NATIONAL FIELD INVESTIGATIONS CENTER
CINCINNATI

RETURN SLUDGE FLOW CONTROL

BY
ALFRED W. WEST, P.E.
CHIEF - WASTE TREATMENT BRANCH

PREPARED FOR THE INTERNATIONAL WORKSHOP ON
INSTRUMENTATION CONTROL AND AUTOMATION
FOR WASTEWATER TREATMENT SYSTEMS

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OPERATIONAL CONTROL OF THE ACTIVATED SLUDGE PROCESS
-RETURN SLUDGE FLOW CONTROL-

Alfred W. West, P.E.

Chief, Waste Treatment Branch
National Field Investigations Center - Cincinnati
Office of Enforcement and General Counsel
United States Environmental Protection Agency

The return sludge flow, or more precisely, the clarifier sludge flow which includes both return sludge and excess waste sludge flows, should be adjusted to meet measurable process requirements. Attempts to maintain arbitrary return sludge flow percentages, for example 25%, 50%, or 100%, etc., of the wastewater flow will seldom achieve optimum sludge quality and process balance. Fortunately, the results of the one-hour mixed liquor settlometer test, the 15-minute mixed liquor and return sludge centrifuge test, and the final clarifier sludge blanket test reading provide the basic data for simple calculation of the clarifier sludge flow rate needed to maintain or restore process equilibrium.

Symbols Used in Formulas and Calculation Examples

ATC = Aeration Tank Concentration - The mixed liquor concentration determined by the standard 15-minute centrifuge test, expressed as the percent of the centrifuge tube occupied by the compacted mixed liquor sludge.

CFO = Clarifier Flow - Out of Clarifier (Final Effluent)

CFP = Final Clarifier Sludge Flow Percent - (CSF/CFO) From metered values, expressed decimally.

CFPD = Final Clarifier Sludge Flow Percent Demand - Required sludge removal rate as a percent of the final effluent flow (expressed decimally).

CSF = Final Clarifier Sludge Flow - (RSF+XSF)

CSFD = Final Clarifier Sludge Flow Demand - Required sludge removal rate expressed in either cu m/d or mgd.

MLTSS = Mixed Liquor Total Suspended Solids Concentration (mg/l)

RFP = Return Sludge Flow Percent (RSF/CFO as a decimal)

RSC = Return Sludge Concentration - The return sludge concentration determined by the standard 15-minute centrifuge test, expressed as the percent of the centrifuge tube occupied by the compacted return sludge.

RSF = Return Sludge Flow (to aeration tanks)

RSTSS = Return Sludge Total Suspended Solids Concentration (mg/l)

SSC_t = Settled Sludge Concentration - The calculated concentration of the mixed liquor after "t" minutes settling in the settlometer. (SSC_t = 1000 ATC/SSV_t)

SSV_t = Settled Sludge Volume - The volume occupied by the mixed liquor after "t" minutes settling in the settlometer. (cc/l)

XSF = Excess Sludge Flow to Waste

The Clarifier Sludge Flow Demand Formula

In practice, at least once per eight-hour shift, operators should record the actual wastewater and clarifier sludge flow rates, determine mixed liquor settleability by the settlometer test, check the mixed liquor and return sludge concentrations by the centrifuge test, calculate the clarifier sludge flow demand (CSFD) from the following formula, and then adjust the clarifier sludge flow to approximate the demand.

The observed rate at which settled sludge is removed from the final clarifier can be expressed either as the metered flow (CSF) or as a percentage (CSP-recorded as a decimal fraction) of final effluent flow out of the clarifier. The demands (CSFD or CFPD) can also be calculated in terms of flow rates or percentages.

$$CSFD = CSFx(RSC-ATC)/(SSC_t-ATC)$$

$$CFPD = CFPx(RSC-ATC)/(SSC_t-ATC)$$

Sludge Settling (SSV) and Concentration (SSC) Test Data

Mixed liquor sludge concentration characteristics, determined by the settlometer and centrifuge tests, define sludge quality and are used to determine clarifier sludge removal requirements. The settlometer test differs from the conventional sludge settling test for SVI determination in that:

a. A larger diameter (12.5 cm = 5 inches) shorter length (15 cm = 6 inches) graduated cylinder is used to minimize the settling rate distortions that occur when slowly settling sludge is tested in the narrow standard 1,000 cc graduated cylinder.

b. Settled sludge volume is observed and recorded at intervals throughout one hour (or longer for special studies) instead of the single 30-minute reading used for SVI.

c. Sludge quality is revealed by the shape and the end-point (1.0 hr) of the sludge concentration curve that is calculated from the mixed liquor concentration and the settled sludge volumes. (SSC=1,000 ATC/SSV).

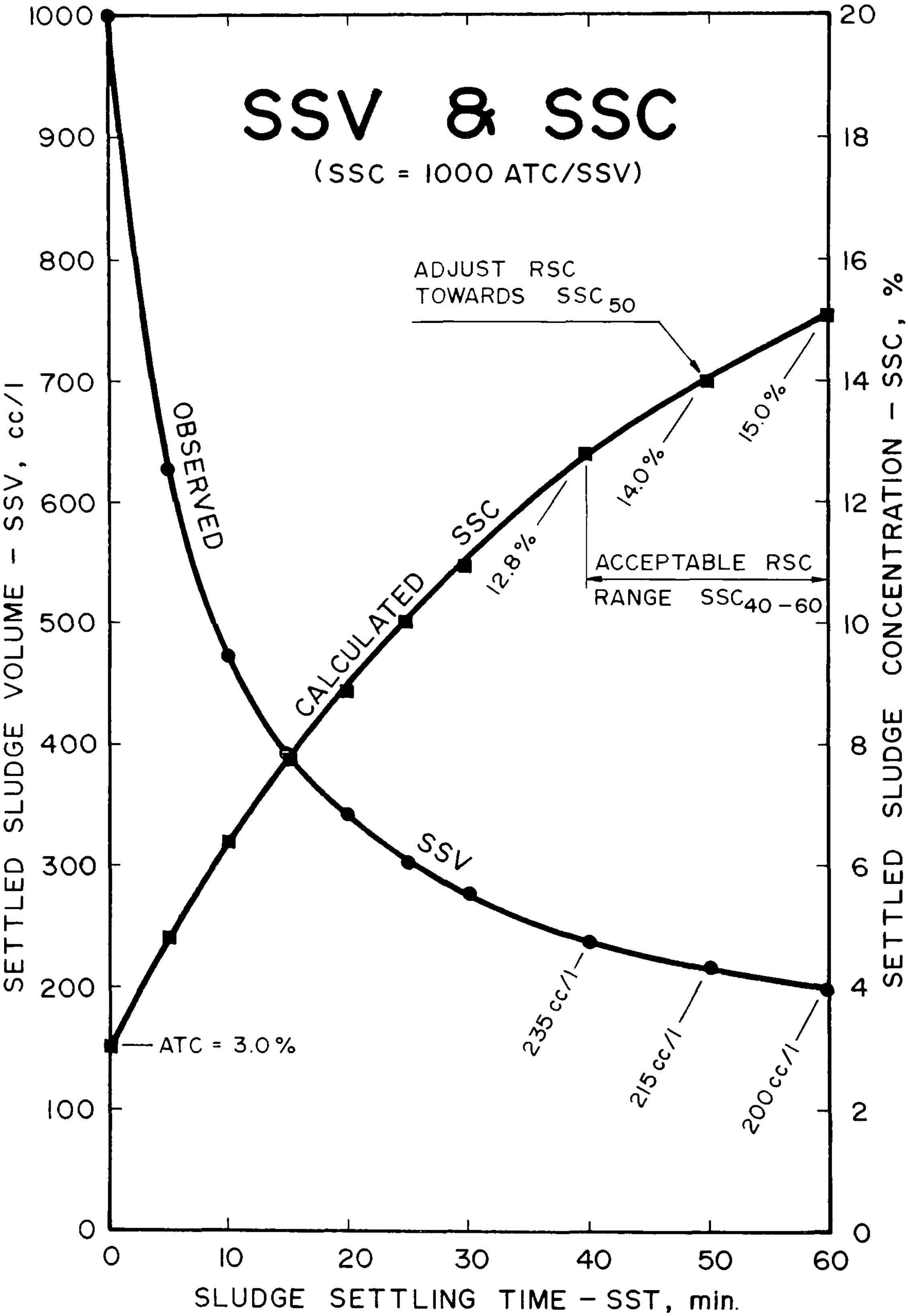
The settlometer test results displayed in Figure 1 show that the Settled Sludge Volume (SSV) reached 235 cc per liter at 40 minutes, 215 at 50 minutes, and 200 at 60 minutes.

The Settled Sludge Concentration (SSC) curve, revealed that the mixed liquor sludge, with an initial centrifuged concentration of ATC=3.0% at time zero, compacted to a calculated concentration of 12.8% in 40 minutes, 14.0% in 50 minutes, and 15.0% in 60 minutes.

Using these sludge concentration test data and the waste water and the clarifier sludge flow meter readings, the

FIG. 1

Sludge Settling and Concentration Characteristics



operator can calculate the clarifier sludge withdrawal rate that will provide approximately one hour sludge compaction time in the clarifier.

Ideally, removing sludge from the final clarifier at a concentration approximating the 60-minute SSC value usually minimizes the sludge detention time in the anaerobic final clarifier environment and reduces the amount of water that is pumped back with the sludge solids to practical minimums. In practice, operators usually use the 50-minute SSC as their target value to minimize the chance of increasing RSC above the 60-minute SSC value and thereby lengthening the clarifier sludge detention time unduly during periods of rapidly rising waste water flows. SSC targets greater or less than the 50 minute value are used only in exceptional cases when other control procedures are also modified to overcome plant or process balance abnormalities.

It may be impractical to try to maintain RSC at the precise target SSC value at all times. The operators, therefore, usually select a range of RSC's, between SSC 40 and SSC 60, within which the clarifier sludge flow is not changed even though RSC does not equal the SSC target value. Therefore, for the sludge concentration characteristics shown in Fig. 1, the operator should change the clarifier sludge flow rate only if the observed return sludge concentration (RSC) value is less than 13% or greater than 15%. If it is, he should insert ATC=3.0 and SSC =14.0 into the clarifier sludge flow demand formula and then adjust the clarifier sludge flow to meet the current demand.

Clarifier Sludge Flow Demand Examples

The following examples illustrate the step-by-step calculation procedures used to determine the clarifier sludge flow needed to achieve process balance where mixed liquor sludge characteristics equalled those in Fig. 1 and the observed return sludge concentration (RSC) equalled 16.0%. Observed flow meter readings are posted in the examples.

Examples

Metric Units

Observed:

ATC = 3.0%
RSC = 16.0%
SSC = 14.0%
CFO = 37,850 cu m/d
RSF = 18,170 cu m/d
XSF = 760 cu m/d

English Units

Observed:

ATC = 3.0%
RSC = 16.0%
SSC = 14.0%
CFO = 10.0 mgd
RSF = 4.8 mgd
XSF = 0.2 mgd

Wanted: CSFD and CFPD required to reduce RSC from 16% to 14%

Therefore: (Metric Units)

CSF = RSF+XSF
= 18,170 + 760
= 18,930 cu m/d

CSFD = CSFx(RSC-ATC)/(SSC_{50}-ATC)
= 18,930x(16.0-3.0)/(14.0-3.0)
= 18,930x1.18
= 22,340 cu m/d

CFP = CSF/CFO
= 18,930/37,850
= 0.50

CFPD = CFPx(RSC-ATC)/(SSC_{50}-ATC)
= 0.50x1.18
= 0.59
= 59%

Therefore: (English Units)

CSF = RSF+XSF
= 4.8 + 0.2
= 5.0 mgd

CSFD = CSFx(RSC-ATC)/(SSC_{50}-ATC)
= 5.0x(16.0-3.0)/(14.0-3.0)
= 5.0x1.18
= 5.91 mgd

CFP = CSF/CFO
= 5.0/10.0
= 0.50

CFPD = CFPx(RSC-ATC)/(SSC_{50}-ATC)
= 0.50x1.18
= 0.59
= 59%

The operator should now increase the clarifier sludge removal pumping rate from 18,930 cu m/day (5.0 mgd) to 22,340 cu m/day (5.9 mgd). In actual practice, operators usually select a maximum allowable sludge flow increase, or decrease, that they will not exceed at any single test and control period. In this case of a 37,850 cu m/d (10.0 mgd) plant, for example, the maximum clarifier sludge flow adjustment permitted after each test period might have been limited to 3,785 cu m/day (1.0 mgd). This is a precaution against over-control that could otherwise occur if very large flow changes are called for.

During the next 8-hour shift, or more frequently if necessary, the operator would make similar observations and calculations and then readjust, if necessary, the clarifier sludge flow to meet the new demand.

During each testing period the operator should also calculate the sludge detention time in the final clarifier and attempt to maintain this value between 30 and 90 minutes. If the process is so badly unbalanced that the clarifier sludge detention time equalled or exceeded two hours, he should increase the clarifier sludge flow rate more aggressively and probably also step up the sludge wasting rate. The clarifier sludge flow demand, discussed in this paper, must be coordinated with other measurable process requirements that will be described in a forthcoming PROCESS CONTROL pamphlet being developed by the National Field Investigations Center.

Control adjustments could be accomplished more conveniently and accurately if the treatment plant were equipped with an automatic clarifier sludge flow rate controller that continuously adjusted the metered clarifier sludge flow to equal a preset percentage of the measured waste water flow. In such case, the operator would move the controller set-point from 50% to 59% and the increased sludge flow rate would continue to respond to waste water flow rate changes.

Looking to the future, it is easy to visualize how this procedure may be further automated when reliable continuous activated sludge concentration sensors become available.

Response to Return Sludge Flow Adjustments

The return sludge concentration and the mixed liquor sludge concentration responses to changed return sludge flow percentages are illustrated in Figures 2 and 3, which contain two weeks of data from the Merrimack, New Hampshire, Waste Treatment Plant operating log. During the period, the return sludge percentage was increased from 15 to 127, and then reduced to less than 26.

Return Sludge Concentration (RSTSS in mg/l)

Return sludge concentrations respond rapidly and inversely to return sludge flow adjustments. This normal relationship is evident in Figure 2 where the return sludge concentration fell from 5640 to 2280 mg/l while the return sludge percentage increased. Return sludge concentration then increased to 7110 mg/l while the return sludge percentage was reduced.

Mixed Liquor Concentration (MLTSS in mg/l)

Mixed liquor concentrations, and the associated sludge-age and food-to-microorganism ratios, respond strongly to sludge wasting adjustments but they are not normally affected greatly by return sludge flow adjustments unless the process is badly out of balance. In fact, a direct response, where mixed liquor concentrations increase with higher return sludge flows, usually occurs only after the process balance has been upset by excessive accumulations of sludge solids in the final clarifier.

As shown in Figure 3 the mixed liquor concentration increased only modestly from 1230 to 1470 mg/l while the return sludge flow percentage rose drastically from 15 to 127. Then, the mixed liquor concentration continued to increase to 2400 mg/l even though the return sludge percentage adjustment was reduced from 127 to 37.

Sludge Concentrations vs. Sludge Wasting

Process response to variations in sludge wasting is discussed only briefly since Sludge Wasting Control is beyond the scope of this paper.

Comparison of the mixed liquor and the return sludge concentration curves with the pounds of sludge wasted curve (Figure 4) reveals that the effects of wasting were overwhelmed by other control adjustments from July 17 to

FIG. 2

Return Sludge Concentration Response to Return Sludge Flow Percentage Adjustments

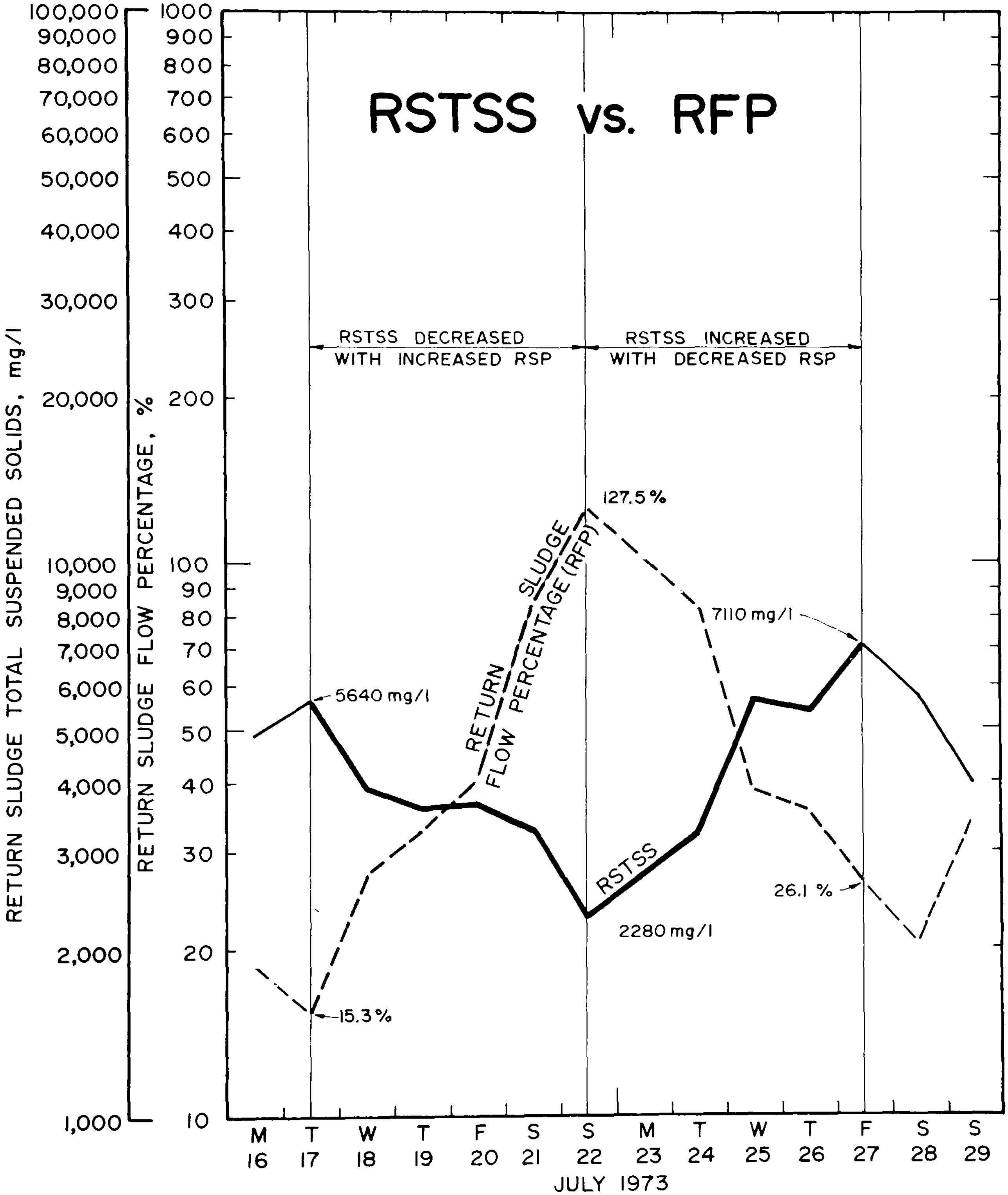


FIG. 3

Mixed Liquor Concentration Response to Return Sludge Flow Percentage Adjustments

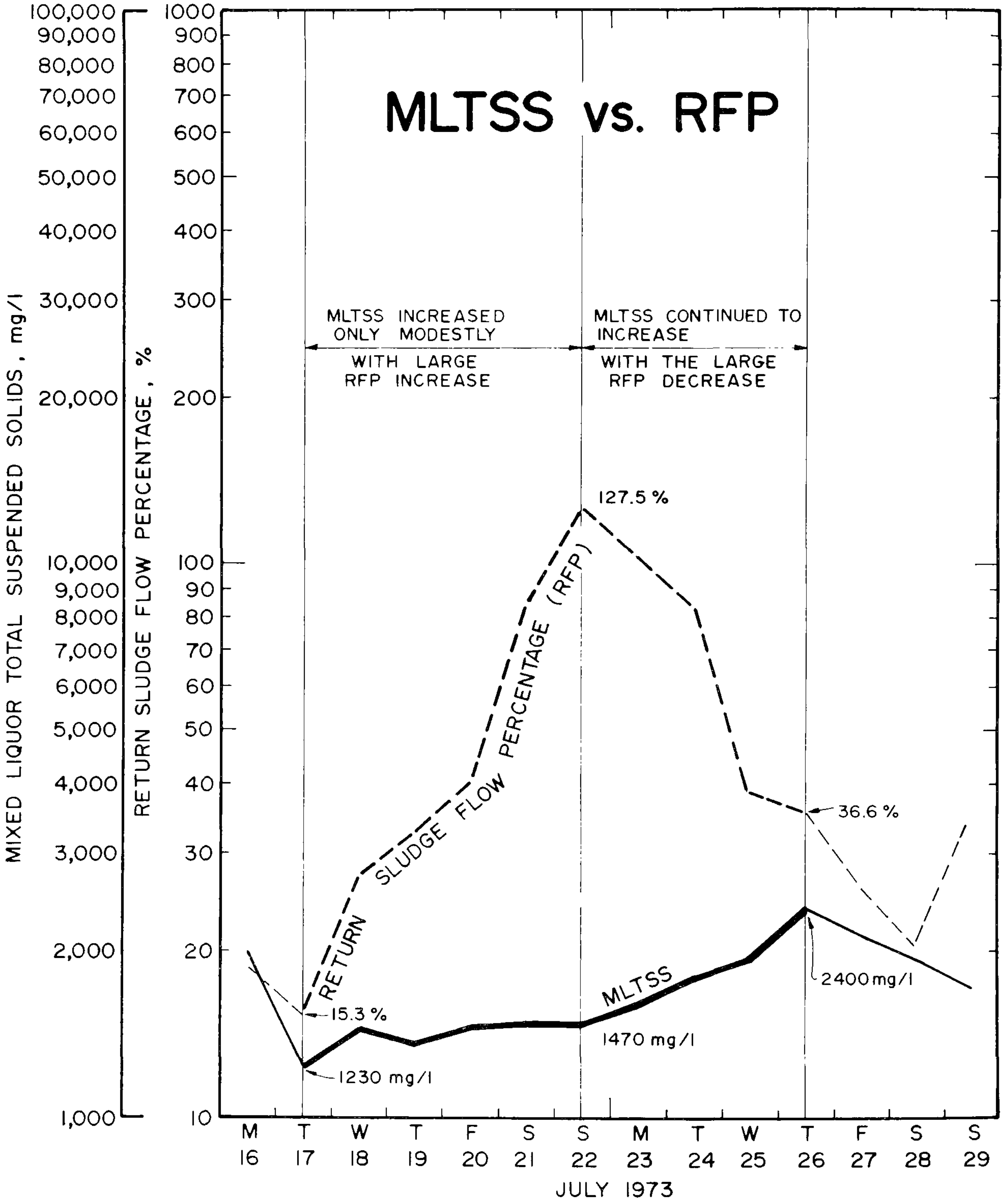
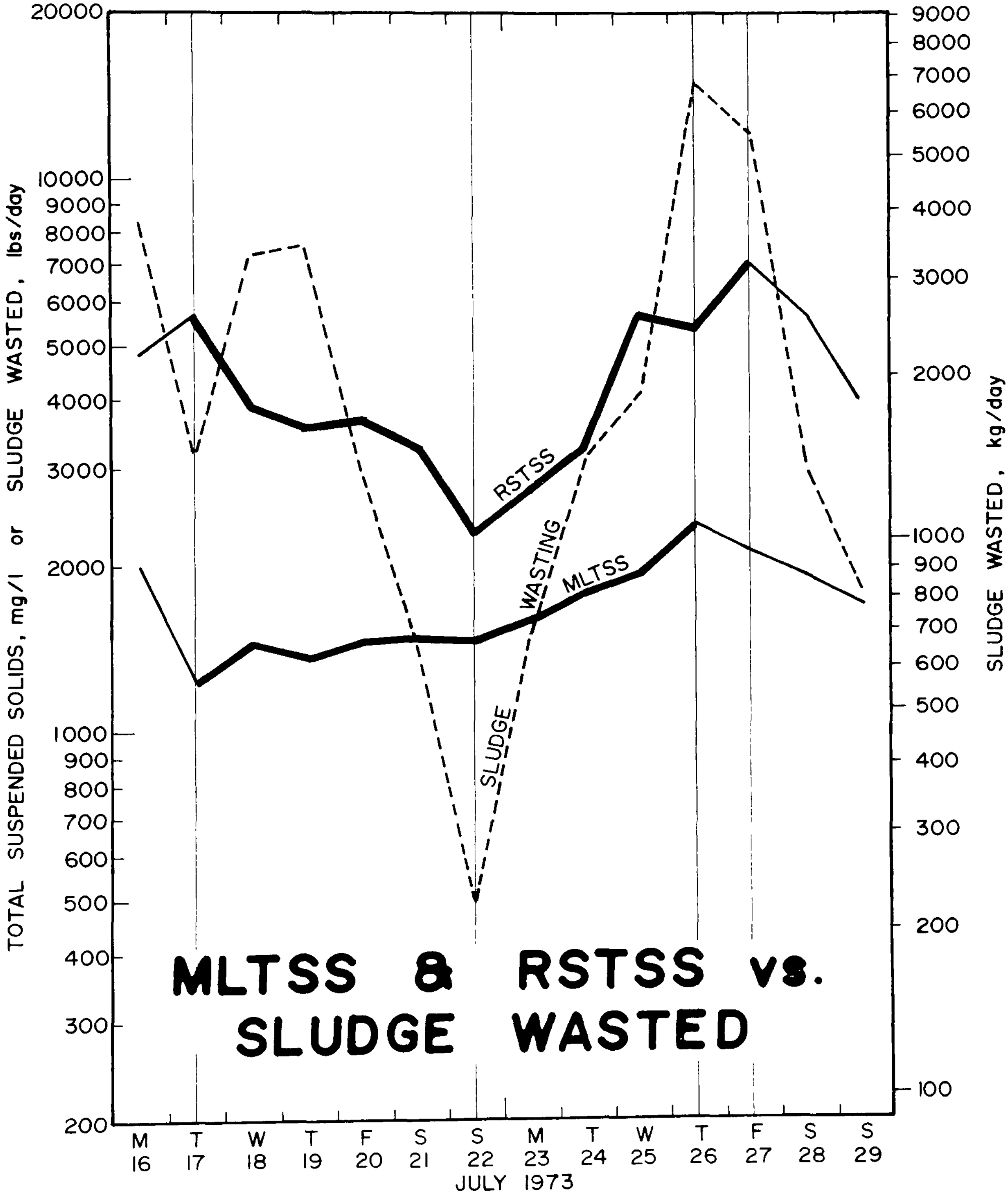


FIG. 4

Mixed Liquor and Return Sludge Concentrations vs. Kilograms (Pounds) of Sludge Wasted



July 26. The sludge concentrations did not increase with the decreased wasting rates, nor did they decrease with the increased wasting rates to the extent they should have if sludge wasting had exerted the principal control pressure. As evidenced in Figure 2, the drastically increased and then decreased return sludge flow percentage, that reduced and then increased the return sludge concentration, exerted the predominant control pressure during this ten-day interval.

Conversely, the relative effects of the wasting and the return controls reversed after July 26, when the response to the exceptionally high sludge wasting rate overpowered the lesser response to the more moderate changes in the return sludge flow percentage. Sludge wasting on July 26 and 27 had been increased to more than three times the previous ten-day average. Both the mixed liquor and the return sludge concentration trends reversed and then decreased in logical response to the predominating sludge wasting control.

Practical Precautions

This clarifier sludge flow adjustment procedure, when coordinated with proper aeration and sludge wasting techniques, has improved performance at practically all plants at which Waste Treatment Branch personnel demonstrated control procedures. Although such procedures can be helpful, they may not solve problems that are imposed by gross overloads or by improper plant design.

Furthermore, certain hydraulic limitations must be taken into consideration at most plants. There is usually a limit below which the return sludge flow cannot be reduced without impeding proper sludge collection or plugging return sludge piping. Similarly, there is usually a limit beyond which the return sludge flow cannot be increased without creating excessive turbulence and scouring flow velocities within the final clarifier. Most operators identify these limits from practical experience and follow the demands throughout the acceptable return sludge flow range. In general, reducing the return sludge flow percent below 15 or increasing it above 150 may induce more problems than those that are solved.

Actual Results

Two examples of final effluent quality achieved while following these control procedures are the most recent 30-day average data summaries from the Merrimack, New Hampshire, and the Albany, Oregon, waste water treatment plants. The National Field Investigation Center's technical support projects were completed on September 30, 1973, at Merrimack and on August 9, 1973, at Albany.

The Merrimack plant treats 8,330 cu m/day (2.2 mgd) of wastes. About 95% of the flow is brewery waste and the remainder comes from a paper coating factory. Wastes are pretreated by a trickling filter before entering the complete-mix type, activated sludge plant equipped with surface-mechanical aerators.

The Albany plant treats 20,820 cu m/day (5.5 mgd) of domestic sewage. Local industries contributed less than 5% of the waste flow during the project. The plant is a conventional complete-mix activated sludge plant utilizing compressed air.

During the first two months of each project, NFIC-C personnel trained plant personnel to use the coordinated control procedures that have been developed by the Waste Treatment Branch. Consultation was provided for the next month or two and the final month's performance, summarized in the Table 1, was achieved by plant personnel without further assistance from NFIC.

TABLE 1 Activated Sludge Plant Performance

	Merrimack		Albany	
	BOD	SS	BOD	SS
Concentrations (mg/l)				
Raw Waste	1168	524	191	254
Aerator Influent	340	325	141	172
Final Effluent	6.9	6.4	5.4	6.0
Reductions (%)				
Preliminary Treat.	70.9	38.0	26.2	32.3
Act. Sludge Process	98.0	98.0	96.2	96.5
Total Plant	99.4	98.8	97.2	97.6

The turbidity of settled final effluent averaged 1.8 JTU at Merrimack and 2.1 JTU at Albany.

Summary

The real value of this control procedure is that it responds to practically all loading, process balance and sludge quality characteristics to reveal the clarifier sludge flow rate that will best satisfy the net requirement of all these interacting variables. The calculated demand satisfies the coordinated requirements imposed by changing mixed liquor sludge concentrations and quality, sludge solids distribution between the aeration tanks and the final clarifiers, and the waste water flow rates. On a progressive long-term basis it also responds to changes in organic loadings and the interrelated sludge-wasting rates. This control procedure satisfies the dynamic requirements of the total process.

Author's Note

A series of pamphlets describing Operational Control Procedures for the Activated Sludge Process is being developed by the Waste Treatment Branch of the National Field Investigation Center - Cincinnati. Part I - OBSERVATIONS, Part II - CONTROL TESTS, and Part III-A CALCULATION PROCEDURES are available for distribution. Part IV - SLUDGE QUALITY, Part V - PROCESS CONTROL, APPENDIX, and a series of CASE HISTORIES will come later. This paper is essentially a preview of a section of proposed Part V - PROCESS CONTROL. Though this paper is limited to a discussion of the clarifier sludge flow control procedures that were evolved by me and are demonstrated by the Waste Treatment Branch, it should be recognized that coordinated control of aeration tank mixing and dissolved oxygen concentrations along with excess sludge wasting procedures is also necessary to obtain best plant performance and effluent quality from the activated sludge process.

Alfred W. West

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