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ABSTRACT

This is the third in a series of documents developed by the National Training and Operational Technology Center describing operational control procedures for the activated sludge process used in wastewater treatment. This document deals with the calculation procedures associated with a step-feed process. Illustrations and examples are included to emphasize how the activated sludge process reacts to changes in wastewater feed-point locations. The summary illustrates the types of changes that occur when a plug-flow system is switched to various step-feed combinations. (CS)

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NATIONAL WASTE TREATMENT CENTER
CINCINNATI

OPERATIONAL CONTROL PROCEDURES
for the
ACTIVATED SLUDGE PROCESS

PART III-B

CALCULATION PROCEDURES

FOR

STEP-FEED PROCESS RESPONSES

FEBRUARY 1975

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER PROGRAM OPERATIONS

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EQUIVALENTS USED FOR ACTIVATED SLUDGE CALCULATIONS

ft	x	0.3048	=	m
inches	x	2.540	=	cm
m	x	3.28083	=	ft
m	x	39.37	=	in
sq ft	x	0.0929	=	sq m
sq m	x	10.7639	=	sq ft
cu ft	x	28.3170	=	liter
cu ft	x	0.028317	=	cu m
cu ft	x	7.48052	=	gal
cu m	x	1000.0	=	liter
cu m	x	35.3145	=	cu ft
cu m	x	264.179	=	gal
gal	x	3.785	=	liter
gal	x	0.003785	=	cu m
liter	x	0.26417	=	gal
mgd	x	3785	=	cu m/day
cu m/day	x	0.000264	=	mgd
gpd/sq ft	x	0.0408	=	cu m/day/sq m
cu m/day/sq m	x	24.51	=	gpd/sq ft
lb	x	0.453592	=	kg
lb	x	453.592	=	g
kg	x	2.20462	=	lb
kg	x	1000.0	=	g
lbs/1000 cu ft	x	16.0	=	g/cu m
g/cu m	x	0.0625	=	lbs/1000 cu ft
cu ft (H^2O)	x	62.4	=	lb (H^2O)
gal (H^2O)	x	8.345	=	lb (H^2O)
liter (H^2O)	x	1.000	=	kg (H^2O)

lb/day	=	mgd x mg/l x 8.345
kg/day	=	cu m/day x mg/l /1000
lb	=	English SLU x (WCR*/1198)
kg	=	Metric SLU x (WCR/10)
English SLU	=	Metric SLU x 264.2
Metric SLU	=	English SLU x 0.003785

*WCR = sludge weight (mg/l)/centrifuged concentration (%)

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NATIONAL WASTE TREATMENT CENTER - CINCINNATI

OPERATIONAL CONTROL PROCEDURES
FOR THE
ACTIVATED SLUDGE PROCESS

PART III-B

CALCULATION PROCEDURES

FOR
STEP-FEED PROCESS RESPONSES

by

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FEBRUARY 1975
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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF WATER PROGRAM OPERATIONS

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FOREWORD

The National Waste Treatment Center (Cincinnati) is developing a series of pamphlets describing Operational Control Procedures for the Activated Sludge Process. This series, describing the "NWTC Procedures", will include Part I OBSERVATIONS, Part II CONTROL TESTS, Part III CALCULATION PROCEDURES, Part IV SLUDGE QUALITY, Part V PROCESS CONTROL and an APPENDIX. Each of these individual parts will be released for distribution as soon as it is completed, though not necessarily in numerical order. The original five-part series may then be expanded to include case histories and refined process evaluation and control techniques.

This pamphlet has been developed as a reference for Activated Sludge Plant Control lectures I have presented at training sessions, symposia, and workshops. It is based on my personal conclusions reached while directing the operation of dozens of different activated sludge plants. This pamphlet is not necessarily an expression of Environmental Protection Agency policy or requirements.

The mention of trade names or commercial products in this pamphlet is for illustrative purposes and does not constitute endorsement or recommendation for use by the Environmental Protection Agency.

Alfred W. West

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TABLE OF CONTENTS

INTRODUCTION

An activated sludge plant that has been designed to permit operation in a plug-flow, step-feed, or contact-stabilization mode provides great control flexibility and can be operated many different ways. Calculations of step-feed process characteristics, however, are more complex than the previously illustrated calculations for aeration tanks operating in the plug-flow mode. Though few operators will perform all the step-feed calculations, all should be generally aware of the oxidation and purification pressure changes that occur when the process mode is shifted through various combinations of step loading.

The Summary, which probably is the most useful part of this section, illustrates the types of changes that occur when a plug-flow system is switched to various step-feed combinations.

Of nearly equal importance are the calculation procedures used to determine the sludge and waste detention times in a step-feed configuration. Then the additional process parameters unique to step-feed are shown. Finally, the rationale of the calculation procedures is included for those who may be interested in the derivations.

The intent of this pamphlet is not to describe specific step-feed locations that are most appropriate for all plant loading and sludge quality combinations. The illustrations and examples are intended to emphasize how the activated sludge process reacts to changes in wastewater feed-point locations. The Calculation Forms present an orderly procedure to determine, and at times predict, process response to various step-feed loadings. Other feed configurations could at times be more beneficial than those shown in the illustrations.

SUMMARY

Treatment plants at which operators can switch wastewater in-flow from one bay of an aeration tank to one or more other bays (step-feeding) have additional ways to meet the process demands of the activated sludge system. Recognition of the process demands that call for such control changes and knowledge of what happens when step-feeding is employed provide the foundation for successful operation of such plants. The curves on Figure 1 show how shifting wastewater in-flow locations exerts forces on mixed liquor *sludge oxidation* that are opposite to those exerted on *wastewater treatment*. Knowledge of these facts alone permits operators to shift step control in the proper direction to correct sludge or final effluent deficiencies and to restore best process balance.

SLUDGE OXIDATION PRESSURES

Oxidative pressures imposed on the activated sludge increase as the wastewater enters farther away from the head and closer to the exit end of the compartmented aeration tanks.

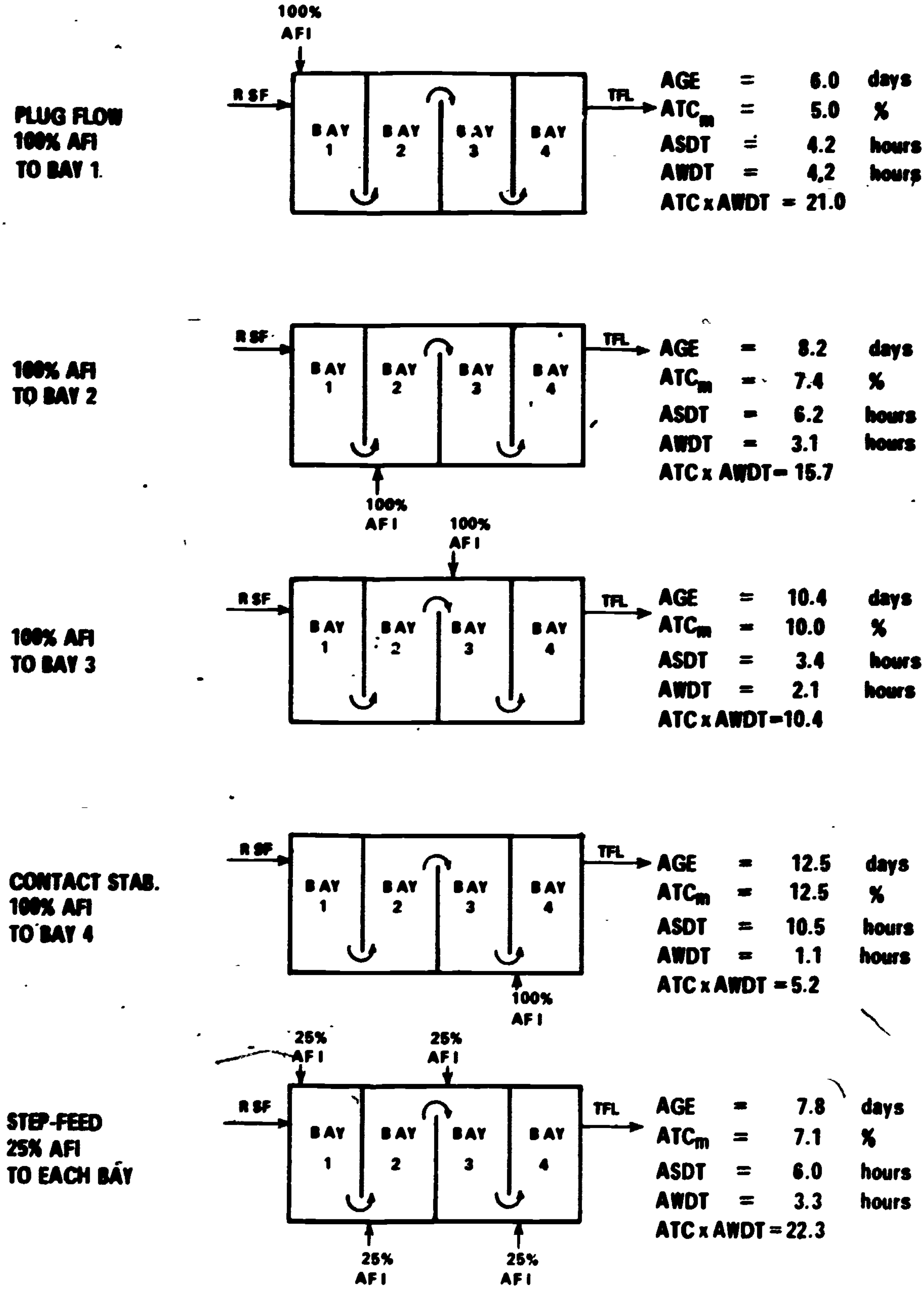
WASTEWATER TREATMENT PRESSURES

Purification pressures exerted on the wastewater decrease as it enters farther away from the head end and closer to the exit end of the aeration tanks.

DISCUSSION

Total aeration tank volumes and return sludge and waste water flows shown in Figure 2 are similar to those used in the calculation examples presented in Part III-A. The aeration tank characteristics used in this Summary example differ from those in Part III-A because the tank is divided into four equal step-feed bays, but the flows differ only slightly when the sludge wasting rate is set at zero.

In addition to the process changes induced directly by switching step-feed inlet locations, the impact of such changes will be further governed by any variation in the sludge wasting rate.



WASTEWATER FEED INLET LOCATIONS FOR FIGURE 1

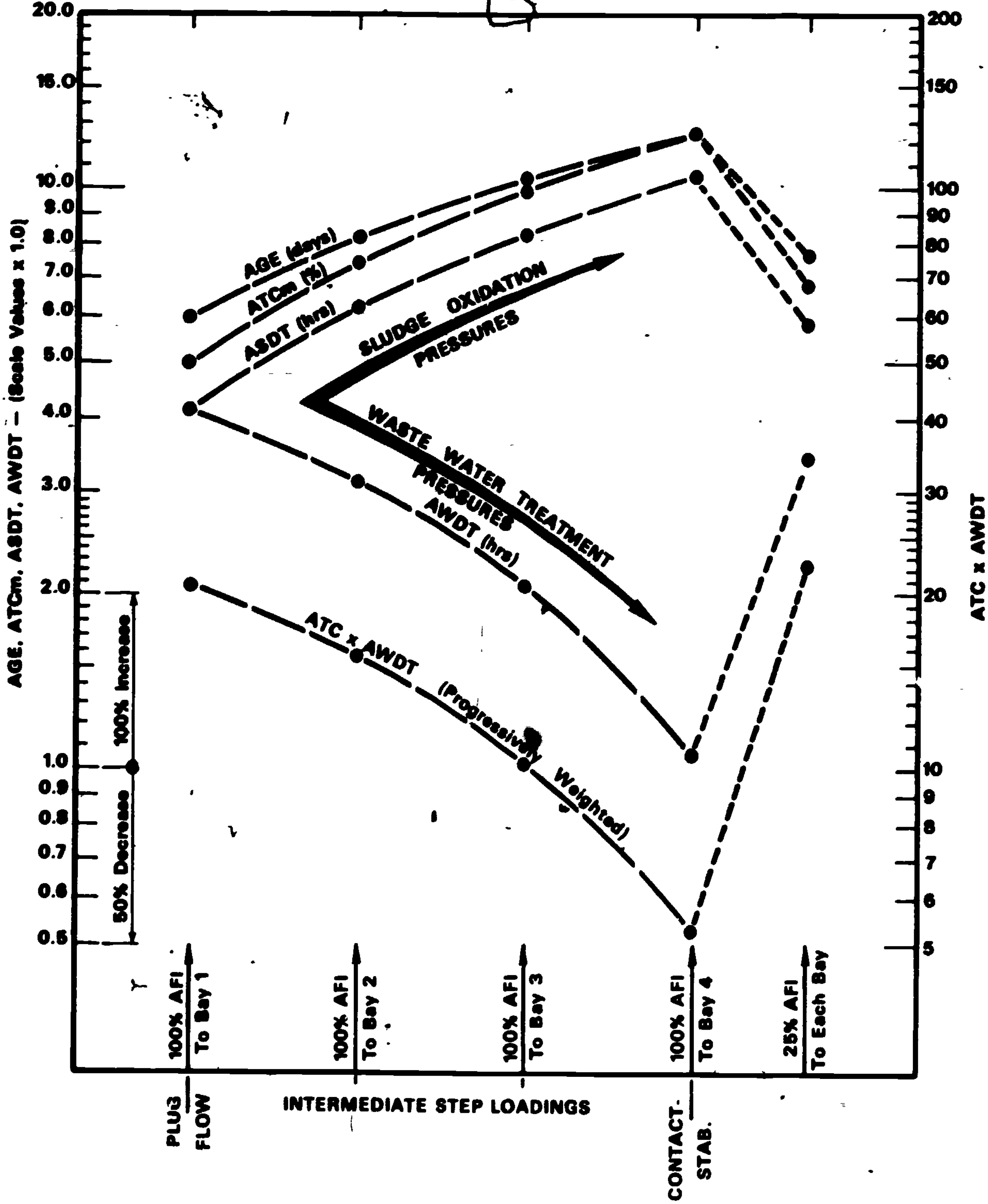


Figure 1

SLUDGE OXIDATION & WASTE TREATMENT PRESSURES

At Various Step-Aeration Loadings

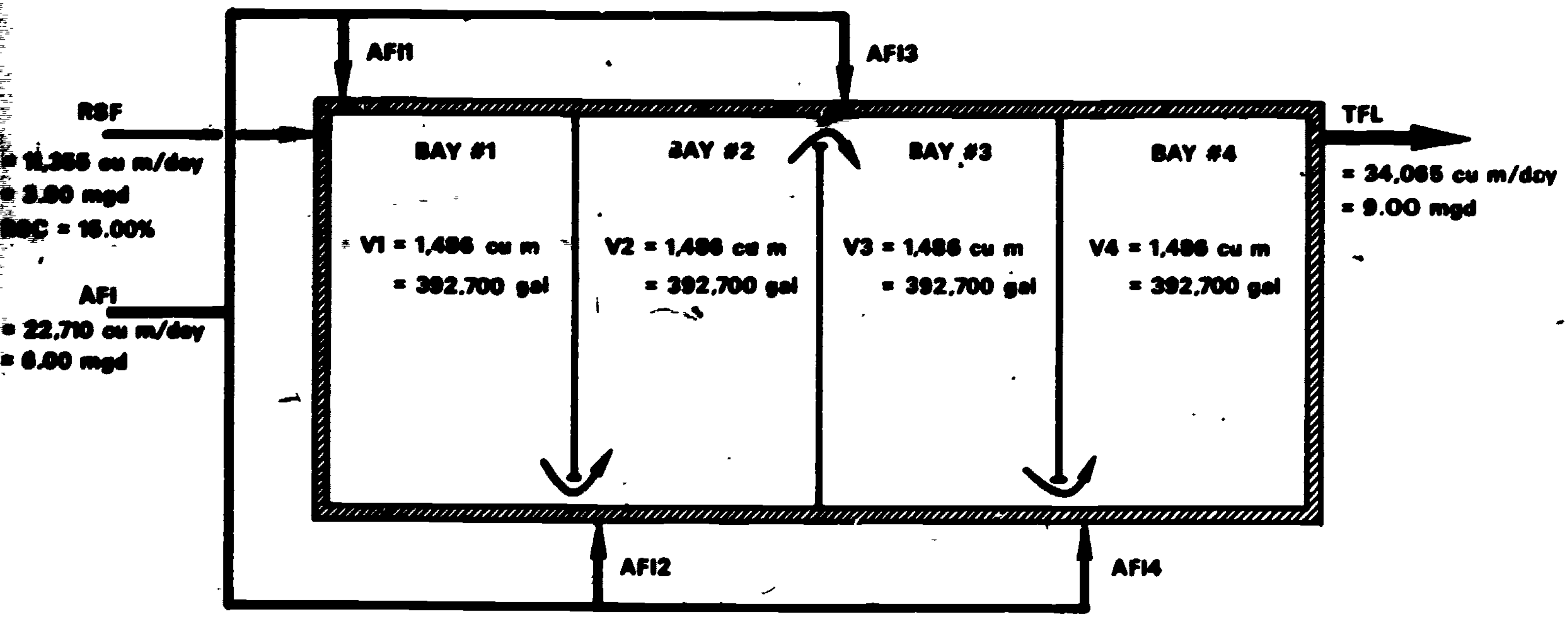


Figure 2

FOUR BAY STEP-AERATION TANK

EXAMPLE A

Sludge Wasting Rate Decreased

Normally increased sludge oxidation pressures can be maximized and normally decreased waste treatment pressures can be improved by a coordinated reduction in the sludge wasting rate when the step-feed in-flow location is shifted toward the bays nearer the aeration tank outlet end.

This is the case discussed in the Summary and illustrated in Figures 1 and 2. The reduced wasting rate, in effect, increases the number of sludge units in the system, eventually restores RSC to 15.0%, and increases sludge age. The mixed liquor concentration in the last bay (ATCn) would also be restored to 5.0% after a short-term sag in both RSC and ATCn. Obviously, aeration devices must be powerful enough to support the increased mixed liquor concentrations, and final clarifiers must provide the depth and surface area needed to permit proper compaction of the slower-settling, high-concentration sludge mass.

This coordinated control procedure, shifting step-feed toward the outlet end while simultaneously reducing sludge wasting, is usually appropriate to restore balance when the mixed liquor sludge settling rates have become too slow but still do not approach the almost negligible rates associated with true classic bulking. Such sludge quality degradation can be caused, for example, by a short-term organic overload that increases production of the new, underoxidized slow-settling component of the mixed liquor mass. The altered process requirements can then be met by moving the wastewater in-flow nearer the aeration tank outlet to increase oxidative pressures and, by decreasing the sludge wasting rate, to increase sludge age slightly.

EXAMPLE B

Sludge Wasting Rate Held Constant

Sludge oxidation pressures will be increased only nominally and waste treatment pressures will be reduced more sharply if the sludge wasting rate is held constant or increased after the in-flow location is shifted, as was done in Example A.

This phenomenon will be detailed in following sections where comparisons of other sludge and process responses to

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varied in-flow locations, wasting rates, and return sludge flow percentages are discussed.

Although not illustrated in Figure 1, the mixed liquor concentration of the outlet bay (ATCn), the number of sludge units returned to the aeration tanks (RSU), and the waste treatment pressure represented by RSU per 1000 gallons of wastewater or per pound of incoming BOD all remained constant throughout Example A but dropped in Example B when the step-feed location was s[illegible] toward the outlet end.

Holding the sludge wasting rate constant, as discussed in Example B, will usually lower sludge blanket levels that have risen too high in hydraulically overloaded final clarifiers. Since identical quality mixed liquor sludges (same AGE, WCR, SSC60, etc.) settle more rapidly as their concentrations (ATC) are reduced, this particular response is governed mainly by the reduced ATCn.

CONCLUSIONS

The following conclusions are based on bo[illegible] fundamental theory and on the author's observations at step-feed plants that were operated according to his direction.

1. *Degraded sludge quality associated with decreasing settling and compaction rates can usually be improved by shifting the step-feed location toward the outlet end of the aeration tanks.*

In this case, sludge oxidation pressures can be maximized by shifting all the way to the last bay to approximate contact stabilization. The final effluent will be temporarily degraded, but restoring proper sludge quality will improve effluent quality to produce a long-term, beneficial effect on receiving waters. The step-feed location is then usually shifted back toward the plug-flow configuration after sludge quality has improved sufficiently.

2. *Final effluent quality can usually be improved by shifting the step-feed location toward the head end of the aeration tanks.*

In this case, the treatment pressures can be maximized by shifting all the way back to the first bay in the conventional plug-flow mode. This presupposes that the plant has adequate capacity and that thorough and complete mixing takes place in each bay.

BASIC CALCULATION PROCEDURES

DATA SOURCES AND TEXT ORGANIZATION

Calculation procedures used by the Waste Treatment Branch of the NFIC-C during technical support projects are described in Part III of the Operational Control Procedures for the Activated Sludge Process. The suggested types and frequency of observations and control tests have been described in Parts I and II.

Part III-A emphasizes calculation procedures for conventional activated sludge plants. This Part III-B utilizes the same text organization format and the same plant geometry. The difference between the two pamphlets is that this Part stresses the calculation procedures for the facility that has been provided with the step-feed capability. In addition to the calculation procedures, comparisons are made to the plug-flow parameters of Part III-A to emphasize those values which change as the process is shifted from the plug-flow to the step-feed mode.

Flow meter readings and control test results comprise the "Observed" data that are entered in the formulas to determine the "Wanted" information.

All calculations are performed in step-by-step fashion and in most cases tabular calculation forms are provided to illustrate the proper sequence of calculation steps to be used in obtaining intermediate and final results. All examples are expressed in separate metric unit and English unit sections to avoid confusion. A table of equivalents is printed inside the front cover. Figure 3 identifies the tank sizes, flow rates, and sludge concentrations used in the calculation examples. For convenience, each example is preceded by definitions of the symbols used in it. A complete list of all symbols and their definitions is included in the Appendix to this pamphlet series.

Though this Part requires numerical notation, the reader need only remember that the number refers to the bay of the aeration tank. For example, ATC2 means the concentration of the mixed liquor (% by centrifuge) in the second bay of the aeration tank. AVG3 means the volume of the third bay expressed in gallons. TFLj means the total flow through the "j th" bay, and finally, TFLj-1 means the total flow through the bay preceding the "j th" bay.

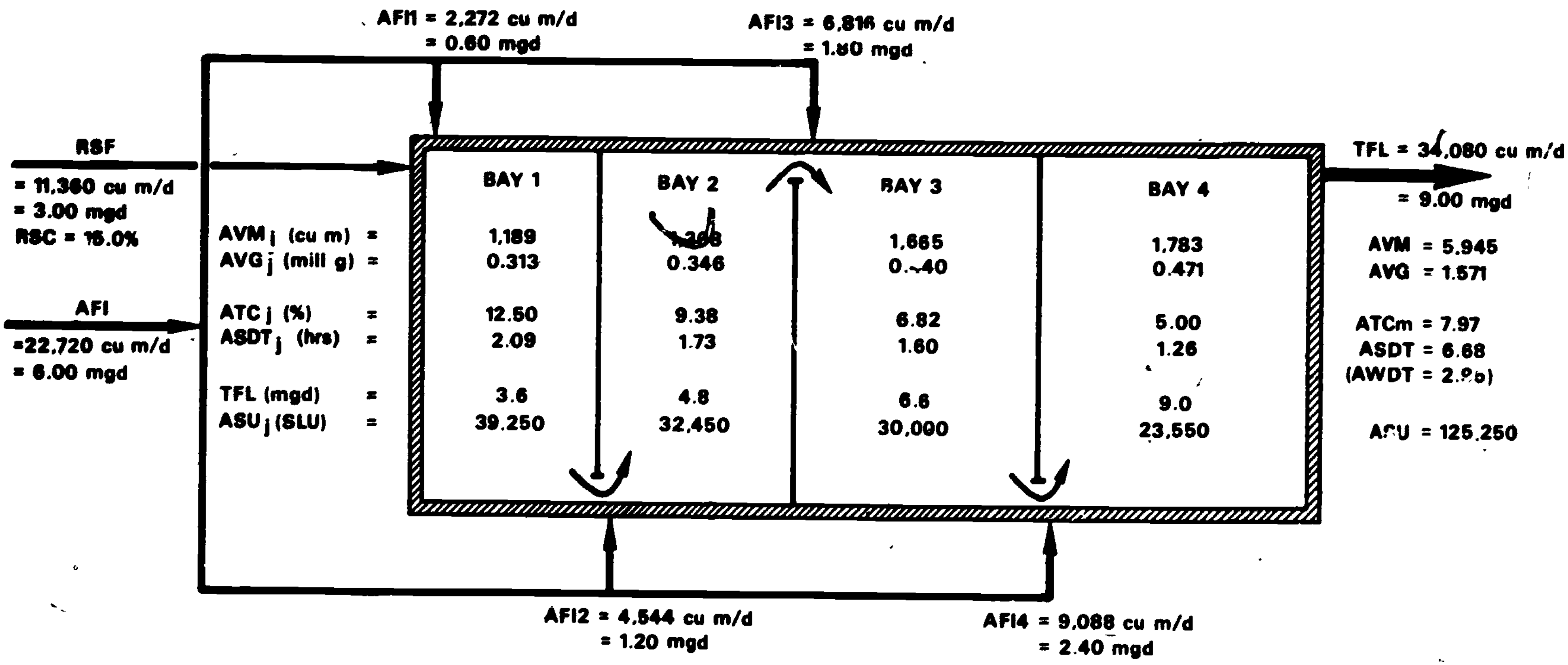

Figure 3

AERATION TANK CHARACTERISTICS FOR THE CALCULATION EXAMPLE

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USE OF CALCULATED RELATIONSHIPS

The Summary statements should help an operator determine what to do when faced with deteriorating sludge or effluent quality. They should help him start shifting wastewater feed location in the proper direction along the aeration tank flow path with greater assurance that he will, in fact, be performing a corrective control adjustment.

But most operators will also wish to know if they are shifting far enough and fast enough. Many will want to determine the actual sludge oxidation and wastewater treatment pressure changes that followed their process control adjustments. And some will wish to trim up their step-feed adjustments to achieve the best net result. To do this, the operator needs more numbers. Although the calculation of certain factors governing step-feed operation is more complex than that in plug-flow operations, it is not really too difficult if approached in an orderly manner. Such numbers can be determined quite easily and rapidly with the aid of a computer and fairly readily using a good desk calculator. Finally, though more time consuming, they can be determined by pencil-and-paper simple arithmetic.

The following tabular formats are geared to help an operator post observed data, record intermediate calculation results, and determine the process pressures and responses without a computer. They should also help the more fortunate few set up orderly computer programs.

If you have not performed step calculations before, don't let the tables and methodology scare you. The procedures are not nearly as formidable as they may appear at first glance, even though you may have to plod laboriously through your first few trials. After that the logic will become more apparent and the procedures more systematized. You may then wish to determine additional process characteristics that can provide you with an even greater insight into the reactions occurring throughout your process. Above all, these efforts should help you produce a better final effluent.

SYMBOLS AND DATA USED IN THE EXAMPLES

To calculate aeration tank characteristics for step-feed or contact stabilization, it is necessary to average the characteristics over the separate compartments of the aeration tanks and, because the compartments may not all be the same volume, a weighted average must be used.

SYMBOLS

ADT - Aeration Tank Detention Time (Hours)
AFI - Aeration Tank Wastewater Flow-In
ASDT - Aeration Tank Sludge Detention Time (Hours)
ASU - Aeration Tank Sludge Units
ATC - Aeration Tank Concentration (% by Centrifuge)
ATCm - Mean Aeration Tank Concentration
ATCn - Aeration Tank Concentration (Final Bay)
AV - Aeration Tank Volume
AVG - Aeration Tank Volume (Gallons)
AVM - Aeration Tank Volume (Cubic Meters)
AWDT - Aeration Tank Waste Detention Time (Hours)
BODi - Five-day Biochemical Oxygen Demand of the Wastewater Entering (In) the Aeration Tanks
BODo - Five-day Biochemical Oxygen Demand of the Final Clarifier Effluent (out)
RSC - Return Sludge Concentration (% by Centrifuge)
RSF - Return Sludge Flow
TFL - Total Flow to Aeration Tank

EXAMPLES

Metric Units	English Units
Observed:	**Observed:**
Bays = 4	Bays = 4
ATC1 = 12.50 %	ATC1 = 12.50 %
ATC2 = 9.38 %	ATC2 = 9.38 %
ATC3 = 6.82 %	ATC3 = 6.82 %
ATC4 = 5.00 %	ATC4 = 5.00 %
AVM1 = 1,189 cu m	AVG1 = 314,000 gal
AVM2 = 1,308	AVG2 = 346,000
AVM3 = 1,665	AVG3 = 440,000
AVM4 = 1,783	AVG4 = 471,000
AVM = 5,945 cu m	AVG = 1,571,000 gal
AFI1 = 2,272 cu m/d	AFI1 = 0.600 mgd
AFI2 = 4,544	AFI2 = 1.200
AFI3 = 6,816	AFI3 = 1.800
AFI4 = 9,088	AFI4 = 2.400
AFI = 22,720 cu m/d	AFI = 6.000 mgd
RSF = 11,360 cu m/d	RSF = 3.000 mgd
RSC = 15.0 %	RSC = 15.0 %

CALCULATION FORMS

FORM A

Calculation Form A is used to compute those step-feed parameters that must be determined differently from the calculation of plug-flow parameters that were illustrated in Part III-A. The step-feed parameters involved include ASU, ASDT, AWDT and ATCxAWDT. Once these specific values are determined, however, calculation of other aeration tank parameters and the use of these values to compute additional relationships follow the simpler methods of Part III-A.

Calculation Form A is used directly when the mixed liquor concentration (ATC) in each bay has been measured and the wastewater flow into each bay (AFI) and the return sludge flow (RSF) have been metered. The known and the observed values in the example are italicized (*0.314, 12.50, 3.4* etc.) for convenient reference. Intermediate calculated values are shown in regular type (3.925, 39,250 etc.) and the final results are shown in bold, large type (**125,240 = ASU, ASDT = 6.68** etc.).

Calculations are started by posting all observed values in columns 1, 2, 5, 6, 7, 8, 9 and 12. Intermediate values are then calculated, step by step, by following the instructions printed in each column. The instruction of "1x2" in column 3, for example, states that for the first bay (J=1), the intermediate "AVxATC" value is obtained by multiplying the *0.314* AVG in column 1 by the *12.50* ATC in column 2, i.e., *0.314* x *12.50* = 3.925 as posted in column 3.

According to the "5+6+7+8+9" instruction in column 10:

TFL = *3.00* + *0.60* + 0.00 + 0.00 + 0.00 = 3.60 for Bay 1
TFL = *3.00* + *0.60* + *1.20* + 0.00 + 0.00 = 4.80 for Bay 2
TFL = *3.00* + *0.60* + *1.20* + *1.80* + 0.00 = 6.60 for Bay 3
TFL = *3.00* + *0.60* + *1.20* + *1.80* + *2.40* = 9.00 for Bay 4

After all intermediate calculations have been performed, the desired process characteristic is determined by following the printed instructions at the bottom of the Table. The mean ATCxAWDT (shown below column 25), for example, is determined by dividing the total of the four column 25 values (121.930) by the total of four column 12 values (6.00), e.g., ATCxAWDT = 121.930/6.00 = 20.32

CALCULATION FORM A

To Determine ASU, ASDT, AWDT and ATCxAWDT

From Observed: ATC, RSF, and AFI

Bay No.	1 Obs AVG (mil g)	2 Obs ATC (%)	3 AVx ATC 1x2	4 ASU (SLU) $(10)^4$x3	5 Obs RSF (mgd)
j=1	0.314	12.50	3.925	39,250	3.00
j=2	0.346	9.38	3.244	32,440	3.00
j=3	0.440	6.82	3.000	30,000	3.00
j=4	0.471	5.00	2.355	23,550.	3.00
TOTAL	1.571 = AVG			125,240 = ASU	

Bay No.	6 Obs AFI1 (mgd)	7 Obs AFI2 (mgd)	8 Obs AFI3 (mgd)	9 Obs AFI4 (mgd)	10 TFL (mgd) 5+6+7 +8+9	11 ASDTj (hr) $\frac{(24)\times 1}{10}$
j=1	0.60				3.60	2.09
j=2	0.60	1.20			4.80	1.73
j=3	0.60	1.20	1.80		6.60	1.60
j=4	0.60	1.20	1.80	2.40	9.00	1.26
TOTAL						ASDT = 6.68

Note: $(10)^4$ and (24) are conversion factors, not Col. Nos.

CALCULATION FORM A (CONTINUED)

Bay No.	12	13	14	15	16	17	18
	Obs APIj (mgd)	ASDT1 (hr)	ASDT2 (hr)	ASDT3 (hr)	ASDT4 (hr)	SUM (hr)	PRO-DUCT
		From Column 11				13+14+15+16	12x17
j=1	0.60	2.09	1.73	1.60	1.26	6.68	4.008
j=2	1.20		1.73	1.60	1.26	4.59	5.508
j=3	1.80			1.60	1.26	2.86	5.148
j=4	2.40				1.26	1.26	3.024
TOTAL	6.00						17.688

Divide Col. 18 TOTAL by Col. 12 TOTAL

17.688/6.00 = AWDT = 2.95

Bay No.	19	20	21	22	23	24	25
	ATCjx ASDTj	ATC1x ASDT1	ATC2x ASDT2	ATC3x ASDT3	ATC4x ASDT4	SUM	PRO-DUCT
	2x11	From Column 19				20+21+22+23	12x24
j=1	26.125	26.125	16.219	10.909	6.300	59.553	35.732
j=2	16.219		16.219	10.909	6.300	33.428	40.114
j=3	10.909			10.909	6.300	17.209	30.976
j=4	6.300				6.300	6.300	15.120
TOTAL							121.930

Divide Col. 25 TOTAL by Col. 12 TOTAL

121.930/6.00 = ATCxAWDT = 20.32

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TABLE A

SUMMARY OF CALCULATIONS

TEST RESULTS	METRIC UNITS	ENGLISH UNITS
AV1	1,190 cu m	0.314 mil g
AV2	1,310	0.345
AV3	1,670	0.440
AV4	1,780	0.471
AV	5,950 cu m	1.571 mil g
AFI1	2,270 cu m/day	0.60 mgd
AFI2	4,540	1.20
AFI3	6,810	1.80
AFI4	9,080	2.40
AFI	22,710 cu m/day	6.00 mgd
RSF	11,360 cu m/day	3.00 mgd
BODi	160 mg/l	160 mg/l
BODo	10 mg/l	10 mg/l
MLVSS	3,000 mg/l	3,000 mg/l
RSTSS	12,000 mg/l	12,000 mg/l
ATC1	12.50 %	12.50 %
ATC2	9.38 %	9.38 %
ATC3	6.82 %	6.82 %
ATC4	5.00 %	5.00 %
ATCm	7.97 %	7.97 %
ASU1	149 SLU	39,250 SLU
ASU2	123 SLU	32,440 SLU
ASU3	114 SLU	30,000 SLU
ASU4	89 SLU	23,550 SLU
ASU	474 SLU	125,240 SLU

TABLE A (CONTINUED)

RESULTS OF INTERMEDIATE CALCULATIONS

	METRIC UNITS	ENGLISH UNITS
BODi	3,630 kg/day	8,010 lb/day
MLVSS	17,840 kg	39,325 lb
RSTSS	136,270 kg/day	300,420 lb/day
ASDT	6.68 hr	6.68 hr
AWDT	2.95 hr	2.95 hr
RFP	50.00 %	50.00 %
RSC	15.00 %	15.00 %
RSU	1,700 SLU/day	450,000 SLU/day

AERATION TANK LOADINGS

	METRIC UNITS	ENGLISH UNITS
BODi/AV	610 g/cu m	38.14 lb/1000cu ft
BODi/ASU	7,660 kg/1000ASU	63.96 lb/1000ASU
BODi/MLVSS (F/M)	0.20 kg/kg	0.20 lb/lb

PURIFICATION PRESSURES

	METRIC UNITS	ENGLISH UNITS
ATCxAWDT	20.32	20.32
ATCxAWDT/1000mg/1 BODi	127	127
RSU/1000AFI	75 RSU/1000cu m	75 RSU/1000gal
RSU/BODi	0.47 RSU/kg	56 RSU/lb
RSTSS/BODi	38 kg/kg	38 lb/lb

Explanatory Note: Some of the time-concentration dependent parameters in step-feed (for example, the ATCxAWDT factor described above) are based on the accumulated sums of products of factors for each specific bay of the aeration tank. As such, the weighted mean answers cannot be determined by the simple division of some of the previously calculated mean values. This fact need not be alarming because the instructions printed on the Calculation Forms take care of these special requirements.

The following explanation will help clarify the values that might be obtained from different calculation procedures.

The calculation procedure to determine ATCxAWDT for step-feed cannot be simplified by multiplying ATCm of 7.97 % (Table A) by the AWDT of 2.95 hours (Form A), 7.97 x 2.95 = 23.51, which does not equal the 20.32 ATCxAWDT oxidation pressure shown in Form A.

The reason for this becomes more apparent from the following more familiar example calculation of the average number of pounds of BOD5 entering a plant during a 3-day interval.

	Flow (mgd)	x	BOD5 (mg/l)	x 8.345 =	lb of BOD5/day
Day 1	2.4	x	152	x 8.345 =	3,044
Day 2	1.5	x	140	x 8.345 =	1,752
Day 3	3.5	x	250	x 8.345 =	7,301
Sum	7.4		542		12,097
Avg.	2.467		180.67		4,032

But the BOD5 calculated from the average Flow and BOD5 (2.467 x 180.67 x 8.345 = 3,713) does not equal the 4,032 average of the three previously calculated BOD values.

AERATION TANK WASTEWATER FLOW-IN - AFI

Calculation Form A can be used directly to determine essential process relationships if flow rates (especially AFI1, AFI2, etc.) have been metered and if mixed liquor and return sludge concentrations (especially ATC1, ATC2, etc.) have been determined. In all too many plants, however, individual flow rates to each aeration tank bay cannot be measured. In such cases, the AFI values needed for use in Calculation Form A can be calculated from the measured RSF, RSC, and ATC values. Calculation Form B can be used to determine these AFI values.

CALCULATION FORM B

To Determine AFI

From Observed: RSF, RSC, and ATC

Bay No.	1	2	3	4	5	6
	Obs ATC j-1 (%)	Obs ATC j (%)	Dif (%)	TFL j-1 (mgd)	AFI j (mgd)	TFL j (mgd)
	From 2		1-2	From 6	3x4 / 2	4+5
j=1	*15.00	12.50	2.50	**3.00	0.60	3.60
j=2	12.50	9.38	3.12	3.60	1.20	4.80
j=3	9.38	6.82	2.56	4.80	1.80	6.60
j=4	6.82	5.00	1.82	6.60	2.40	9.00
TOTAL	AFI1 + AFI2 + AFI3 + AFI4 = AFI = 6.00					

* ATC @ (j-1) for Bay 1 = RSC
** TFL @ (j-1) for Bay 1 = RSF

The step-by-step calculation procedures in Form B are self-explanatory. As emphasized in Calculation Form B, the measured RSC is the "Observed ATC" for Bay j-1, and the metered RSF is the "Observed TFL" for Bay j-1. It is essential that all calculations for the first bay be completed before starting calculations for the second bay. As emphasized by the arrows on the form, the calculated TFL through Bay 1 (3.60) must be posted in the "TFLj-1" column in line "j=2" for use in calculating the AFI to the second bay. Calculations can then proceed from bay to bay until all AFI values are determined for use in Calculation Form A.

DISCUSSION OF EFFECTS OF SWITCHING TO VARIOUS STEP-FEED CONFIGURATIONS

Use of the calculation procedures to estimate the changes that could logically occur if the operational mode were changed all the way from plug-flow (all wastewater entering Bay #1) to contact stabilization (all wastewater entering Bay #4) is discussed and illustrated in this section.

Let's assume that a plant is operating in the plug-flow mode, sludge quality has been deteriorating for a week or more. The one-hour settled sludge concentration (SSC60), for example, has finally fallen from 15.0% to a dangerously low level of 6.0%. Let's further assume that the operator has been increasing return sludge flow percentages according to the calculated demands, but that he has finally reached the maximum capacity of his return sludge pumps at a flow rate equal to 100% of the incoming wastewater flow. Then let's finally assume that he has been unable to improve sludge quality by concurrent aeration intensity and sludge wasting control efforts. Such occurrences are not uncommon at plants suffering from either temporary or sustained overloads.

In cases like this, final effluent quality frequently remains excellent as long as the final clarifier sludge blanket formed by the slowly settling mixed liquor sludge is not forced up and out over the effluent weirs. It is, therefore, imperative that the operator modify control procedures before the decreasing sludge settling rates induce classic sludge bulking with the accompanying drastic deterioration of final effluent quality. Switching from plug-flow to step aeration would increase sludge oxidation pressures and most probably improve mixed liquor settling and concentration rates. Although final effluent quality will probably sag somewhat because of the reduction in the wastewater treatment pressures, such a sag will not nearly approach that which might otherwise occur if the present trend were permitted to continue right on to sludge bulking.

At this time, or preferably before the SSC60 had fallen to 6%, the operator could calculate the wastewater and sludge detention times that would result from step-feed configurations and then change into the mode he believes most appropriate. Shortly thereafter he should check the actual effect of the switchover by observing the changes reflected in the results of his operational control tests and utilizing tabular Forms A and B to calculate process parameters (ATCxAWDT, etc). Ultimately, he would modify the percentages of wastewater flow into the various aeration tank bays to best meet the actual plant loading and sludge quality requirements.

The operator will obviously measure flow rates and perform the normal operational control tests during and after the switch from plug-flow to contact stabilization. He should be able to observe distinctive changes in sludge quality within 3 to 7 days after the switchover. By this time better sludge quality, as indicated by increasing SSC60 values, can be expected. He should then be able to continue reduced sludge wasting rates to further increase ATC, RSC, sludge age, upgrade sludge quality, and improve process performance.

The object of this mode switch and these process control adjustments has been to improve sludge quality and force the SSC60 value upward. When this objective is reached or approached, the operator will then be primarily concerned with final effluent quality. He will want to maximize treatment pressures by shifting the step-feed loading back toward the plug-flow configuration. Now that the danger of sludge bulking has been removed, he can, for example, readjust the wastewater distribution to send approximately one-third of the waste flow to Bay 1 and continue routing two-thirds to Bay 4. As conditions improve, he can then decide to shift the two-thirds of the waste loading from Bay 4 to Bay 3 to further increase purification pressures. If all goes well, he should continue backing up in this manner until he can once again route all wastes to Bay 1, restore the process to plug-flow, and maximize the waste treatment pressures.

There are dozens of step-feed configurations that can be used to meet process demands. As discussed in the Summary Section, *shifting toward contact stabilization will increase sludge oxidation pressures and shifting toward plug-flow will increase wastewater purification pressures.*

TABLE B

Comparison Between Plug Flow & Contact Stabilization
@AFI=6.00 mgd, RSF=6.00 mgd, SSC60=6.0%,WCR=800, MLVSS=75%

TEST RESULTS (Measured or Calculated Values)					
	PLUG FLOW	CONTACT STABILIZATION @ CONSTANT TSU		CONTACT STABILIZATION @ CONSTANT RSC	
			% *		% *
AVG (mil gal)	1.5708	1.5708	100	1.5708	100
AVG-Contact Tk	1.5708	0.3927	25	0.3927	25
AFI1 (mgd)	6.000	0	-	0	-
AFI2 (mgd)	0	0	-	0	-
AFI3 (mgd)	0	0	-	0	-
AFI4 (mgd)	0	6.000	-	6.000	-
AFI-Total (mgd)	6.000	6.000	100	6.000	100
RSF (mgd)	6.000	6.000	100	6.000	100
ATC1 (%)	3.0	4.0	133	6.0	200
ATC2 (%)	3.0	4.0	133	6.0	200
ATC3 (%)	3.0	4.0	133	6.0	200
ATC4 (%)	3.0	2.0	67	3.0	100
ATCm (%)	3.0	3.5	117	5.25	175
RSC (%)	6.0	4.0	67	6.0	100
RSU/Day	360,000	240,000	67	360,000	100
RSTSS (mg/l)	4,800	3,200	67	4,800	100
RSTSS (lb/day)	240,300	160,200	67	240,300	100
MLVSS (mg/l)	1,800	1,200	67	1,800	100
MLVSS (lb/day)	23,600	3,930	17	5,900	25
BODi (mg/l)	160	160	100	160	100
BODi (lb/day)	8,010	8,010	100	8,010	100
BODo (mg/l)	10	10	100	10	100

* Percent of Plug-Flow Value

	PLUG FLOW	CONTACT STABILIZATION			
		@ CONSTANT TSU		@ CONSTANT RSC	
			% *		% *
ASU-Total	47,100	54,700	116	82,500	175
CSU-Total	22,500	14,900	67	22,500	100
TSU-Total	69,600	69,600	100	105,000	150
ASU-Contact	47,100	7,850	17	11,780	25
AERATION TANK LOADINGS					
BODi/1000AVF	38	152	400	152	400
BODi/ 1000ASU	170	1,020	600	680	400
BODi/MLVSS (F/M)	0.34	2.04	600	1.36	400
SLUDGE OXIDATION PRESSURES					
ASDT (hrs)	3.14	5.5	175	5.5	175
CSDT (hrs)	1.50	1.5	100	1.5	100
SAH (hrs/day)	16.2	18.8	116	18.8	116
SAP	0.677	0.786	116	0.786	116
AGE (Days)	6.0	6.0	100	9.0	150
AAG (Days)	4.06	4.71	116	7.1	175
WASTEWATER PURIFICATION PRESSURES					
AWDT (hrs)	3.14	0.79	25	0.79	25
ATCxAWDT	9.42	1.56	17	2.36	25
ATCxAWDT/ 1000BODi	59.0	9.8	17	14.7	25
RSU/1000AFI	60.0	40.0	67	60.0	100
RSU/lb BODi	45.0	30.0	67	45.0	100
RSTSS/lb BODi	30.0	20.0	67	30.0	100

* Percent of Plug-Flow Value

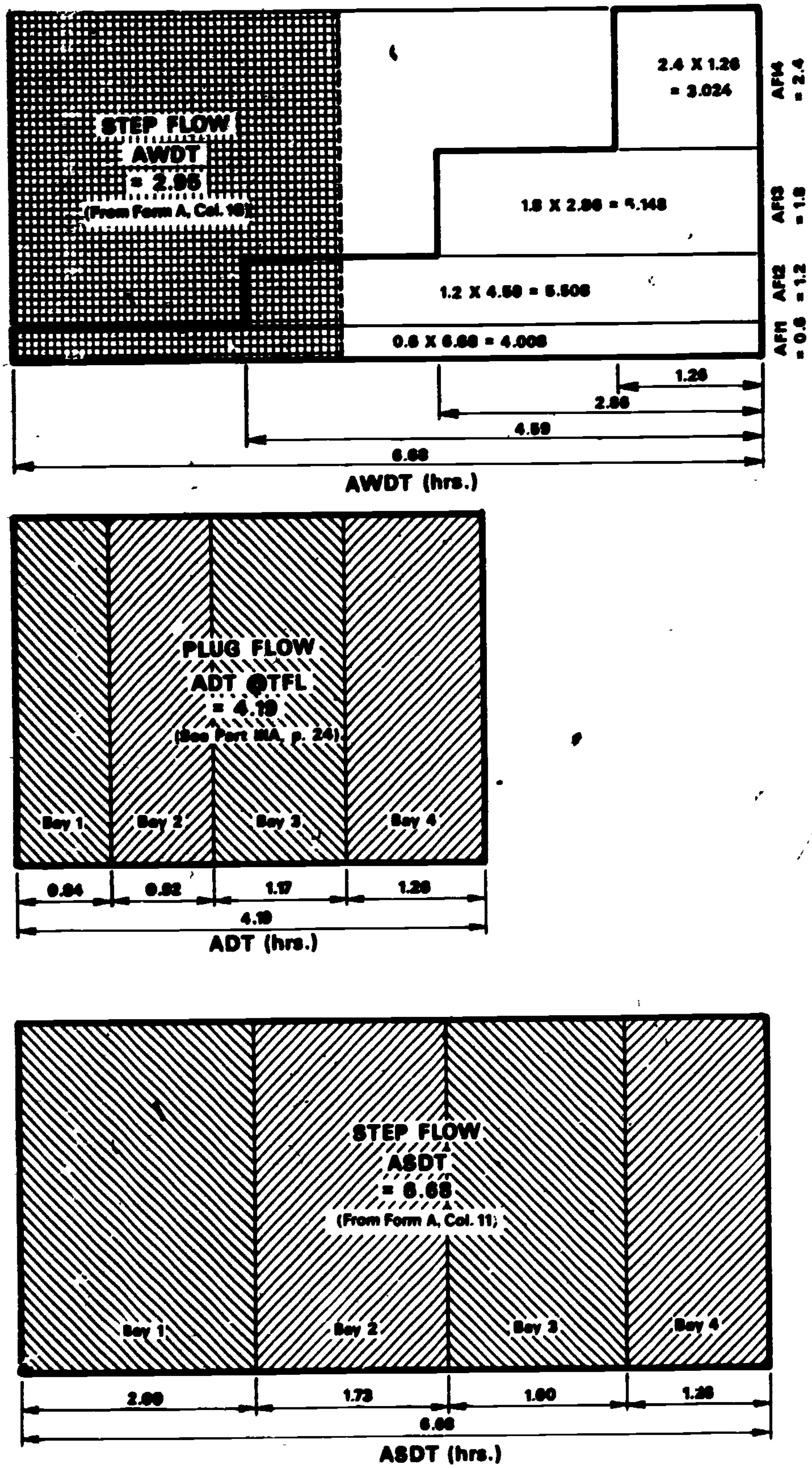

Figure 4
AERATION TANK DETENTION TIME

RATIONALE OF PROCEDURE DEVELOPMENT

The following diagrams were developed for those interested in reviewing the rationale used in developing the step-feed calculation procedures.

AWDT, ADT, & ASDT

The three shaded areas, representing detention times in Figure 4, reveal at a glance the extent to which sludge and wastewater aeration tank detention times are changed when the process mode is switched from plug-flow to step-feed. ADT, which is the same for both sludge and wastewater at plug-flow, is indicated by the size of the shaded middle sketch. The relative size of the shaded area of the upper sketch shows that the time wastewater is subjected to aeration (AWDT) was reduced to 70% of the plug-flow value after the mode was switched to step-feed. The relative size of the shaded area of the lower sketch shows that the time that sludge was subjected to aeration (ASDT) was increased to 160% of the former plug-flow value.

The ADT for plug-flow, illustrated in the middle sketch, is the sum of the time that the combined return sludge and wastewater (TFL) remained in each of the four bays.

The ASDT for step-feed, which is the time that sludge remains under aeration, (bottom sketch) is also the sum of the time that the combined return sludge and wastewater remained in each of the four bays. But in this case only a fraction of the wastewater flow was directed into each of the Bays. This reduced the total flow (TFL) through each of the first three bays (Column 10, Form A) and therefore increased the detention time in each of these bays (Column 11, Form A). Switching from plug-flow to step-feed increases the time that sludge is subjected to aeration.

Wastewater detention time (AWDT in the upper sketch) is calculated somewhat differently. The 0.6 mgd portion of the wastewater introduced to Bay 1 flows through all four bays and is therefore subjected to aeration for 6.68 hours. The product of this portion of the flow multiplied by its aeration detention time (0.6 x 6.68 = 4.008) is illustrated by the size of the bottom rectangle in the upper sketch.

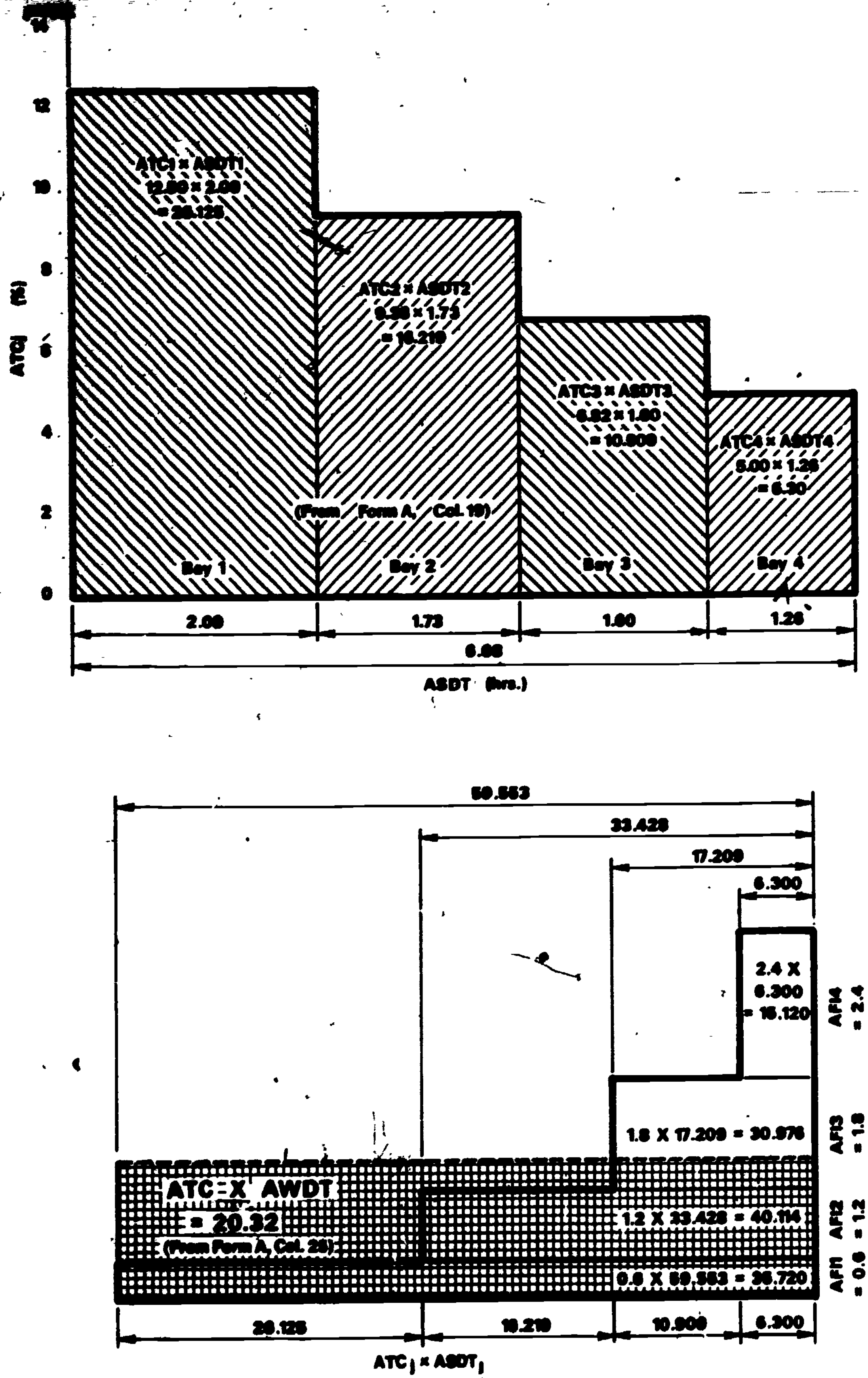

Figure 5

ATC × AWDT from ATC & ASDT

The 1.20 mgd portion of wastewater introduced into Bay 2, however, flows through only the last three bays and is subjected to aeration for only 4.59 hours. This product (1.2 x 4.59 = 5.508) is illustrated by the size of the second lower rectangle in the upper sketch.

Similarly, the portions of wastewater flow introduced into Bays 3 and 4 are subjected to even less aeration.

The shaded area of the upper sketch is equal to the sum of the areas of the four separate horizontal rectangles. The weighted mean wastewater detention time (AWDT) is therefore equal to the sum of the products of the individual flow portions times their respective aeration detention times divided by the wastewater flow (AFI). (17.688 from Column 18, Form A, divided by 6.0 from Column 12, Form A = 2.95 = AWDT)

ATC x AWDT

Calculation of the ATCxAWDT factor for step-feed is also based on a progressively weighted mean value determined somewhat similar to the previously described AWDT.

Wastewater flowing through each aeration tank bay is subjected to the ATCj x ASDTj in each bay (upper sketch and Column 19, Form A).

But, here again, only the 0.6 mgd portion of the wastewater that enters Bay 1 is subjected to the sum of the ATCj x ASDTj pressures in all four bays. This value (0.6 x 59.553 = 35.72) is represented by the lower rectangle in the bottom sketch.

The 1.2 mgd portion of the wastewater that enters Bay 2 is subjected to the sum of the ATCj x ASDTj pressures in the last three bays, etc. And so on.

The shaded area of the lower sketch in Figure 5 is equal to the sum of the areas of the four horizontal rectangles. The weighted mean ATC x AWDT for the entire cycle is equal to the sum of AFIj multiplied by the accumulated sum of ATCj x ASDTj; all are divided by the total AFI entering the aeration tank. (121.930 from Column 25, Form A, divided by 6.0 from Column 17, Form A = 20.32 = ATCxAWDT)

MEAN AERATION TANK CONCENTRATION - ATCm

Since, in step-feed, the ATC will decrease from the first to the last compartment, a weighted mean ATC replaces the plug-flow ATC. To determine the weighted mean ATC, (ATCm), multiply each compartment's ATC by the compartment's volume, add these terms together, and divide by the total aeration tank volume. Thus, for a four compartment aeration tank with the individual compartment ATC's measured:

$$ATC_M = (ATC1 \times AV1 + ATC2 \times AV2 + ATC3 \times AV3 + ATC4 \times AV4) \ / \ AV$$

Figure 6 graphically displays this calculation procedure. The area outlined with the heavy line is the sum of ATC1xAV1 + ATC2xAV2 + ATC3xAV3 + ATC4xAV4. This area must and does equal the shaded area. ATCm is then calculated by dividing the area by the total aeration tank volume, AV.

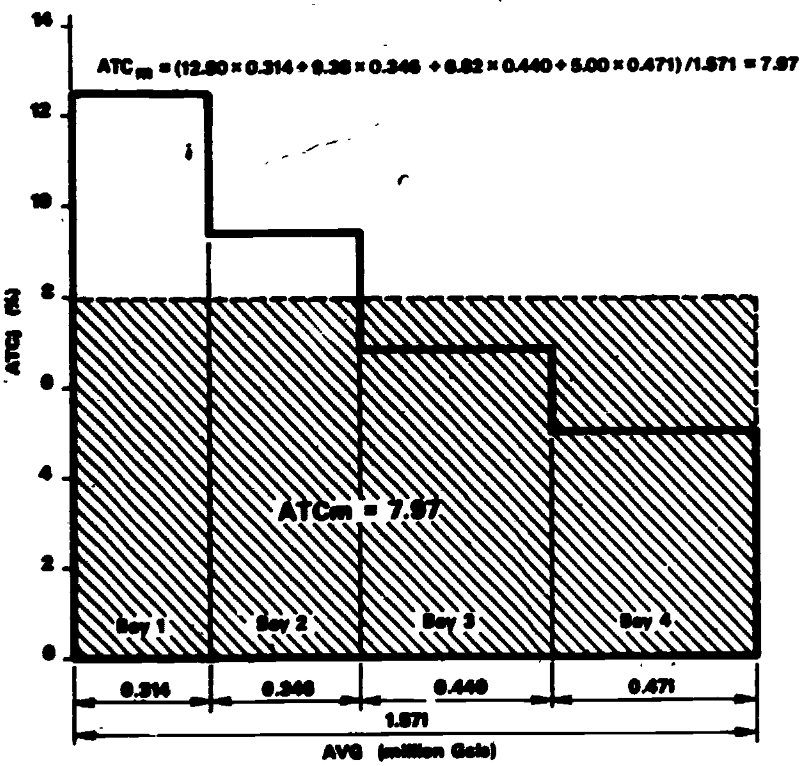

Figure 6

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FORMULAS FOR STEP-FEED CALCULATIONS

The formulas used to determine the various step-feed relationships are provided for those who may wish to set up their own special calculation procedures or program a computer to do the work. All equations are set up on the basis of a four-bay aeration system.

FORMULAS USED IN CALCULATION FORM A

The following formulas show the equations for the process evaluation factors shown in Form A:

$$ASDT_j = \frac{24 \times AVG_j}{TFL_j}$$

$$ASDT = \sum_{j=1}^{n} ASDT_j$$

$$AWDT = \frac{\sum_{i=1}^{n} AFI_i \sum_{j=i}^{n} ASDT_j}{AFI}$$

$$ATC \times AWDT = \frac{\sum_{i=1}^{n} AFI_i \sum_{j=i}^{n} ASDT_j \times ATC_j}{AFI}$$

$$ASU = 10{,}000 \times AV \times ATC_m$$

FORMULAS USED IN CALCULATION FORM B

If the AFI to each bay is unmetered and unknown, each AFIj or percent of AFI can be calculated from AFI, RSF, RSC, and ATCj from the following:

$$AFI1 = (RSF)(RSC-ATC1) / ATC1$$

$$AFI2 = (RSF+AFI1)(ATC1-ATC2) / ATC2$$

$$AFI3 = (RSF+AFI1+AFI2)(ATC2-ATC3) / ATC3$$

$$AFI4 = (RSF+AFI1+AFI2+AFI3)(ATC3-ATC4) / ATC4$$

ATC_M & ATC_N

The following two equations are used to calculate the weighted mean aeration tank concentration (ATCm) and if it should be required the concentration of the last bay in the aeration tank (ATCn):

$$ATC_m = \sum_{j=1}^{n} \frac{ATC_j \times V_j}{AV}$$

The last compartment ATC is given by:

$$ATC_N = RSFxRSC / (RSF+AFI) = RSFxRSC / TFL$$

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OPERATIONAL CONTROL PROCEDURES FOR THE ACTIVATED SLUDGE PROCESS

ADDENDUM NO. 1

To The February 1975

PART III-B

CALCULATION PROCEDURES

FOR

STEP-FEED PROCESS RESPONSES

by

Alfred W. West, P.E.
Director, National Waste Treatment Center

AUGUST 1975

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF WATER AND HAZARDOUS MATERIALS

FOREWORD

The National Waste Treatment Center (Cincinnati) is developing a series of pamphlets describing Operational Control Procedures for the Activated Sludge Process. The series will include Part I OBSERVATIONS, Part II CONTROL TESTS, Part III CALCULATION PROCEDURES, Part IV SLUDGE QUALITY, Part V PROCESS CONTROL and an APPENDIX. Parts I and II were originally printed as separate pamphlets dated April 1973. The May 1974 printing combined the two Parts which includes some revisions concerning use of the centrifuge and dilution settlometer tests. Each part will be released for distribution as soon as it is completed, though not necessarily in numerical order. The original five-part series may then be expanded to include case histories and refined process evaluation and control techniques.

This pamphlet has been developed as a reference for Activated Sludge Plant Control lectures I have presented at training sessions, symposia, and workshops. It is based on my personal conclusions reached while directing the operation of dozens of activated sludge plants. This pamphlet is not necessarily an expression of Environmental Protection Agency (EPA) policy or requirements.

The mention of trade names or commercial products in this pamphlet is for illustrative purposes and does not constitute endorsement or recommendation for use by the EPA.

Alfred W. West

CALCULATION FORM A

Calculation Form A on pages 12 & 13 of the February 1975 PART III-B was set up in a step-by-step format to correspond directly to the explanatory Rationale of Procedure Development on pages 22 through 26.

Once the governing principles and assumptions are understood, however, some of the steps can be combined for more direct, and somewhat simpler, calculation of the Process Characteristics. The following Simplified Calculation Form Example, that does not require AFIj input, can be used instead of the original FORM A.

SIMPLIFIED CALCULATION FORM EXAMPLE

<u>Direct Measurements</u>

No. of Bays = 4
AFI = 6.0 mgd
AVG = 1.571 mgd
RSF = 3.0 mgd
RSC = 15.0%

<u>Intermediate Summations</u>

Bay No.	1	2	3	4
	AV (mil g)	ATC (%)	AV x ATC	AV x ATC
	Obs.	Obs.	1 x 2	2 x 3
j=1	0.314	12.50	3.925	49.063
j=2	0.346	9.38	3.245	30.443
j=3	0.440	6.82	3.001	20.465
j=4	0.471	5.00	2.355	11.775
TOTAL	1.571		12.526	111.746

PROCESS CHARACTERISTIC CALCULATIONS

To use the following Process Characteristic equations, the preceding Intermediate Summations Table must first be completed. The column TOTALS are then substituted into the equations as indicated.

$$\text{ATCm} = \text{Column } 3 \;/\; \text{Column } 1$$

$$= 12.526 \;/\; 1.571$$

$$= 7.97$$

$$\text{ASDT} = 24 \times \text{AVG} \times \text{ATCm} \;/\; \text{RSF} \times \text{RSC}$$

$$= 24 \times 1.571 \times 7.97 \;/\; 3.0 \times 15.0$$

$$= 6.68$$

$$\text{AWDT} = 24 \times \text{AVG} \times (\text{RSC} - \text{ATCm}) \;/\; \text{AFI} \times \text{RSC}$$

$$= 24 \times 1.571 \times (15.0 - 7.97) \;/\; 6.0 \times 15.0$$

$$= 2.95$$

$$\text{ATCxAWDT} = 24 \times \text{AVG} \left[\text{ATCm} - (\text{Col. } 4 \;/\; \text{RSC} \times \text{AVG})\right] / \text{AFI}$$

$$= 24 \times 1.571 \left[7.97 - (111.746 \;/\; 15.0 \times 1.571)\right] / 6.0$$

$$= 20.28$$

$$\text{ASU} = 10{,}000 \times \text{AVG} \times \text{ATCm}$$

$$= 10{,}000 \times 1.571 \times 7.97$$

$$= 125{,}240$$

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FORMULAS USED IN CALCULATION OF FORM B

The first group of four formulas on page 28 of the February 1975 Part III-B must be used in proper sequence. That is, AFI1 must be calculated first for use in the AFI2 formula, and AFI1 and AFI2 are needed to calculate AFI3, etc.

The following two formulas permit direct AFIj and TFLj calculations for any bay.

$$AFI_j = RSF \times RSC\left(\frac{1.0}{ATC_j} - \frac{1.0}{ATC_{j-1}}\right)$$

(where ATCj-1 = RSC for Bay 1)

$$TFL_j = \frac{RSF \times RSC}{ATC_j}$$

REQUEST FOR AFIC-C AUDIOVISUAL INSTRUCTION UNITS

The Audiovisual request form on page 29 erroneously implied that the tapes and slides were available at no charge.

Actually; the catalogs are free, the tapes and slides may be borrowed, but the cost of reproduction is charged for permanent acquisition of the tapes and slides.

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FORMULAS USED IN CALCULATION OF ORIGINAL FORM A

There were errors in subscripts and summations in the formulas on page 27 of the February 1975 Part III-B. Furthermore, the ASU formula results are expressed in millions of sludge units.

The following formulas supercede and replace those on page 27. Cut out this page on the dotted lines and insert over the existing formulas.

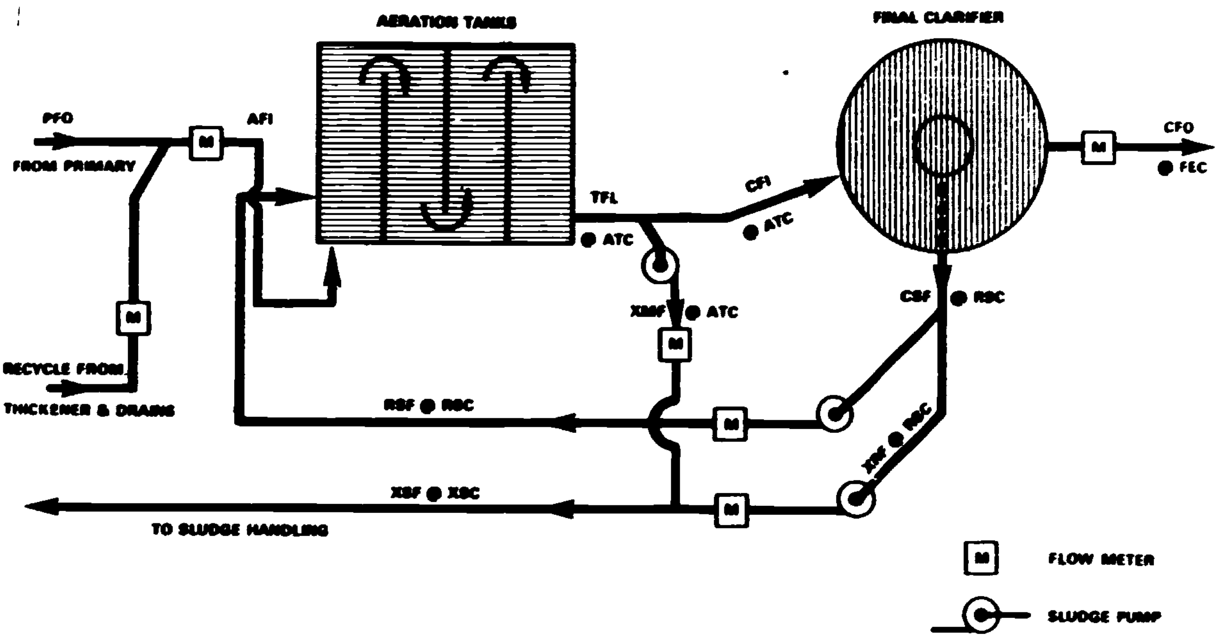
$$ASDT_j = \frac{24 \times AVG_j}{TFL_j}$$

$$ASDT = \sum_{j=1}^{n} ASDT_j$$

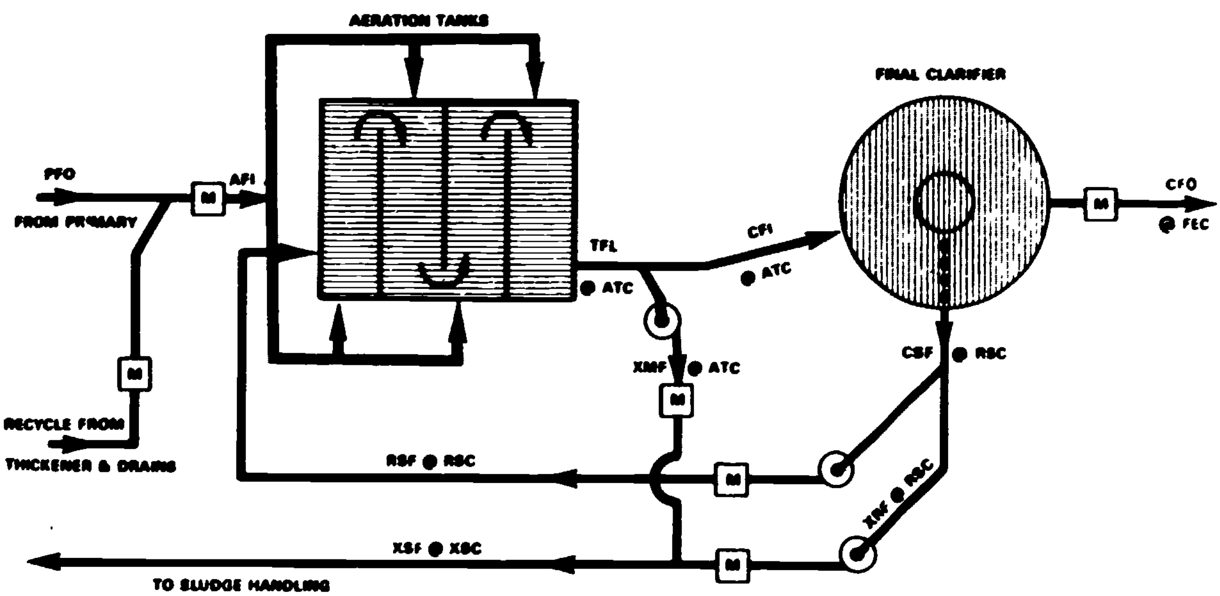
$$AWDT = \frac{\sum_{i=1}^{n} AFI_i \sum_{j=i}^{n} ASDT_j}{AFI}$$

$$ATC \times AWDT = \frac{\sum_{i=1}^{n} AFI_i \sum_{j=i}^{n} ASDT_j \times ATC_j}{AFI}$$

$$ASU = 10{,}000 \times AV \times ATC_m$$



TYPICAL PLUG FLOW ACTIVATED SLUDGE PLANT



TYPICAL STEP-FEED ACTIVATED SLUDGE PLANT