)
1	Cyclone	5	10	15
2	Cyclone	15	10-20	25
3	Mixer	5	-	1
4	Mixer	15	-	0
5	Mixer + Cyclone	< 5	10	11
6	Mixer + Cyclone With Recirculation	15	10	28

CONCLUSIONS

Based on the results from storm event No. 71-5, it was demonstrated that cofloculation of beads and suspended solids found in combined sewer overflows was possible. Experiments on storm events 71-1, 71-2, and 71-3 were of very limited value with respect to data production. They served to pinpoint plant startup problems which had to be solved before any meaningful data could be generated. Unfortunately project funds were depleted with only one storm event generating useful data.

Although operating conditions were certainly not optimal for storm event 71-5, good effluent quality resulted. Overflow rates were low, about 2 gpm/sq ft , when compared with those usual to the test facility for air flotation, about 3-4 gpm/sq ft. It is not known whether solids separation efficiency would be significantly affected at higher overflow rates. The low rates for event 71-5 were necessitated by the operating requirement for a longer retention time for mixing flocculant, flotation aid and sewage solids. This requirement was met by maximizing the length of pipe through which coagulated sewage solids, flotation aid, and flocculant could flow while simultaneously mixing. This required routing essentially the entire test flow through the split flow loop, and the capacity of this loop was limited to approximately 1000 gpm.

Several technical problems arose during the field testing phase which limit the practical applicability of the concept. These may be summarized as follows:

1. Maintenance problems in the handling of flotation aids and the high energy requirements for keeping these in suspension.

2. Sensitivity of the successful cofloculation of flotation aids and suspended matter to the type of flocculant.

Problem No. 1 (above) may be mitigated to a great extent by the installation of an on-stream bead expansion and dry feed facility but this would also add additional cost to the total cost of treatment. Storage and mixing of the flocculant (Hercofloc 810) was troublesome during the field tests. However, when this polymer is used in sufficient quantity to justify the installation of proper equipment for dry storage, rapid mixing and immediate use, as would be the case in a plant installation, these problems would disappear.

The logistics of using beads for a flotation aid are very cumbersome when compared with air bubbles. The mechanism of attaching coagulated sewage solids to the bead flotation aid is a somewhat complex surface chemistry phenomenon. Radical changes in the nature of the sewage would probably necessitate an equally radical change in flocculant, whereas with air flotation the flocculation mechanism is not so sensitive. The recovery and recycle of flotation aids have been demonstrated only on a laboratory scale, although the used aids were collected from an actual storm overflow test run. Indications have been that the recovered beads may exhibit some loss of efficiency. Combined sewer overflows occur at unpredictable and inconvenient times from the point of view of system maintenance and supervision. With all the above considerations in mind, it is concluded that the operational complexities of the mechanical version of the flocculation/flotation process are such that although the process is technically workable, it is not practical and should not be utilized in the treatment of combined sewer overflows. Any future field testing should be terminated.

SECTION VI

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Project Officers: Clifford Risley, 312-353-2200
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16. ABSTRACT

The objectives of this study were to investigate the flocculation/flotation characteristics of combined sewer overflow through laboratory and field testing. The concept involves the introduction of chemicals and buoyant flotation aids into the overflow and the subsequent coflocculation of the suspended sewage solids about the aids which rise to the surface from where they may be removed by skimming.

Recovery, cleaning and reuse of the flotation aids was judged essential to economic feasibility for the flocculation/flotation process. Field testing of recovered used aids indicated a disparity in requirements. When the bonding, or coflocculation, of suspended sewage solids to the fresh aid surface was sufficiently strong to provide a high degree of suspended solids removal, subsequent efforts to clean or remove the solids in anticipation of aid reuse were unsuccessful. This deficiency, coupled with the overall mechanical complexity of the process, resulted in the investigation concluding that the flocculation/flotation process is not as promising for broad field application to the storm overflow problem as the similar dissolved air flotation process. No further investigation of the flocculation/flotation process is recommended.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Coagulation, *Combined sewers, Flocculants, *Flocculating, *Flotation, Flotation conditioning, Flotation Reagents, Sewage, Water pollution, Sewage treatment,	Combined sewer overflows, Treatment screening/ dissolved air flotation, Sewage effluents	13 B

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