REPORT

on

THE EFFECTS OF DESIGN AND OPERATING VARIABLES ON REMOVAL OF M. B. A. S. BY TRICKLING FILTERS

For

The Soap and Detergent Association

by

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INTRODUCTION

The effects of the changeover from the use of ABS to LAS compounds in detergent formulations were studied extensively before, during, and after conversion by the detergent industry. The many investigations included laboratory, pilot plant, and full-scale field studies of a wide variety of biological treatment facilities and indicate clearly that the changeover to LAS was followed by very significant improvements in removals of methylene blue active substances (M.B.A.S.) during biological treatment which resulted in sharply reduced surfactant discharges into receiving streams.

Many authors have indicated that efficiency of LAS removal is related to overall quality of treatment, and it has been suggested that a direct relationship frequently may exist in biological treatment between the degrees of LAS and BOD removals. However, this correlation appears to vary significantly among different biological treatment facilities, some types of plants inherently giving more efficient LAS removals than others.

The results of field sampling programs indicated that the degrees of LAS removal attained in different trickling filter plants may appear to be inconsistent at times. For example, the high-rate trickling filter plant in Chapel Hill, North Carolina, typically gives LAS removals of about 40%, with BOD removal of 75-80%. On the other hand, many other trickling filter installations in the U.S.A., and more especially in England, consistently produce much higher LAS removals, numerically approximating the degrees of BOD removal by those same facilities. Further, published results for laboratory or small pilot units frequently have shown higher LAS removals than those observed in the Chapel Hill plant.

This situation suggested that unidentified design or operating variables could have radical influence on efficiencies of LAS removals in trickling filter installations. Continued interest of the Soap and Detergent Association in improving LAS removals in wastes treatment facilities led to establishment of this project in the hope that identification and evaluation of the key process variables might suggest modifications in design and operation of trickling filter plants which could improve efficiencies of these facilities.

PURPOSE AND SCOPE OF THE INVESTIGATION

The overall purpose of this project was to evaluate the effects of several variables on removal efficiencies of LAS and BOD by trickling filters. More specifically, the variables investigated included: (a) frequency of dosing, (b) recycle ratio, (c) BOD loading, and (d) filter depth.

The effect of each variable was investigated over a wide range, using two relatively large pilot plants constructed at the Mason Farm Sewage Treatment plant of the town of Chapel Hill. This arrangement provided, in effect, three units from which experimental information could be obtained--the Chapel Hill sewage treatment plant itself, and the two pilot units designed to operate on the same flow sheet with the same influent.

CHAPEL HILL WASTEWATER TREATMENT PLANT

The Chapel Hill, North Carolina, Wastewater Treatment facility is a thoroughly conventional high-rate trickling filter plant, a flow-sheet of which is shown across the top of Figure 1. Influent wastewater passes through a

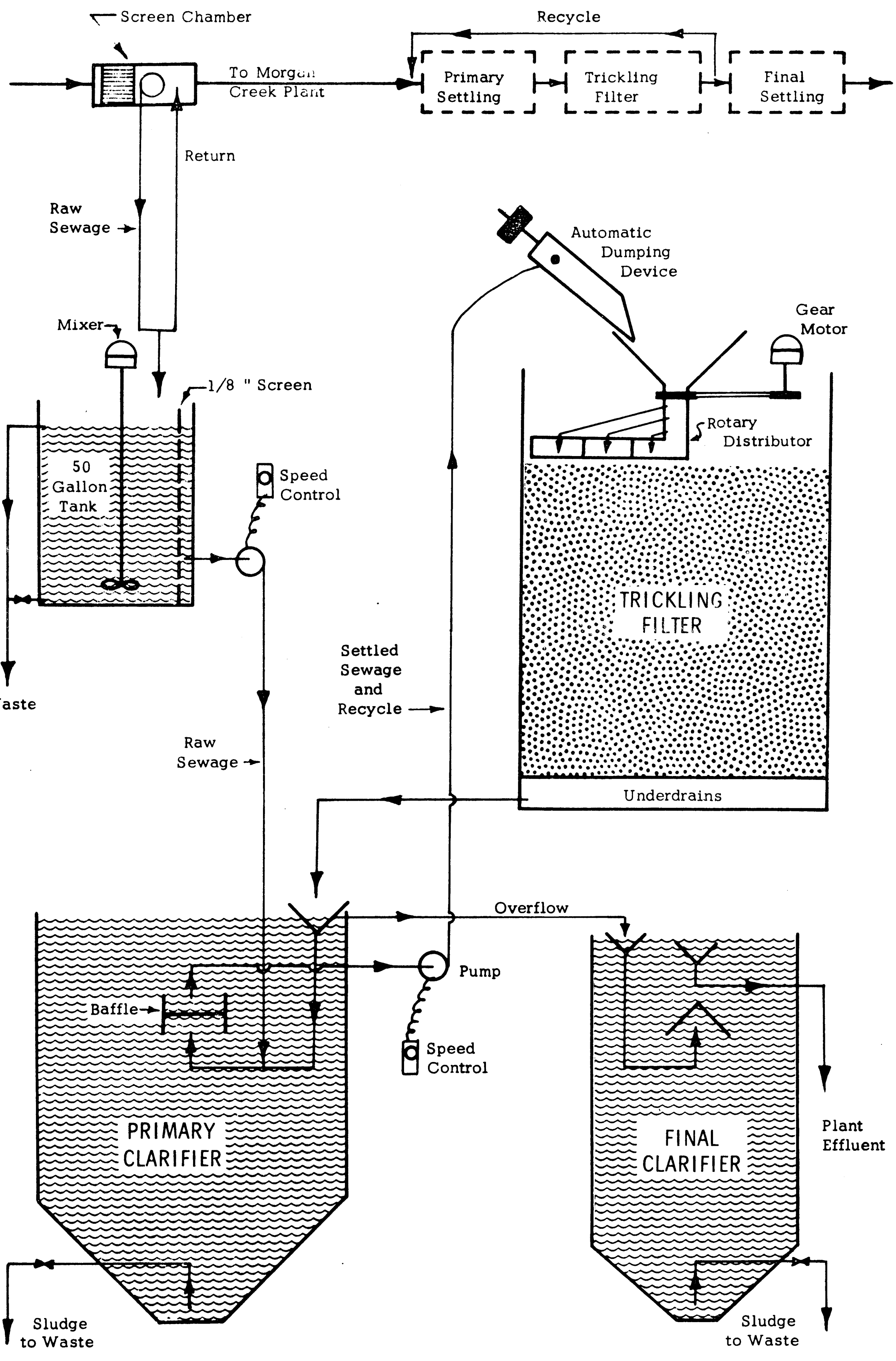

FIGURE I

FLOW SHEET OF PILOT FACILITIES

mechanically cleaned screen for removal of large suspended materials which could interfere with plant operation. Subsequently, screened sewage passes into the primary settling basin, after being mixed with recycled trickling filter effluent.

Design parameters for the plant, summarized in Table 1, are based on 1.50 mgd of untreated wastewater and a recycle rate of 3.00 mgd. The 70 foot diameter primary clarifier provides a detention of 1.8 hours at design flow for mixed influent and recycle. The trickling filter is 120 feet in diameter, with a stone depth of 4.25 feet, providing a loading of 53 lbs. of BOD/day/1000 cf and a hydraulic application rate of 17.4 MGAD. Effluent from the trickling filter passes through a wet well from which recycle is withdrawn at desired rates up to 3.0 mgd. The plant throughput passes to the final clarifier, which is 45 ft. in diameter and provides a detention of 1.9 hours. The plant also includes a single 50 ft. diameter anaerobic digester, equipped with floating cover and heat exchanger. Sludge drying is by open sand beds.

The facility receives wastewater from the Town of Chapel Hill. This is predominantly domestic sewage, with no industrial type of contribution except for a hospital and laboratories connected with the University. Operation of the treatment plant routinely was performed on a part-time basis by personnel in the Public Works department of the Town.

DESIGN AND OPERATION OF PILOT UNITS

After careful analyses of alternatives it was decided that the most desirable approach for this investigation would be to build and operate two relatively large pilot plants, generally similar to the full-scale Chapel Hill facility. These should be of sufficient size and operated in a fashion to insure performance equivalent to the full-scale unit, requiring that they be constructed at the sewage treatment plant.

TABLE 1

DESIGN PARAMETERS FOR CHAPEL HILL WASTEWATER TREATMENT PLANT

Average Design Flow, mgd	1.50
Recycle, mgd	3.00
Primary Clarifier:	
Diameter, feet	70
Water Depth, feet	12
Overflow Rate, gals/ft^2/day	1180
Detention, Hours	1.8
Trickling Filter:	
Diameter, feet	120
Stone Depth, feet	4.25
*BOD Load, lbs/day	2550
*BOD Loading, lbs/day/1000 c.f.	53
Hydraulic Loading, MGAD	17.4
Final Clarifiers:	
Diameter, feet	45
Water Depth, feet	10
Overflow Rate, gals/ft^2/day	960
Detention, Hours	1.9

*Neglecting removal in primary settling.

The pilot units were designed to provide maximum experimental flexibility, using a basic flow sheet identical with that for the Chapel Hill plant, as shown in Figure 1. A centrifugal pump continuously circulated screened but unsettled sewage from the influent of Morgan Creek sewage treatment plant to the site of the pilot facility and back to the screen chamber. The flow in this system was considerably in excess of pilot plant requirements to insure adequate velocity and short detention time in the pipeline. A portion of the flow (5-10 gpm) was allowed to pass into a 50-gallon tank, located in a building adjacent to the pilot facility, and sewage in excess of that required by the two pilot plants overflowed continuously to waste.

The drum was continuously mixed to prevent settling of solids and influent sewage to the pilot units was withdrawn through a screen with openings of 1/8 inch to prevent clogging of small pumps and pipelines. This screen had no significant effect on LAS, BOD, or suspended solids content of wastes applied to the pilot units.

Each pilot plant represented a scale of 0.11% of the full Chapel Hill plant and design influent flow was approximately 1.2 gpm. Other design criteria are shown in Table 2. All flows were controlled through use of variable speed pumps, with D.C. motors regulated by silicon controlled rectifiers. Pilot plant influent was discharged into the inlet of the primary clarifier and daily measurements of influent rates of flow indicated that they remained substantially constant for long periods of time.

The primary settling tank provided the same detention time at design flow as in the Chapel Hill plant. To avoid geometric distortion of the unit, its depth was reduced to 5 feet 6 inches from the 12 foot water depth of the large plant. These design parameters produce a pilot plant overflow rate substantially lower than that for the Chapel Hill plant. The raw sewage and effluent from the trickling filter were mixed just

TABLE 2

DESIGN PARAMETERS FOR PILOT PLANTS

Volumetric Scale Factor: Pilot/Chapel Hill	0.11%
Design Flow, gpm	1.16
Recycle, gpm	2.32
Primary Clarifier:	
Diameter, feet	3.75
Water Depth, feet	5.5
Volume, gallons	385
Overflow Rate, gals/ft^2/day	460
Detention, Hours	1.8
Trickling Filter:	
Diameter, feet	4.0
Stone Depth, feet	4.25
*BOD Loading, lbs/day/1000 c.f.	53
Hydraulic Loading, MGAD	17.4
Final Clarifier:	
Diameter, feet	2.25
Water Depth, feet	5.3
Volume, gallons	132
Overflow Rate, gals/ft^2/day	420
Detention, Hours	1.9

*Neglecting removal in primary settling.

prior to entering the clarifier, as in the full-scale plant.

The plant throughput was controlled by allowing effluent from the trickling filter to overflow into the inlet of the final settling tank. This basin also was designed on the basis of providing the same detention time, but an overflow rate substantially lower than that of the Chapel Hill plant, because of shallower depth. All settling tanks were equipped with sludge drawoff lines for hydrostatic removal of solids accumulated.

Settled effluent from the primary tank, including both sewage and recycle, was pumped to the trickling filter. Because one of the variables to be investigated was frequency of liquid application, an automatic, hydraulically-actuated, dumping unit was installed to allow accumulation of flow for periodic discharge onto the filter. Upon dumping, the influent passed rapidly down through a funnel and flow splitting device to a motorized rotary distributor. The latter operated at 30 rpm and was carefully designed to distribute influent flow uniformly over the stone in proportion to surface area served by each segment of the rotating element. The period of time required for distribution of contents of the dumping unit over surface of the filter was about three seconds.

The filters were designed to operate under conditions simulating, as closely as possible, a typical section or "core" of the Chapel Hill filter. A diameter of four feet was selected for the pilot filters, this being considered as reasonably safe for minimizing wall effects. Conventional filter underdrains were used, as manufactured by Pomona Pipe Products Company, identical with those used in the full-scale plant. Filter effluent flowed into an open channel leading to the influent of the primary clarifier and effluent in excess of that needed for recycle to the filter overflowed by gravity to the final tank.

Inner and outer walls of the filter consisted of two vertical concentric sections of Armco corrugated steel pipe, six feet long and 48 and 54 inches in diameter, respectively. The annular space between these sections of pipe was filled with rock wool insulation to reduce heat losses during cold-weather operation. Stone placed in the filter was selected to meet specifications of the N.C. Stream Pollution Control authorities, requiring that it be retained on a two-inch square screen and pass a 3½ inch square screen, with less than 45% passing a 2½ inch screen. Stone received at the site was manually passed over a two inch mesh to insure exclusion of particles smaller than the allowable minimum. Subsequently, it was hand-placed in the filters to a depth of 4.25 feet, which is the same as that of the Chapel Hill filters. Design of the pilot filters permitted future increases in depth with minimum difficulty.

Because it was desired to obtain data on a year round basis, all units were enclosed except for the filters, which were insulated as indicated previously. The settling tanks, pumps, flow control equipment, and sampling equipment all were installed in a building constructed for the purpose and electric heaters made it possible to maintain liquid temperatures of at least 12° C at all times, except during one or two unusually cold spells.

Samples were taken automatically at hourly intervals and composited into containers in a refrigerator. Those collected included Chapel Hill plant influent, Chapel Hill plant effluent, and effluent from each of the two pilot plants. All pipelines were automatically flushed thoroughly before collection of each sample. Based on past experience, it was not deemed worthwhile to analyze samples on a daily basis; but weekly composites would have required much too long on each flow pattern before collection of enough data to permit realistic conclusions. Accordingly, the daily refrigerated samples were composited before analyses to provide one of each type of sample covering Monday and Tuesday, one covering Wednesday and Thursday, and one covering Friday, Saturday, and Sunday.

CORRELATION BETWEEN THE DIFFERENT PLANTS

Construction of the pilot facilities was initiated in June, 1966, and completed in September. Sewage and recycle flows were applied beginning about September 15 and continued for approximately five weeks thereafter before samples were collected for analyses. This period of preliminary operation was considered the minimum necessary to allow establishment of biological growth. Also during that time, certain plants modifications were made to insure a reliable, trouble-free installation.

The first test period consisted of several weeks of operation in parallel with the Chapel Hill facility to determine whether performance of the pilot units correlated reasonably closely with each other and with the full-scale plant. All samples were analyzed for methylene blue active substances (MBAS), five-day BOD, and suspended solids, in accordance with procedure specified in Standard Methods for the Examination of Water and Wastewater (12th Edition).

Table 3 summarizes the operating data for all three plants from November 14 to December 13. The period from October 23 to November 13 was eliminated from the averages because of occasional minor operating difficulties. Unfortunately, the Chapel Hill plant was incapable of maintaining a recycle ratio of 2.0 during this period, as originally planned, because of mechanical difficulties. Accordingly, it is not feasible to compare directly results from the pilot plants and the Chapel Hill plant and no firm conclusions can be reached concerning their correlation. On the other hand, the difference in performance appear to be entirely reasonable, when considered in the light of lower recycle ratio and temperature in the Chapel Hill plant. Further, the level of MBAS removal by the pilot plants is well within the range frequently observed for the Chapel Hill plant at higher temperatures and recycle, when BOD removals had been comparable

TABLE 3

SUMMARY OF DATA - PERIOD NO. 1

PERFORMANCE OF PILOT PLANTS IN PARALLEL OPERATION

OCTOBER 23 - DECEMBER 13, 1966*

Parameter	Pilot Plant No. 1	Pilot Plant No. 2	Chapel Hill Plant
Influent MBAS, mg/l	5.0	5.0	5.0
Effluent MBAS, mg/l	2.8	2.7	3.3
MBAS Removal, %	44	46	34
Influent BOD, mg/l	157	157	157
Effluent BOD, mg/l	31	26	47
BOD Removal, %	80	83	70
Influent S.S., mg/l	175	175	175
Effluent S.S., mg/l	38	23	66
S.S. Removal, %	78	87	64
Influent Temp. °C	20	20	20
Effluent Temp. °C	16	16	13
Influent Flow, gpm	1.19	1.20	1250
Recycle, gpm	2.35	2.38	1110
Recycle Ratio	1.97	1.98	0.89
BOD Loading, lbs/day/1000 c.f.	42	42	49
Hydraulic Loading, MGAD	17.7	17.8	13.1
Dosing Frequency, Sec.	15	15	22
Primary Detention, Hrs.	1.82	1.79	2.45
Primary Overflow, Gals/ft^2/day	460	470	880
Final Detention, Hrs.	1.85	1.83	1.59
Final Overflow, Gals/ft^2/day	430	440	1130

*Results based on data collected Nov. 14 - Dec. 13

with those observed in the pilot units during this period (summarized in Figures 2 and 3, pages 36 and 38).

Data from the two pilot plants indicate substantial agreement with each other in MBAS and BOD removals. Although the performance of pilot plant No.2 appears to be slightly better than that of No. 1, the margin of difference is too small to be considered significant in view of variability normally expected in such systems.

Table 4 summarizes additional data obtained during another period of parallel operation of the pilot plants about a year later, but at higher operating temperatures. These data also reveal comparable performance of two plants when operated under identical conditions. Improved BOD and MBAS removals in Table 4 can be attributed to higher operating temperatures.

The data in Tables 3 and 4, and others to be presented subsequently, indicate clearly that the two pilot plants produced equivalent performance when operated under comparable conditions.

EFFECT OF DOSING FREQUENCY

It has been noted that LAS removals by the Chapel Hill sewage treatment plant are substantially lower than some which have been described in the literature for pilot investigations. One obvious difference between pilot and full-scale trickling filters is that wall effects in a small unit may be substantial. A detrimental effect could be encountered because of short circuiting along the wall, or a beneficial one because of the additional area available for accumulation of biological growth. In these investigations, wall effects were minimized by using large - 4 foot diameter - filters.

Another obvious difference is the method of dosing. In a full-scale trickling filter, with rotary distributor, each small area of stone is dosed intermittently as the distributor arms pass over it. In the Chapel Hill plant the interval between applications may vary from about 15 seconds, at a recycle ratio of 2.0,

TABLE 4

SUMMARY OF DATA - PERIOD NO. 6

PLANTS IN PARALLEL OPERATION

SEPTEMBER 1 - OCTOBER 25, 1967*

Parameter	PILOT PLANT NO. 1	PILOT PLANT NO. 2
Influent MBAS, mg/l	3.9	3.9
Effluent MBAS, mg/l	1.5	1.6
MBAS Removal, %	61	59
Influent BOD, mg/l	218	218
Effluent BOD, mg/l	24	23
BOD Removal, %	89	89
Influent S.S., mg/l	243	243
Effluent S.S., mg/l	46	41
S.S. Removal, %	81	83
Influent Temp. °C	25	25
Effluent Temp. °C	21	21
Influent Flow, gpm	1.22	1.21
Recycle, gpm	2.46	2.46
Recycle Ratio	2.0	2.0
BOD Loading, lbs/day/1000 c.f.**	60	60
Hydraulic Loading, MCAD	18	18
Primary Detention, Hrs.	1.74	1.74
Primary Overflow, Gals/ft^2/day	480	480
Final Detention, Hrs.	1.80	1.80
Final Overflow, Gals/ft^2/day	440	440

*Results based on data collected September 24 - October 25

**Neglecting removal in primary settling

to over 40 seconds with no recycle. Thus, in spite of continuous flow to the filter, each specific area of stone receives its proportional share of that flow within 1-2 seconds, or less, at a frequency of 15-40 seconds. This could result in a flow pattern down through the bed significantly different from that in most small pilot units, where the application usually is in smaller increments at more frequent intervals.

This consideration led to development of a hypothesis that the removal of LAS by a filter could be significantly affected by the dosing pattern. Because this variable would be present in all of the studies, and could be very difficult to control, it was selected as the first for investigation. The hydraulically-actuated dumping device on pilot plant No. 2 was inactivated, allowing the flow to pass continuously through the distributor. With a distributor speed of 30 rpm, this gave an actual dosing interval of two seconds on any specific area of stone. The dumping unit on plant No. 1 was adjusted for a convenient, relatively long period--in this instance about 25 seconds.

The two pilot plants were operated in this fashion approximately at design flow, as shown in Table 5, from December 14 through February 21, 1967. From February 22 through March 19 they were reversed in function, No. 1 being dosed continuously while No. 2 received intermittent application of influent as shown in Table 6. This was done to insure that results obtained during the first test period were not artifacts of the two systems, but truly represented the effect of dosing frequency. The relatively long investigation, approximately three months, was adopted to insure that the pilot plants had stabilized in performance. Results for the two periods are summarized individually in Tables 5 and 6. Table 7 summarizes all of the data for both experimental periods, from December 14 through March 19.

Table 5 indicates slightly better performance of the unit receiving continuous application of sewage and recycle, but this observation is nullified in

TABLE 5

SUMMARY OF DATA - PERIOD NO. 2

EFFECT OF DOSING FREQUENCY ON PLANT PERFORMANCE

DECEMBER 14, 1966 - FEBRUARY 21, 1967*

Parameter	PILOT PLANT NO. 1	PILOT PLANT NO. 2
Influent MBAS, mg/l	4.6	4.6
Effluent MBAS, mg/l	2.8	2.6
MBAS Removal, %	39	42
Influent BOD, mg/l	129	129
Effluent BOD, mg/l	33	28
BOD Removal, %	74	78
Influent S.S., mg/l	166	166
Effluent S.S., mg/l	31	28
S.S. Removal, %	81	83
Influent Temp. °C	16	16
Effluent Temp. °C	16	16
Influent Flow, gpm	1.17	1.18
Recycle, gpm	2.40	2.39
Recycle Ratio	2.05	2.03
BOD Loading, lbs/day/1000 c.f.	34	34
Hydraulic Loading, MGAD	17.9	17.9
Dosing Frequency, Sec.	27	Continuous
Primary Detention, Hrs.	1.80	1.80
Primary Overflow, Gals/ft^2/day	470	470
Final Detention, Hrs.	1.88	1.87
Final Overflow, Gals/ft^2/day	430	430

*Results based on all data, except Jan. 13-22

TABLE 6

SUMMARY OF DATA - PERIOD NO. 3

ADDITIONAL STUDIES OF EFFECT OF DOSING FREQUENCY

FEBRUARY 22 - MARCH 19, 1967*

Parameter	PILOT PLANT NO. 1	PILOT PLANT NO. 2
Influent MBAS, mg/l	5.1	5.1
Effluent MBAS, mg/l	2.9	2.7
MBAS Removal, %	43	47
Influent BOD, mg/l	177	177
Effluent BOD, mg/l	40	33
BOD Removal, %	77	81
Influent S.S., mg/l	180	180
Effluent S.S., mg/l	29	27
S.S. Removal, %	84	85
Influent Temp. °C	17	17
Effluent Temp. °C	16	1[illegible]
Influent Flow, gpm	1.18	1.1[illegible]
Recycle, gpm	.3[illegible]	.3[illegible]
Recycle Ratio	2.02	2.00
BOD Loading, lbs/day/1000 c.f.	47	47
Hydraulic Loading, MGAD	17.[illegible]	17.9
Dosing Frequency, Sec.	Continuous	22
Primary Detention, Hrs.	1.80	1.80
Primary Overflow, Gals/ft^2/day	470	470
Final Detention, Hrs.	1.86	1.85
Final Overflow, Gals/ft^2/day	430	430

*Results based on data collected Mar. 5-19

Table 6 which shows the opposite. It appears that the variations in performance may be related more to inherent difference between the two plants than to frequency of dosing. In all instances, the MBAS removal was well within the range commonly observed in the full-scale plant when BOD removals in that facility were comparable with those in Tables 5 and 6.

Table 7 was prepared by averaging all data for both experimental periods to permit overall evaluation of the effect of dosing frequency. The first column in Table 7 was derived by averaging all results for plant No. 2 in Table 5 and plant No. 1 in Table 6.

It is concluded that the removals of MBAS, BOD, and suspended solids were not influenced significantly by dosing frequency within the range investigated. Of course, it would be reasonable to expect that extension of dosing frequency to very long periods could affect plant performance, as observed in some relatively recent studies in England. However, the range of dosing frequency investigated here covers that which would be experienced in the Chapel Hill plant, in most of this pilot plant work, and probably in most full-scale rotary distributor trickling filters. Thus, for the purpose of these studies, it may be concluded that dosing frequency is not a key variable causing discrepancies between LAS removals observed in the Chapel Hill plant and higher removals reported for other plants or pilot units.

EFFECT OF RECIRCULATION

The next variable selected for investigation was recirculation. Based on observations by others concerning effects of variables on removals of BOD and chemicals, it was anticipated that MBAS removals should increase with recycle ratio.

On April 14, 1967, the recycle in Plant 1 was increased to a ratio of 3.75:1 and recycle was eliminated entirely in Plant 2 by delivering sewage in

TABLE 7

EFFECT OF DOSING FREQUENCY ON PLANT PERFORMANCE

SUMMARY OF ALL DATA, PERIODS 2 AND 3

Parameter	Continuous Dosing	Intermittent Dosing
Influent MBAS, mg/l	4.7	4.7
Effluent MBAS, mg/l	2.7	2.8
MBAS Removal, %	42	40
Influent BOD, mg/l	138	138
Effluent BOD, mg/l	30	33
BOD Removal, %	78	76
Influent S.S., mg/l	169	169
Effluent S.S., mg/l	28	30
S.S. Removal, %	83	82
Effluent Temp. °C	16	16
Recycle Ratio	2.03	2.04
BOD Loading, lbs/day/1000 c.f.	37	37
Hydraulic Loading, MGAD	17.9	17.9
Dosing Frequency, Sec.	Continuous	26

excess to the primary clarifier and pumping settled sewage to the trickling filter at a flow equal to the rate of application of raw sewage to Plant 1. Effluent from trickling filter No. 2 was diverted directly to the final settling tank. Thus, Plant No. 2 operated on a once-through pattern, similar to a low-rate trickling filter at BOD and MBAS loadings equivalent to Plant 1.

Table 8 summarizes data obtained under this operating mode from April 14 through May 23. BOD and suspended solids removals responded to differences in recirculation ratios in general accord with expectations. However, although increase in recirculation from zero to 3.75:1 increased BOD removal from 80% to 89%, a corresponding response was not observed in MBAS removal which remained 72% for both plants in spite of the radical difference in recycle ratio. Inspection of data and operating logs revealed no clear reason for this phenomenon, and it was decided to reverse the two plants to explore the possibility of operational artifacts in the two systems. Accordingly, Plant No. 2 was converted to a recycle ratio of 3.68:1 and recycle was eliminated on Plant 1, with rate of sewage application retained at the same level as in earlier studies.

Table 9 summarizes the results obtained from June 14 through August 31, 1967 and shows clearly a favorable effect of higher recycle on MBAS, BOD, and suspended solids removals. A substantial spread is observed in MBAS removals for the two plants, with a spread in BOD removals greater than that in Table 8. Comparison of data in Tables 8 and 9 appeared to be consistent with the possible hypothesis that Plant No. 2 could be inherently more efficient than Plant No. 1 for MBAS removal, causing equal performances in Table 8 and widely spread performances in Table 9. Although this hypothesis was inconsistent with earlier observations, it was decided that the plants should be returned to parallel operation to evaluate again their equivalence in performance.

TABLE 8

SUMMARY OF DATA - PERIOD NO. 4

EFFECT OF RECIRCULATION ON PLANT PERFORMANCE

APRIL 14 - MAY 23, 1967*

Parameter	PILOT PLANT NO. 1	PILOT PLANT NO. 2
Influent MBAS, mg/1	3.9	3.9
Effluent MBAS, mg/1	1.1	1.1
MBAS Removal, %	72	72
Influent BOD, mg/1	326	326
Effluent BOD, mg/1	37	65
BOD Removal, %	89	80
Influent S.S., mg/1	263	263
Effluent S.S., mg/1	48	86
S.S. Removal, %	82	67
Influent Temp. °C	20	20
Effluent Temp. °C	18	18
Influent Flow, gpm	1.18	1.27
Recycle, gpm	4.43	None
Recycle Ratio	3.75	0
BOD Loading, lbs/day/1000 c.f.**	87	93
Hydraulic Loading, MGAD	28.1	6.4
Dosing Frequency, Sec.	18	15
Primary Detention, Hrs.	1.15	4.43
Primary Overflow, Gals/ft^2/day	735	165
Final Detention, Hrs.	1.86	1.73
Final Overflow, Gals/ft^2/day	430	460

*Results based on data collected May 3-23

**Neglecting removal in primary settling

TABLE 9

SUMMARY OF DATA - PERIOD NO. 5

EFFECT OF RECIRCULATION ON PLANT PERFORMANCE

JUNE 14 - AUG. 31, 1967*

Parameter	PILOT PLANT NO. 1	PILOT PLANT NO. 2
Influent MBAS, mg/l	3.2	3.2
Effluent MBAS, mg/l	1.8	0.7
MBAS Removal, %	44	78
Influent BOD, mg/l	212	212
Effluent BOD, mg/l	69	17
BOD Removal, %	67	92
Influent S.S., mg/l	357	357
Effluent S.S., mg/l	121	78
S.S. Removal, %	66	78
Influent Temp. ^{o}C	25	25
Effluent Temp. ^{o}C	21	21
Influent Flow, gpm	1.26	1.19
Recycle, gpm	None	4.39
Recycle Ratio	0	3.68
BOD Loading, lbs/day/1000 c.f.**	60	57
Hydraulic Loading, MGAD	6.3	27.9
Dosing Frequency, Sec.	22	16
Primary Detention, Hrs.	4.42	1.38
Primary Overflow, gals/ft^2/day	180	730
Final Detention, Hrs.	1.75	1.85
Final Overflow, gals/ft^2/day	460	430

*Results based on data collected June 21 - August 31

**Neglecting removal in primary settling

On September 1, 1967, the plants were again placed in parallel operation with identical rates of sewage application and recycle ratio of 2.0, as summarized earlier in Table 4. This is basically the same operational mode as that reported in Table 3. Also, since dosing frequency in the range investigated was found to have no significant effect, these data also are comparable with those reported in Tables 5 and 6. In such comparisons, however, it should be noted that the operating temperatures were several degrees higher for data reported in Table 4, which accounts for higher BOD and MBAS removals. It is obvious from Table 4 that there was no significant difference in performance with the two plants in parallel operation during a period of almost two months. This reconfirms the earlier conclusion and effectively cancels the hypothesis concerning disparities between results reported in Tables 8 and 9.

Because of the disparity in results, data for Table 9 had been collected over several weeks to assure stability of operation as contrasted with Table 8, which covered a substantially shorter term while the filters were undergoing transition from cold to warm operating conditions. Thus, it was felt that results in Table 8 constituted the weaker link and the plants were returned to that operating mode for further study. Table 10 summarizes results obtained from October 26 - December 6, with 4.0:1 recycle on Plant 1 and no recycle on Plant 2. This mode of operation was not continued longer because results appeared to be very consistent, without recognizable trends away from the data reported in Table 10. A distinct beneficial effect was observed by higher recirculation and this effect applied to both MBAS and BOD removals. The difference in general levels of performance between Tables 9 and 10 appear to be reasonable when attributed to temperature effects.

Comparison of Table 10 with Table 8, representing similar operating conditions including temperature, creates something of a scientific dilemma.

TABLE 10

SUMMARY OF DATA - PERIOD NO. 7

EFFECT OF RECIRCULATION ON PLANT PERFORMANCE

OCTOBER 26 - DECEMBER 6, 1967*

Parameter	PILOT PLANT NO. 1	PILOT PLANT NO. 2
Influent MBAS, mg/l	3.5	3.5
Effluent MBAS, mg/l	1.7	2.3
MBAS Removal, %	51	34
Influent BOD, mg/l	172	172
Effluent BOD, mg/l	32	55
BOD Removal, %	81	68
Influent Temp. °C	21	21
Effluent Temp. °C	17	17
Influent Flow, gpm	1.23	1.21
Recycle, gpm	4.92	None
Recycle Ratio	4.0	0
BOD Loading, lbs/day/1000 c.f.**	48	47
Hydraulic Loading, MGAD	31	6.1
Primary Detention, Hrs.	1.04	5.3
Primary Overflow, Gals/ft^2/day	810	160
Final Detention, Hrs.	1.79	1.82
Final Overflow, Gals/ft^2/day	450	440

*Results based on data collected Nov. 9 - Dec. 6

**Neglecting removal in primary settling

Under identical operating patterns, several months apart, entirely different levels of performance were obtained and different recirculation effects were noted. The author frankly is at a loss to explain these discrepancies, but is more inclined to accept data in Table 10 in preference to those in Table 8. One reason for this decision is that results reported in Table 8 for Plant 2 are highly inconsistent with MBAS removals observed earlier at Chapel Hill, which indicate that at BOD removals around 80%, MBAS removals typically approximate 40% - 50%, never experiencing removals as high as 72%. Results for Plant 1, on the other hand, do not appear to be unreasonable with respect to the relationship between BOD and MBAS removals. A second reason for being more inclined to accept the data in Table 10 is that during March - May the pumps originally installed in the plant began to give occasional electrical and mechanical problems. They were replaced during the summer with new units, giving improved hydraulic control. Further, the several parallel runs described earlier indicated clearly that the two plants were indeed comparable in performance, which is inconsistent with Table 8.

Thus, results in Tables 9 and 10 appear to be much more consistent with the overall mass of data than those in Table 8 and lead to the conclusion that recirculation has a beneficial effect on removal of MBAS, as it does on BOD removal.

EFFECT OF INFLUENT LOADING

Results of the earlier studies in this program indicated clearly that obtaining of consistently high MBAS removals in high rate trickling filter plants would require design and operational modifications beyond mere increases in recycle ratio within ranges commonly employed in practice. Accordingly, the investigation was continued to evaluate the effects of rate of influent application to the filter on efficiency of MBAS removal.

On January 20, Plant No. 1 was returned to the "design" influent flow rate of 1.25 gpm and a recycle ratio of 2.0, which produce loadings substantially equivalent to those in the Chapel Hill plant. The influent to Plant No. 2 was reduced to 0.30 gpm, and recycle ratio was set at 2.0 (0.60 gpm). Table 11 summarizes data obtained between February 8 and March 18 under those operating conditions. B.O.D. and M.B.A.S. removals by Plant No. 1 are consistent with results obtained earlier under comparable conditions. Plant No. 2 produced substantially higher BOD and MBAS removals, indicating clearly a substantial beneficial effect from reduction in influent loading.

From March 19 to May 29, the flows applied to Plant No. 2 were increased to a level to one-half of those for Plant No. 1 to obtain further information on the effect of loading on M.B.A.S. removals, while Plant No. 1 was continued under the "design" conditions as a control. Improved BOD and M.B.A.S. removals in Table 12 for Plant No. 1, over those reported in Table 11, can be attributed to increased temperatures and appear to be generally consistent with effects observed earlier. Table 12 shows removals of M.B.A.S. and BOD for Plant No. 2 comparable with those in Table 11, in spite of doubling the rate of influent application, which may be attributed to increased operating temperature. It will be noted that the difference in performance between Plants 1 and 2 was substantially less than that reported in Table 11 which appears to be consistent with the changes in operating conditions (loading and temperature) between the two periods.

On June 1, the two plants were reversed in operating mode until June 26 to provide a brief confirmation that differences in performance noted earlier actually could be attributed to differences in loadings, as opposed to artifacts of the two treatment facilities. Table 13 summarizes results for this period, which are consistent with those reported in Table 12. It is concluded that

TABLE 11

SUMMARY OF DATA - PERIOD NO. 8

EFFECT OF INFLUENT LOADING ON PLANT PERFORMANCE

JANUARY 20 - MARCH 18, 1968*

Parameter	PILOT PLANT NO. 1	PILOT PLANT NO. 2
Influent MBAS, mg/l	3.7	3.7
Effluent MBAS, mf/l	2.1	1.0
MBAS Removal, %	43	73
Influent BOD, mg/l	159	159
Effluent BOD, mg/l	43	16
BOD Removal, %	73	90
Influent S.S., mg/l	320	320
Effluent S.S., mg/l	58	14
S.S. Removal, %	82	96
Influent Temp. °C	9	9
Effluent Temp. °C	8	8
Influent Flow, gpm	1.25	0.30
Recycle, gpm	2.50	0.60
Recycle Ratio	2.0	2.0
BOD Loading, lbs/day/1000 c.f.**	48	11
Hydraulic Loading, MGAD	19	4.5
Primary Detention, Hours	1.70	6.2
Primary Overflow, gals/ft^2/day	490	120
Final Detention, Hours	1.76	7.3
Final Overflow, gals/ft^2/day	460	110

*Results based on data collected Feb. 8 - March 18

**Neglecting removal in primary settling

TABLE 12

SUMMARY OF DATA - PERIOD NO. 9

EFFECT OF INFLUENT LOADING ON PLANT PERFORMANCE

MARCH 19 - MAY 29, 1968

Parameter	PILOT PLANT NO. 1	PILOT PLANT NO. 2
Influent MBAS, mg/l	2.9	2.9
Effluent MBAS, mg/l	1.0	0.8
MBAS Removal, %	66	73
Influent BOD, mg/l	160	160
Effluent BOD, mg/l	22	17
BOD Removal	86	89
Influent S.S., mg/l	198	198
Effluent S.S., mg/l	19	17
S.S. Removal, %	90	92
Influent Temp. °C	19	19
Effluent Temp. °C	18	18
Influent Flow, gpm	1.30	0.60
Recycle, gpm	2.50	1.20
Recycle Ratio	1.9	2.0
BOD Loading, lbs/day/1000 c.f.*	47	22
Hydraulic Loading, MGAD	19	9
Primary Detention, Hours	1.7	3.1
Primary Overflow, gals/ft^2/day	500	240
Final Detention, Hours	1.8	3.6
Final Overflow, gals/ft^2/day	470	220

*Neglecting removal in primary settling

TABLE 13

SUMMARY OF DATA - PERIOD NO. 10

EFFECT OF INFLUENT LOADING ON PLANT PERFORMANCE

JUNE 1 - JUNE 26, 1968

Parameter	PILOT PLANT NO. 1	PILOT PLANT NO. 2
Influent MBAS, mg/l	2.8	2.8
Effluent MBAS, mg/l	0.8	1.0
MBAS Removal, %	72	64
Influent BOD, mg/l	108	108
Effluent BOD, mg/l	13	10
BOD Removal, %	88	91
Influent Temp. °C	23	23
Effluent Temp. °C	22	22
Influent Flow, gpm	0.6	1.2
Recycle, gpm	1.2	2.4
Recycle Ratio	2.0	2.0
BOD Loading, lbs/day/1000 c.f.*	15	29
Hydraulic Loading, MGAD	9	18
Primary Detention, Hours	3.1	1.6
Primary Overflow, gals/ft^2/day	240	470
Final Detention, Hours	3.6	1.8
Final Overflow, gals/ft^2/day	220	440

*Neglecting removal in primary settling

differences on performance discussed earlier can be attributed to differences in loading.

Results in Tables 11, 12 and 13 are summarized in Table 14 and indicate clearly that efficiency of M.B.A.S. and BOD removals are responsive to filter loadings. Also, they appear to indicate greater influence of loading on MBAS removal than on BOD removal, in the ranges investigated. This will be discussed in more detail in subsequent sections of this report.

EFFECT OF FILTER DEPTH

In the latter part of June, the operation of Plant No. 1 was discontinued and the trickling filter increased in height to provide a stone depth of 12 feet. The two plants then were placed in parallel operation, with 1.2 gpm of sewage applied to each and a recycle ratio of 2.0. Operation was resumed about July 1st and a period of 3-4 weeks provided for development of growth on new stone in the upper zone of Filter No. 1.

Table 15 summarizes data obtained during the period August 1 - September 16, when unusually low influent MBAS concentrations were experienced. It has been impossible to establish specific reasons for the radical drop in MBAS concentrations, other than to point out that the Town of Chapel Hill was undergoing a severe water shortage at that time, entailing restrictions on water use and encouragement of the population to minimize home laundry or to travel to nearby communities for that purpose.

Data in Table 15 indicate a significant effect of depth (loading) on MBAS removal, although BOD removal was not influenced appreciably. Table 16 summarizes data from September 17 - October 16, when influent MBAS had returned to a slightly higher mean concentration. Results obtained during this period were strikingly similar to those in Table 15 and lead to the same conclusions. Table 17 summarizes data from a subsequent period, at slightly lower temperature and higher influent MBAS concentration. Again, it is noted that increased depth of the

TABLE 14

SUMMARY - EFFECT OF LOADING ON PERFORMANCE

Period	MBAS REMOVAL			BOD REMOVAL		
	Standard	½ Load	¼ Load	Standard	½ Load	¼ Load
1/20 - 3/18/68	43		73	73		90
3/19 - 5/29/68	66	73		86	89	
6/1 - 6/26/68*	64	72		91	88	

* Pattern of second period reversed.

TABLE 15

SUMMARY OF DATA - PERIOD NO. 12

EFFECT OF FILTER DEPTH ON PLANT PERFORMANCE

JULY 1 - SEPTEMBER 16, 1968***

Parameter	PILOT PLANT NO. 1*	PILOT PLANT NO. 2
Influent MBAS, mg/l	1.3	1.3
Effluent MBAS, mg/l	0.5	0.7
MBAS Removal, %	62	46
Influent BOD, mg/l	185	185
Effluent BOD, mg/l	41	36
BOD Removal, %	78	80
Influent Temp. °C	23	23
Effluent Temp. °C	22	22
Influent Flow, gpm	1.22	1.22
Recycle, gpm	2.38	2.38
Recycle Ratio	1.95	1.95
BOD Loading, lbs/day/1000 c.f.**	17	51
Hydraulic Loading, MGAD	18	18
Primary Detention, Hours	1.8	1.8
Primary Overflow, gals/ft^2/day	470	470
Final Detention, Hours	1.8	1.8
Final Overflow, gals/ft^2/day	440	440

*12 ft. Stone Depth

**Neglecting removal in primary settling

***Based on data collected August 1 - September 16

TABLE 16

SUMMARY OF DATA - PERIOD NO. 13

EFFECT OF FILTER DEPTH ON PLANT PERFORMANCE

SEPTEMBER 17 - OCTOBER 16, 1968

Parameter	PILOT PLANT NO. 1*	PILOT PLANT NO. 2
Influent MBAS, mg/l	2.0	2.0
Effluent MBAS, mg/l	0.8	1.0
MBAS Removal, %	60	50
Influent BOD, mg/l	205	205
Effluent BOD, mg/l	34	32
BOD Removal, %	83	84
Influent Temp. °C	22	22
Effluent Temp. °C	21	21
Influent Flow, gpm	1.2	1.2
Recycle, gpm	2.4	2.4
Recycle Ratio	2.0	2.0
BOD Loading, lbs/day/1000 c.f.**	19	56
Hydraulic Loading, MGAD	18	18
Primary Detention, Hours	1.8	1.8
Primary Overflow, gals/ft^2/day	470	470
Final Detention, Hours	1.8	1.8
Final Overflow, gals/ft^2/day	440	440

*12 ft. Stone Depth

**Neglecting removal in primary settling

TABLE 17

SUMMARY OF DATA - PERIOD NO. 14

EFFECT OF FILTER DEPTH ON PLANT PERFORMANCE

OCTOBER 17 - NOVEMBER 25, 1968

Parameter	PILOT PLANT NO. 1*	PILOT PLANT NO. 2
Influent MBAS, mg/l	2.3	2.3
Effluent MBAS, mg/l	1.0	1.4
MBAS Removal, %	57	39
Influent BOD, mg/l	143	143
Effluent BOD, mg/l	29	33
BOD Removal, %	80	77
Influent Temp. °C	20	20
Effluent Temp. °C	19	19
Influent Flow, gpm	1.2	1.2
Recycle, gpm	2.4	2.4
Recycle Ratio	2.0	2.0
BOD Loading, lbs/day/1000 c.f.**	13	39
Hydraulic Loading, MGAD	18	18
Primary Detention, Hours	1.8	1.8
Primary Overflow, gals/ft^2/day	470	470
Final Detention, Hours	1.8	1.8
Final Overflow, gals/ft^2/day	440	440

*12 ft Stone Depth

**Neglecting removal in primary settling.

stone exerted little influence on BOD removal but appeared to improve MBAS removal significantly.

Table 18 summarizes data from November 26 - January 1, 1969, when efforts were made to obtain very high BOD and MBAS removals through reducing the influent loading on the twelve foot deep filter to one quarter of the "design" value and by "spiking" influent to both plants with LAS supplied by The Soap and Detergent Association. The data indicate that the attempt to obtain very high BOD removal in Plant No. 1 was unsuccessful, probably because of the sharp drop in temperature to 11°C. The impact of reducing the loading is evident, however, because BOD removal was slightly higher than in the preceding period (Table 17), in spite of a 9°C drop in temperature, and MBAS removal also was substantially higher at the lower loading. The MBAS removal during this period was 48% in Plant No. 2, which corresponds reasonably well or is slightly higher than MBAS removals observed in past studies when operating conditions produced BOD removals approximating 75% (see Figure 2). Thus, it is concluded that addition of the "spike" had little influence on efficiency of MBAS removal, certainly too little influence to account for the relatively low MBAS removals which have been observed consistently in the Chapel Hill sewage treatment plant and in the two trickling filter pilot plants operated during this program.

Results obtained during this phase of the investigation indicate that increased depth exerts a beneficial effect on removal of MBAS and that the benefit exceeds that which is observed in BOD removal under comparable conditions. Addition of a "spike" of known characteristics did not appear to exert radical influence on the efficiency of MBAS removal by the pilot plants.

RELATIONSHIP BETWEEN MBAS AND BOD REMOVALS

Figure 2 summarizes all of the results obtained during this investigation using four foot deep filters at various recycle ratios, influent loadings, and

TABLE 18

SUMMARY OF DATA - PERIOD NO. 15

EFFECTS OF LOADING AND SPIKING ON PLANT PERFORMANCE

NOVEMBER 26, 1968 - JANUARY 1, 1969

Parameter	PILOT PLANT NO. 1*	PILOT PLANT NO. 2
Influent MBAS, mg/l***	6.8	6.9
Effluent MBAS, mg/l	2.3	3.6
MBAS Removal, %	66	48
Influent BOD, mg/l	150	150
Effluent BOD, mg/l	27	38
BOD Removal, %	82	75
Influent Temp. °C	12	12
Effluent Temp. °C	11	11
Influent Flow, gpm	0.3	1.2
Recycle, gpm	0.6	2.4
Recycle Ratio	2.0	2.0
BOD Loading, lbs/day/1000 c.f.**	3.4	41
Hydraulic Loading, MGAD	4.5	18
Primary Detention, Hours	7.2	1.8
Primary Overflow, gals/ft^2/day	120	470
Final Detention, Hours	7.2	1.8
Final Overflow, gals/ft^2/day	110	440

*12 ft. Stone Depth

**Neglecting removal in primary settling

***Influent MBAS before spike addition was 2.3 mg/l

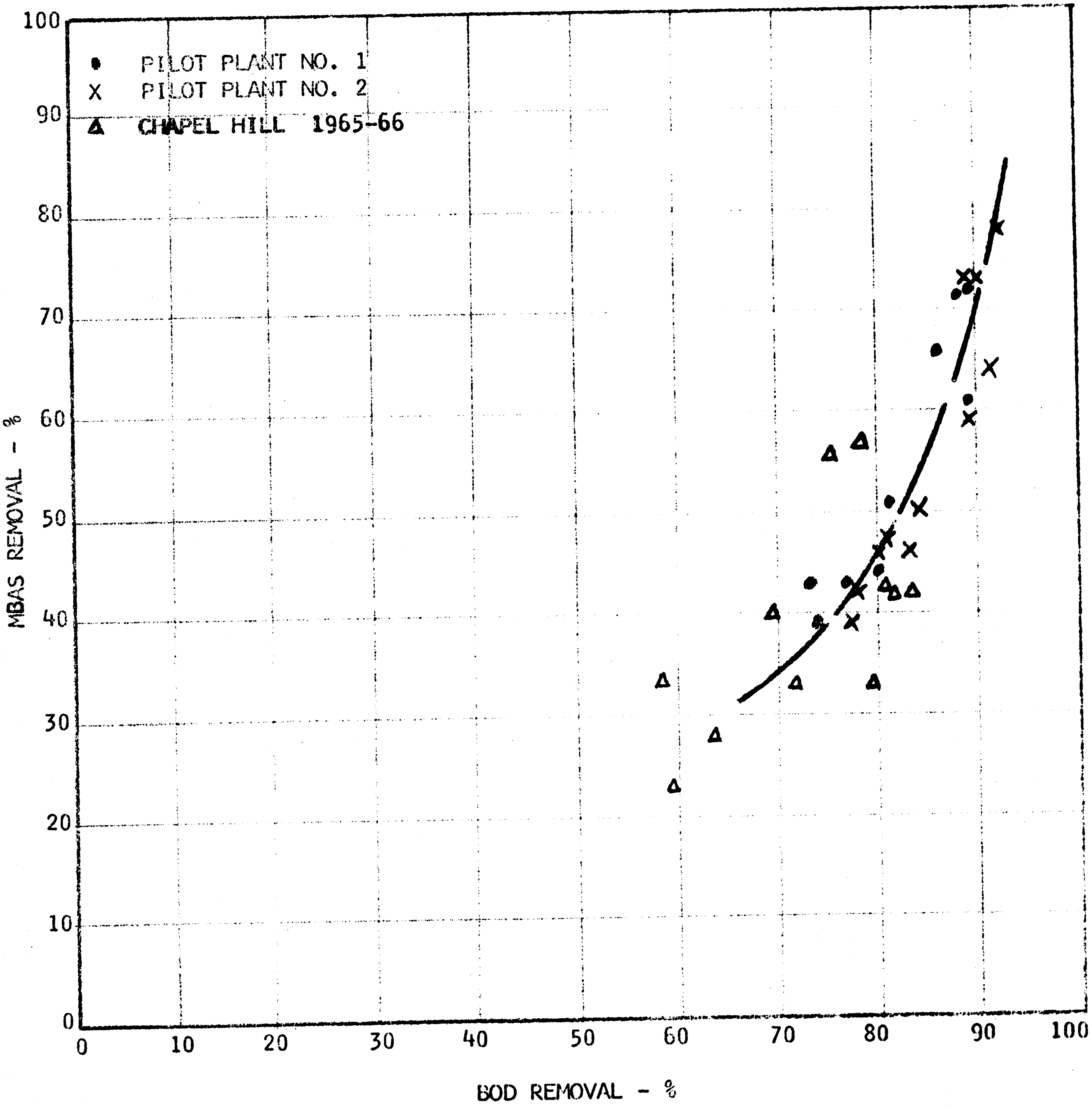

FIGURE 2

SUMMARY OF PILOT PLANT DATA

temperatures. All of the data are presented, regardless of the magnitude of variables, to show the relationship between MBAS and BOD removals.

The first point which is obvious in examining Figure 2 is that, when compared in this fashion, the two pilot plants were equivalent in performance. Also, a relatively clear relationship exists between MBAS removals by the plants and BOD removals attained by the same facilities. The nature of this relationship indicates that MBAS removals are only about 40% at BOD removals approximating 75%, but with increase in BOD removals above 75%, MBAS removals increase sharply. The shape of the trend line suggests that MBAS removals consistently in the range of 80-90% could be attained only at very high BOD removals (well above 90%).

Figure 3 shows the trend line reproduced from Figure 2 and summarizing the relationship between MBAS and BOD removals in the pilot plants. Superimposed upon that trend line are data obtained from (a) the full scale Chapel Hill trickling filter plant; (b) the Durham, N.C., Third Fork Treatment Plant (two stage, trickling filter); (c) the Durham, N.C., Northside Treatment Plant (trickling filters followed by activated sludge); (d) the Coven Heath Sewage Works (trickling filters); and (e) Coisley Hill Works, Sheffield (activated sludge); the latter two as reported in British literature(1). The five full-scale installations include a variety of biological treatment facilities operating over a very wide range of BOD and MBAS removals.

In spite of wide variations in geography, plant types, construction and operation techniques, and other characteristics, there is a very striking correlation between BOD and MBAS removals in all of the plants when plotted in this fashion. Also, it appears evident that data obtained from the pilot plants operated during this investigation are entirely consistent with operating data from the several full scale plants. Further, the grouping of points from the

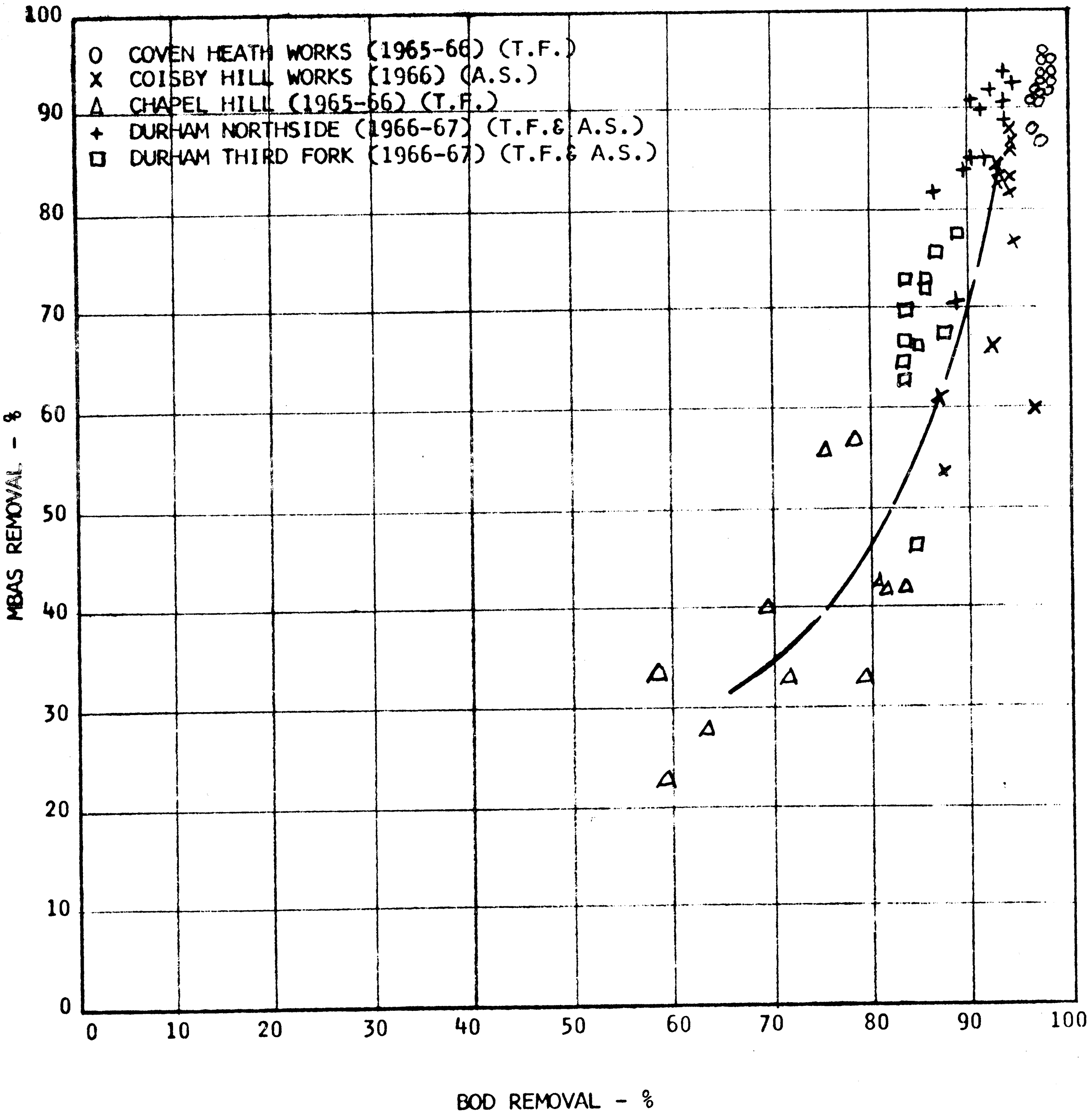

FIGURE 3

COMPARISON OF PILOT DATA WITH

FULL-SCALE PLANTS

several installations about the trend line suggests strongly that the type of relationship between BOD and MBAS removals observed during this investigation have broader implications than merely to trickling filter installations. In fact, Figure 3 suggests strongly that relatively high BOD removal is required to insure even moderate removals of MBAS, regardless of type of plant. Thus, MBAS removals of 50% or higher are suggested only in instances where BOD removals exceed, perhaps, 80% and MBAS removals of 80-90% could not be expected through biological treatment unless BOD removals approximate 90-95%. Figure 3 implies that MBAS is somewhat more refractory to biological treatment than BOD in general. The grouping of points in Figure 3 also suggests further that reported differences in MBAS removals between trickling filter and activated sludge plants may be attributed to a large extent to higher BOD removals customarily attained in activated sludge plants. It appears at least doubtful that the trickling filter process is inherently less efficient for removing MBAS than activated sludge.

REFERENCES

1. "Ninth Progress Report of the Standing Technical Committee on Synthetic Detergents"; Ministry of Housing and Local Government; Her Majesty's Stationary Office, London (1967).