Account 44 ?LH
6-27-84

Completion Report

to

Wastewater Treatment: Adaptive Design

Strategies for a Dynamic Environment

(EN 83-R-115)

E-028

C. Patrick Koelling
Assistant Professor
School of Industrial Engineering and Management

July 1, 1983 - June 30, 1984

Summary

This research has examined wastewater treatment costs from an operational, adaptive design perspective. An operational model of the activated sludge treatment process was extended to represent system "add-ons". The model is used to transform certain specified system parameters of an existing treatment facility into biological and flow output specifications. This results in a complete description of the operating system including certain add-on treatment schemes. An economic evaluation of this system is then preformed. This evaluation utilizes traditional engineering economic analysis to derive the equivalent uniform annual cost of facility operation.

The entire analysis package has been developed on a Radio Shack TRS-80 microcomputer. This was judged to be an important step in enhancing the ultimate usefulness of this type of analysis.

Introduction

Throughout Oklahoma, and the world, wastewater treatment is an ongoing exercise. It is a necessary practice in order to protect our environment from the undesirable side-effects of untreated waste. Of major concern is treating the wastewater in the most economical manner.

Earlier research in this regard resulted in the development of a model to determine the least-cost design for the activated sludge process (Kincannon and Koelling, No. EN 81-R-150-W). This prior research concerned treatment facility design. However, many more plants are currently operating than are being designed, and a great savings potential exists in these operating facilities. Additional research was performed to develop an operational and economic model of an existing treatment plant as a first step in optimizing the system subject to environmental shocks (Koelling and Kincannon, No. EN 82-R-78-W).

All wastewater treatment facilities operate in an increasingly volatile environment. Current design practices fail to adequately plan for the dynamic situation and therefore shortly render the facility incapable of performing at a necessary level. This may be evident by an inability to handle the wastewater flow or failure to achieve discharge requirements. Recognizing that the cost of operating treatments plants is increasing rapidly, the impact of upgrading an existing plant is considerable. This is not a rare occurrence, but is happening quite frequently as communities continue to grow, and concern for the environment affects effluent requirements.

The current research centered on developing an adaptive design strategy that will specify appropriate, minimum-cost modifications to an existing plant for particular environmental changes. It is anticipated that such a strategy would be important in many settings throughout the country, and many here in Oklahoma. Decisions are being made daily regarding required upgrading of existing facilities. This procedure will allow them to be made in a cost-efficient manner.

An additional merit of this research is its mode of application. The entire model is developed for microcomputer application. This not only enhances its ease-of-use but also its portability.

The activated sludge process, one of the major wastewater treatment processes, was used as the modeled system. The major components of the activated sludge process are shown in Figure 1. Sludge treatment costs must also be considered. There are several alternatives in this regard, one of which is presented in Figure 2.

Objectives of Research

The initial research effort centered on extending the current model of the activated sludge process in the operational mode. This model is capable of specifying sludge treatment operational parameters. This model integrates the concepts of engineering economic analysis to derive an economic model of treatment operation, reflecting annual costs related to operation, maintenance, and energy consumption.

Subsequent research effort emphasized the current model's extension to include specific system upgrades to allow the facility to adapt to environmental shocks. The consideration of upgrading current facilities required the inclusion and analysis of several other treatment factors. These served as sub-objectives of the proposed research. These sub-objectives are:

1. Adapting models for Biological Towers and Rotating Biological Contactors as alternatives to the Aeration Basin.
2. Model possible add-on treatment schemes, such as filtration and chemical precipitation.
3. Model additional sludge treatment alternatives.
4. Examine the impact of nitrification on the treatment process.
5. Develop an adaptive design model.
6. Evaluate impact on the facility of changing power costs, tighter effluent requirements, and inflation.

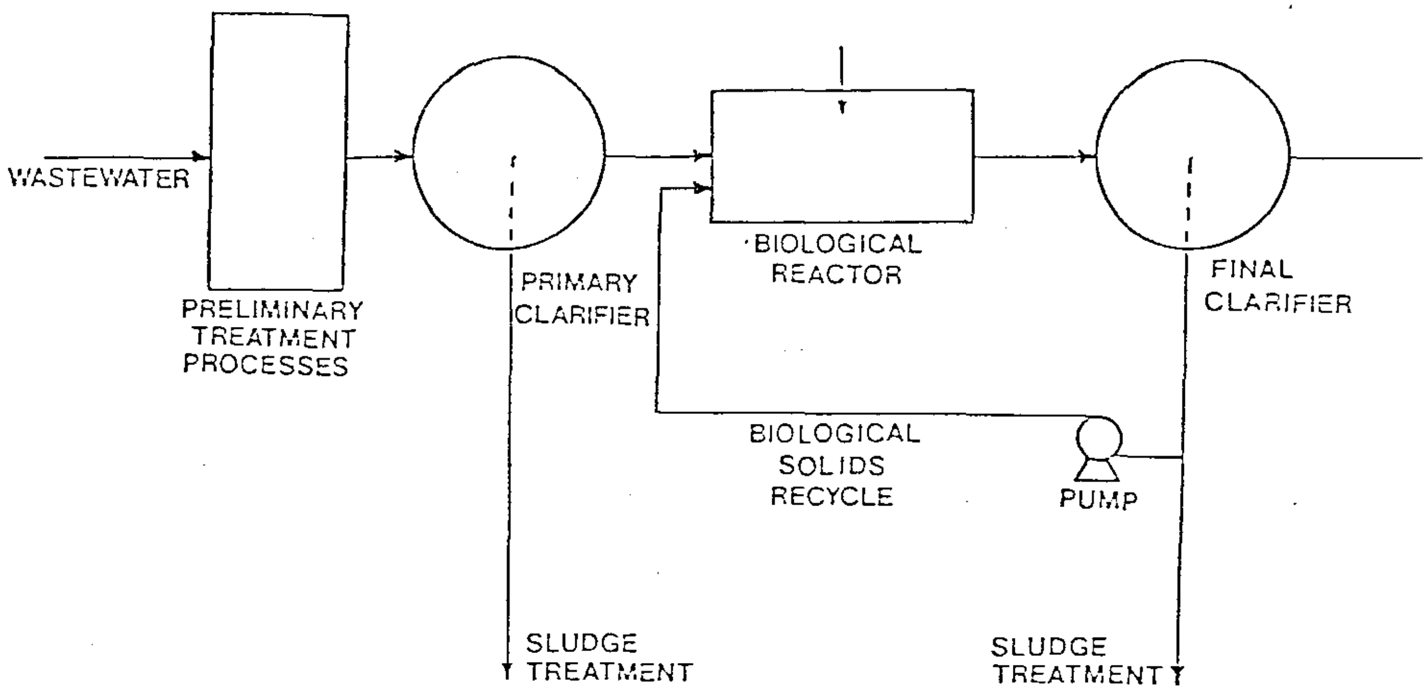


Figure 1. Flow diagram of activated sludge process.

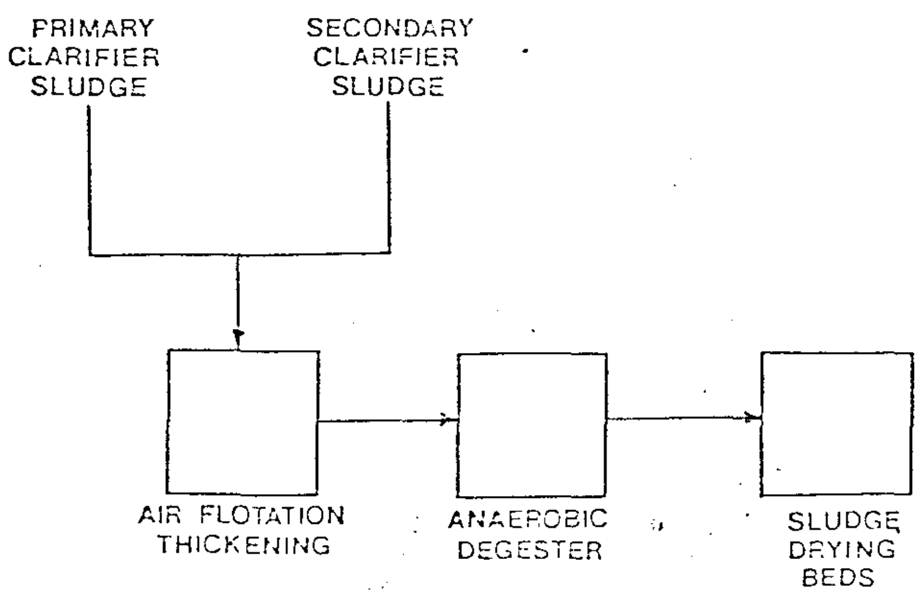


Figure 2. Flow diagram of sludge treatment process.

The results of the research were to be a thorough analysis of the impact of a changing environment on the treatment facility and its cost, as well as a model which determined the most economic system adaptions for specific environmental shocks.

Variable Definition

Listed below are the variables which are used throughout this report. Notice that they are categorized as either input or output variables. Input variables represent inputs to the computer program to derive operational specifications (output variables). In essence, they represent current system parameters.

VARIABLE DEFINITIONS

---

1) INPUT VARIABLES

****

A. GENERAL

VARIABLE	DEFINITION	UNITS
BS	BOD-5 EFFLUENT STANDARD	MG/L
XE	SUSPENDED SOLID EFFLUENT STANDARD	MG/L
K1	BOD-5 RATIO OF SUSPENDED SOLIDS	NONE
S0	SOLUBLE INFLUENT BOD-5	MG/L
F	FLOW	MGD
APC	AREA OF PRIMARY CLARIFIER	SQ. FT.
XO	INFLUENT SUSPENDED SOLIDS	MG/L
V	VOLUME OF BIOLOGICAL REACTOR	MGAL
UM	U-MAX BIOKINETIC CONSTANT	LB/DAY/LB

KB	K-B BIOKINETIC CONSTANT	LB/DAY/LB
KD	K-D BIOKINETIC CONSTANT	DAY^{-1}
YT	Y-T BIOKINETIC CONSTANT	LB/LB
A	A SETTLEABILITY CONSTANT	FT/MIN
N	N SETTLEABILITY CONSTANT	NONE
AFC	AREA OF FINAL CLARIFIER	SQ.FT
MXR	MAXM. POSSIBLE XR	MG/L
H	LOW LIFT STATION PUMP HEAD	FEET
IPI	INDUSTRIAL PRICE INDEX	NONE
AF	AIR FLOW THRU DIFFUSERS	CFM
LAD	LOCAL AIR DENSITY	LB/FT^3
CD	CHLORINE DOSAGE	MG/L

B. <u>MECHANICAL AERATION</u>

NO	OXYGEN RATING OF AERATOR	LB/HP/HR
B	SALINITY-SURFACE TENSION CORRECTION FACTOR	NONE
CW	OXYGEN SATURATION CONCENTRATION FOR WASTE	MG/L
CL	DISSOLVED OXYGEN CONCENTRATION	MG/L
TW	TEMPERATURE OF WASTE WATER	DEG.C
AW	OXYGEN TRANSFER CORRECTION FACTOR	NONE

C. <u>DIFFUSED AERATION</u>

AE	TRANSFER EFFICIENCY OF AERATION	NONE

PI	ABSOLUTE INLET PRESSURE	PSIA
PO	ABSOLUTE OUTLET PRESSURE	PSIA
TP	TEMPERATURE OF WASTE WATER	DEG.C
E	COMPRESSOR EFFICIENCY	NONE
X	SUSPENDED SOLIDS IN BIOLOGICAL REACTOR	MG/L
AP	ALPHA-RECYCLE FLOW FRACTION	NONE
XR	SUSPENDED SOLIDS OF WASTE FLOW	MG/L
FW	WASTE FLOW FROM FINAL CLARIFIER	MGD
SFC	SLUDGE PRODUCED FROM FINAL CLARIFIER	LB/DAY
F1	SLUDGE FLOW FROM PRIMARY CLARIFIER	MGD
F2	SLUDGE FLOW FROM FINAL CLARIFIER	MGD
F3	RECYCLE FLOW	MGD
AT	AREA OF THICKENER	FT^2
ADB	AREA OF DRYING BEDS	FT^2

D. PUMPING

H1	PRIMARY CLARIFIER SLUDGE PUMP HEAD	FT
H2	FINAL CLARIFIER SLUDGE PUMP HEAD	FT
H3	RECYCLE PUMP HEAD	FT
EC	ELECTRICAL POWER COST	$/KWH
LC	LABOR COST	$/HR
LO	SOLIDS LOADING TO AIR FLOTATION	LB/DAY/SQ.FT
ED	EFFICIENCY OF ANAEROBIC DIGESTOR	NONE
LD	SOLIDS LOADING TO DIGESTORS	LB/DAY
FS	SOLIDS FRACTION OF PRIMARY SLUDGE	NONE

2) OUTPUT VARIABLES

****

A. GENERAL

VARIABLE	DEFINITION	UNITS
SE	SOLUBLE EFFLUENT BOD-5	MG/L
SI	SOLUBLE INFLUENT AFTER PRIMARY CLARIFIER	MG/L
XI	INFLUENT S.S. AFTER PRIMARY CLARIFIER	MG/L
PS	SLUDGE PRODUCED FROM PRIMARY CLARIFIER	LB/DAY
X	SUSPENDED SOLIDS IN BIOLOGICAL REACTOR	MG/L
AP	ALPHA-RECYCLE FLOW FRIACTION	NONE
XR	SUSPENDED SOLIDS OF WASTE FLOW	MG/L
FW	WASTE FLOW FROM FINAL CALRIFIER	MGD
SFC	SLUDGE PRODUCED FROM FINAL CLARIFIER	LB/DAY

B. MECHANICAL AERATION

POH	POUNDS OF OXYGEN PER HOUR	LB(0_2)/HR
N1	OXYGEN RATING FOR PLANT CONDITIONS	MG/L
HP	HORSE-POWER	HP

C. DIFFUSED AERATION

POD	POUNDS OF OXYGEN PER DAY	LB($_2$)/DAY
PAS	POUNDS OF AIR PER SECOND	LB/SEC
HP	HORSE-POWER	HP
MHP	MIXING HORSE-POWER	HP

METHODS

Two basic components had to be developed for complete system representation. These were an operational model specifying complete system parameters and an economic model used to derive system cost.

OPERATIONAL MODEL

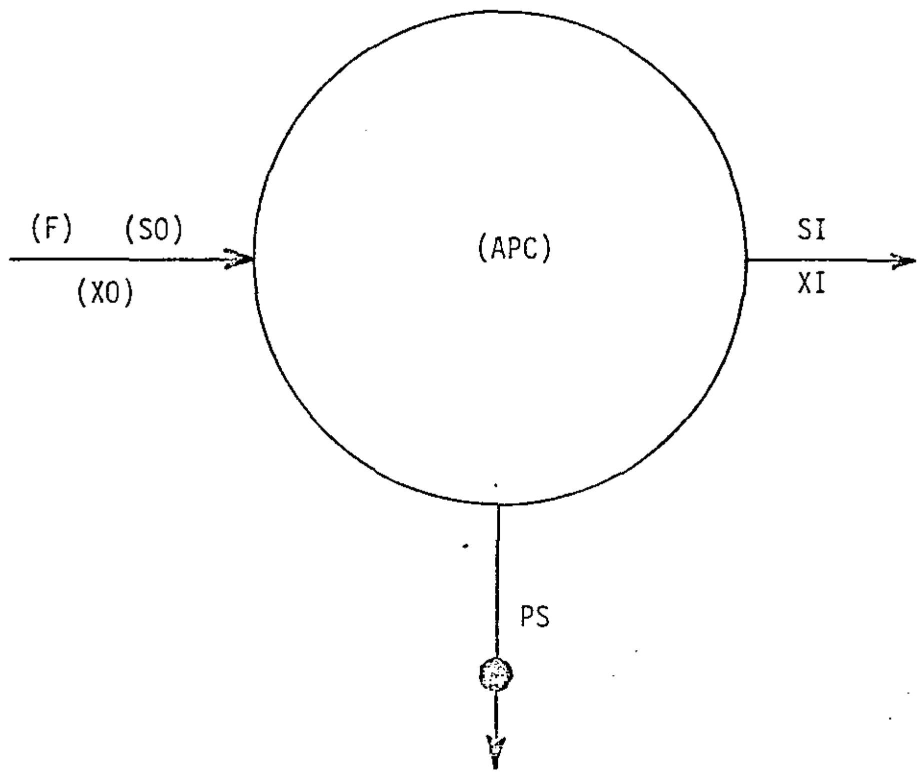
In order to adequately represent the operation of the waste treatment facility it was necessary to extend the comprehensive model of the operational activated sludge process in light of the suggested sub-objectives. This consists of a series of mathematical equations relating the parameters of the system. Mathematical models for unit processes have been developed previously and are presented in Figure 3.

Unfortunately, due to budgetary revisions resulting in a reduction of resources available to perform the research, a restricted research effort was undertaken. Therefore, only two of the suggested six sub-objectives were considered.

1. Model possible add-on treatment schemes, such as filtration and chemical precipitation.

   These add-on schemes will be used as additional wastewater treatment to achieve a desired effluent. It is estimated that trade-offs will exist regarding types and performance of alternatives and cost. Appropriate models must be developed and integrated into the current activated

Primary Clarifier Specifications



$$SE = BS - (KI)(XE)$$

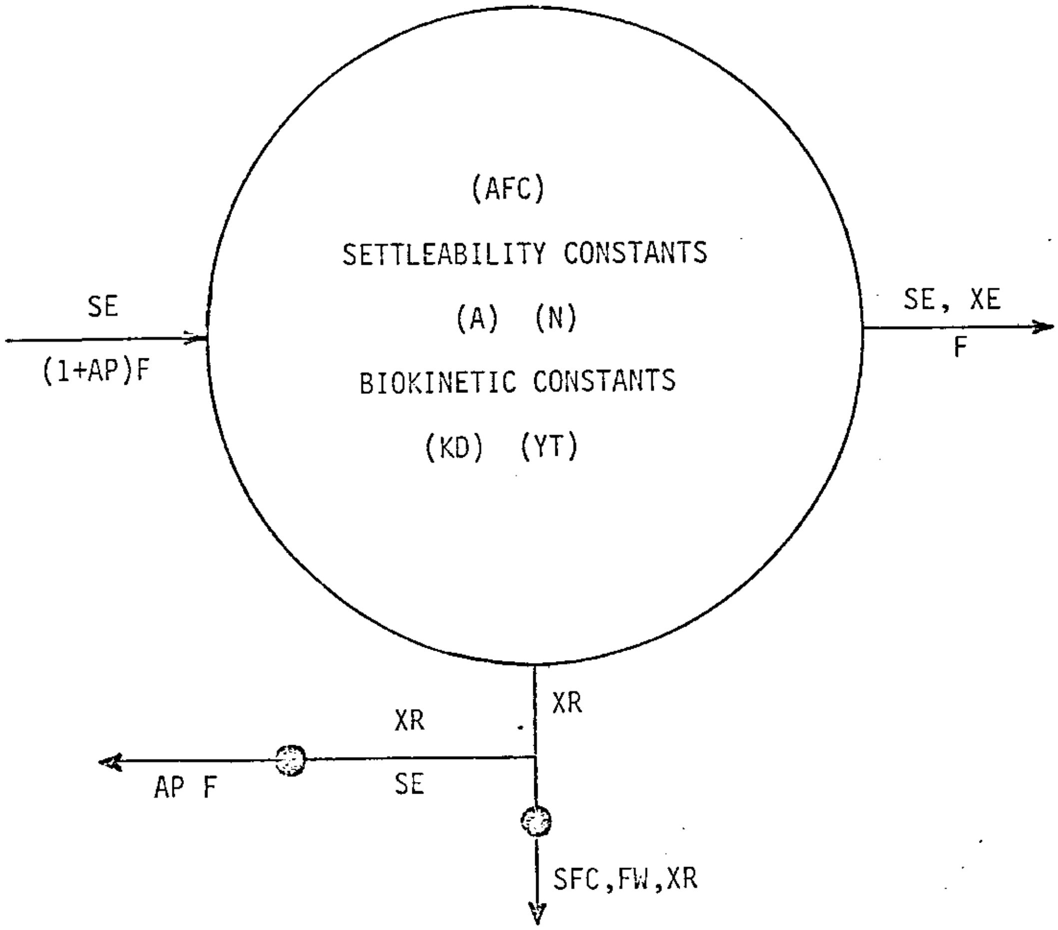
$$XI = X0 - X0\left(0.711 - \frac{474F}{APC}\right)$$

$$SI = S0 + (KI)(XI)$$

$$PS = (F)(X0)8.34\left(0.711 - \frac{474F}{APC}\right)$$

FIGURE 3 UNIT PROCESS MODELS

Final Clarifier Specifications



$$\frac{AP^{n-1}}{(1+AP)^n} = \frac{F(1.0036E-06)^n}{0.01077(AFC)(A)(n-1)\left(\frac{n}{n-1}\right)^n} \quad \text{(solve for AP)}$$

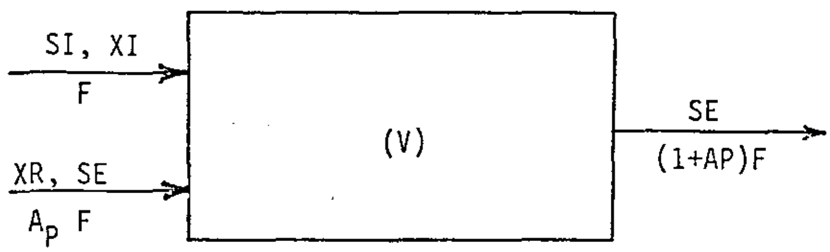
$$XR = \frac{\frac{(KD)(X)(V)}{F} + (1+AP)X + \frac{(YT)(UM)(SI)}{KB + \frac{(F)(SI)}{(X)(V)}}}{AP}$$

$$FW = \frac{(1+AP)(X)(F) - (AP)(F)(XR) - (F)(XE)}{XR-XE}$$

$$SFC = 8.34(XR)(FW)$$

FIGURE 3 (CONT.)

Activated Sludge Specifications



$$X = \frac{8.34F\,\frac{SI}{V}}{\frac{(SI)(UM)}{SI-SE} - KB}$$

FIGURE 3 (CONT.)

sludge models

2. Develop an adaptive design model.

   This stage consists of integrating the aforementioned models into an adaptive design model. This will also require integration of engineering economic analysis to provide a measure of performance of specific adaptive strategies.

The economic analysis will be based upon incremental equivalent uniform annual costs. That is, those costs over and above costs currently being incurred. These may take the form of capital costs for new required construction and additional operation and maintenance cost.

Specifically, chemical additives (chlorine) were considered and included in the extended model. Other additional parameters were also considered.

ECONOMIC MODEL

The economic model utilizes standard engineering economic analysis to derive annual operating and maintenance costs for the system parameters specified in the operational model. Cost equations were formulated and used for this purpose. The cost equations used are presented in Figure 4. A computer program was written and merged with the operational model program to compute system cost.

COMPUTER PROGRAM

This program computes the total annual cost of operation and maintenance of a wastewater treatment plant. The total consists of the following cost components:

1) Operation and maintenance costs,
2) Maintenance labor costs,
3) Operation labor costs,

COST EQUATIONS

CLARIFIERS

OPERATION LABOR

$\$/YR=4.99(A)^{0.577}\ LC$

MAINTENANCE LABOR

$\$/YR=1.936(A)^{0.618}\ LC$

MATERIAL & SUPPLY COSTS

$\$/YR=4.47(A)^{0.758}$

DIFFUSED AIR SYSTEM

OPERATION LABOR

$\$/YR=(27.3)(LC)(CFM)^{0.504}$

MAINTENANCE LABOR

$\$/YR=(9.89)(LC)(CFM)^{0.557}$

ELECTRIC POWER

$\$/YR= HP(24)(.7457)EC(365)$

MECHANICAL AERATION

OPERATION LABOR

$$\$/YR=110.8\left(\frac{V \times 10^{6}}{7480}\right)^{0.518} LC$$

COST EQUATIONS

FIGURE 4

MAINTENANCE LABOR

$$\$/YR = 57.513\left(\frac{V \times 10^6}{7480}\right)^{0.562} LC$$

ELECTRIC POWER

$$\$/YR = (24)(365)(.7457)(HP)(EC)$$

DISSOLVED AIR FLOTATION

TOTAL 0 + M

$$\$/YR = 2.52\left(\frac{0.0024(PS+SFC)}{L0 \times 10^{-6}}\right)^{0.54}$$

LABOR

$$\$/YR = 14.14\left(\frac{0.0024(PS+SFC)}{L0 \times 10^{-6}}\right)^{0.40}$$

POWER

$$\$/YR = 0.0031\left(\frac{0.0024(PS+SFC)}{L0 \times 10^{-6}}\right)^{0.40} EC$$

MATERIAL

$$\$/YR = 855\left(\frac{0.0024(PS+SFS)}{L0 \times 10^{-6}}\right)^{0.12}$$

FIGURE 4 (CONT.)

ANAEROBIC DIGESTER

TOTAL O + M

$$\$/YR=96.6\left(\frac{PS+SFC}{.0019}\right)^{1.3}$$

POWER

$$\$/YR=0.16 \times 10^{-5}(EC)\left(\frac{PS+SFC}{.0019}\right)^{1.3}$$

LABOR

$$\$/YR=57.7\left(\frac{PS+SFC}{.0019}\right)^{.36}$$

MATERIAL

$$\$/YR=33.4\left(\frac{PS+SFC}{.0019}\right)^{.35}$$

SLUDGE DRYING BEDS

TOTAL 0+M

$$\$/YR=1.22\left(\frac{.022\ ED\ (PS+SFC)}{LD \times 10^{-6}}\right)^{0.65}$$

LABOR

$$\$/YR=1.85\left(\frac{.022\ ED\ (PS+SFC)}{LD \times 10^{-6}}\right)^{0.40}$$

FIGURE 4 (CONT.)

MATERIAL

$$\$/YR = 0.37 \times 10^{-3} \left(\frac{.022\ ED\ (PS+SFC)}{LD \times 10^{-6}} \right)^{1.06}$$

PUMPING

OPERATION LABOR

$$\$/YR = (148.39)(LC) \sum_{i=1}^{3} (F_i)^{0.636}$$

MAINTENANCE LABOR

$$\$/YR = (122.45)(LC) \sum_{i=1}^{3} (F_i)^{0.636}$$

ELECTRIC COSTS

$$\$/YR = (0.7454)(24)(365)(62.4)(EC) \sum_{i=1}^{3} (F_i \times H_i)$$

OTHER MATERIAL & SUPPLY

$$\$/YR = (900) \sum_{i=1}^{3} (F_i)^{0.79}$$

FIGURE 4 (CONT.)

4) Electric power costs,

5) Material and Supply costs.

These costs are dependent on some system parameters and output variables. The output variables are again dependent on the system parameters. The program is of the interactive type and the input parameters are entered through the Keyboard of the TRS-80 computer terminal. Within the program there is a provision for computing and comparing the total costs for the mechanical aeration and the diffused aeration. The program is very simple in structure and its flow diagram is shown is Figure 5.

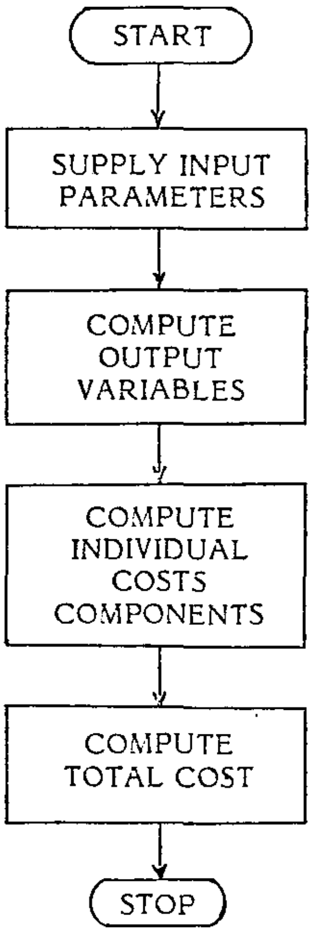
Results

The results of this research generally consist of the operational and economic models, as described earlier, and their representation in the computer program. For each set of system specifications, a total annual operating and maintenance cost can be derived.

Research Benefits

This research has the potential to benefit all local governments which are currently operating wastewater treatment plants. Providing a way in which to evaluate (analytically) annual costs, engineers should be able to reduce that cost by altering system parameters and providing for adaptive design strategies.

This research contributes to the growing field of wastewater treatment cost examination by providing a viable model of current plant operation, including an economic evaluation, with specific add-on treatment schemes.



FLOW DIAGRAM OF THE PROGRAM

FIGURE 5

References

1. Andrews, J.K., "Dynamic Models and Control Strategies for Wastewater Treatment Processes," Water Research, Volume 8, 1976.

2. Kincannon, D.F. and C.P. Koelling, "Cost Minimization of the Wastewater Treatment Process," Paper presented at ORSA/TIMS Joint National Meeting, San Diego, CA, October 27, 1982.

3. Koelling, C. Patrick, "Wastewater Treatment: Design Optimization and Its Implications for Federal and Local Governments," Proceedings, Institute of Industrial Engineers, 1983 Annual Industrial Engineering Conference, May 1983.

4. "Process Control Manual for Aerobic Biological Wastewater Treatment Facilities," EPA-430/9-77-006, March 1977.

5. Smith, D.L. and R.V. Daigh, "Survey of Treatment Plant Design and Operation Deficiencies," Journal Water Pollution Control Federation, Volume 53, August 1981.