"ENERGY EFFICIENT AERATION SYSTEM"

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ABSTRACT

The major energy consumer in an activated sludge plant is the aeration system. The plant capacity is based on projected growth at several years in the future. Waste loads vary significantly on diurnal, weekly and seasonal cycles. To minimize the energy costs the aerators must operate efficiently at loads well below plant capacity. This requires operating flexibility and controllability to respond to the hourly changes in oxygen demand.

This paper shows how recent technology can be applied to reducing the energy usage for the aeration system. An economic justification demonstrates the savings available for 1, 5 and 10 MGD plants. Since more than 60% of a waste treatment plant operating budget is labor and energy, the microprocessor aeration control system can have a great impact because it addresses both. For example, the payback on initial investment is 3½ years for a 1 MGD plant. Larger plants have an even more favorable rate of return. The control system can be readily retrofitted to existing plants.

Proven technologies are combined to produce an efficient aeration system for a wide demand range. The first element is a liquid sensitive impeller capable of high transfer efficiencies over a wide range of power. The second element is a reliable, durable dissolved oxygen probe. This probe has been proven suitable for sustained maintenance free operation in waste. The final element is the microprocessor based controller to match aerator power to the waste load as indicated by the oxygen probe.

INTRODUCTION

A recent report for the Environmental Protection Agency (1) indicates that fully 50% of the municipal secondary treatment plants are not meeting effluent standards. The report continues that 80-90% of these plants are adequately designed. It is probably reasonable to conclude that many plants are also 'over treating' waste. That is producing an effluent exceeding environmental needs at high energy costs. A well run plant meets effluent quality standards with the minimum energy expenditure.

The cost of energy and labor each account for approximately 32% of a typical plant budget (2). These expenditures are substantial by any means of comparison. During the life of a plant the cumulative operating costs will exceed the initial capital investment (3). Therefore, effective design includes serious consideration of operating costs. Achieving the goals of meeting effluent standards, saving energy and reducing operating costs demands innovative solutions.

The single greatest energy consumer in a secondary waste treatment plant is the aeration system. For a 5 MGD plant the aerators consume 64% of the total purchased energy (4). Plants are designed based on a peak load projected for some time in the future. Therefore it is loaded to a fraction of the design capacity for most of the plants useful life. A typical curve of loading versus plant operating life is shown in Figure 1.

For the plant to operate with minimum energy consumption the aerators must be efficient at low waste loads with the operating flexibility to respond to continual changes. When the plant is commissioned waste demand varies from 10-30% of the design capacity. Hence, without system controllability 70-90% of the aerator energy would be expended unnecessarily. The aerator which has a large turndown capacity is shown in Figure 2.

There is a direct relationship between waste load and aerator power. The waste load is the product of the plant influent strength and volumetric flow. Strength is defined as the biochemical oxygen demand (BOD). Reduction of the waste requires oxygen be transferred to the mixed liquor. For a specific basin (mixed liquor) condition, the amount of oxygen is directly proportional to the waste load. By maintaining a constant dissolved oxygen level, the rate of oxygen transfer must follow the demand of the waste load. Assuming constant aerator efficiency, oxygen transfer is directly proportional to aerator power. Therefore, the diurnal variation in waste load (5, 6) results in the power demand variation shown in Figure 3.

Previous attempts at automated aeration control have been hampered by unreliable dissolved oxygen sensors. Many plants designed for automated operation are in fact controlled manually because of the poor reliability and high maintenance requirements of existing probes. A new probe, Figure 4, has been developed which overcomes the limitations of the Clark probe while retaining its desirable features. This probe has been field tested and proven reliable for long periods in industrial and municipal wastes. It is highly resistant to the effects of membrane fouling because of the unique, patented operation.

The final element of the aeration system is the microprocessor controller, Figure 5. Given high quality dissolved oxygen levels, the microprocessor matches aerator power to waste load. The specific control algorithm will depend on the plant features.

In the succeeding sections the operating cost, energy savings and technical details of a microprocessor controlled aeration system will be presented. The first section will deal with the economics justification. The cumulative cost of energy plus the capital investment is compared for several design options. The technical details of the aerator, dissolved oxygen probe, and controller follow.

ECONOMIC JUSTIFICATION

Three different plant sizes are evaluated; 1 MGD, 5 MGD and 10 MGD. Table I gives the significant features of the aeration design for the three. The first two are in the size range where poor operating effectiveness is well documented (1). The last shows the dramatic cost savings available as the size increases.

The layout of each plant includes two basins. The hydraulic layout and controls permit the operator to operate only a single basin. Based on the typical loading assumed in Figure 1, only half of the aeration capacity is required during the first three years. For each size, four aerator design options are considered. These options and the incremental capital costs are listed in Table II. The plant is operated manually for the first two options and automated aerator control are used for the other options.

The ten year savings in 'operating costs' and energy are presented in Table III. The basis of comparison is design option 1. The 'operating costs' include energy (5 ¢/KW-HR) plus the incremental costs for purchasing and installing the energy saving system. The impact of the control system on plant staffing is not included nor is inflation.

As one would expect, the 1 MGD plant has the least favorable financial justification. This is because hardware costs are not proportional to plants size, Table II. The controller, a significant part of the total cost, is practically identical for all three plant sizes. Nevertheless, the smallest plant still achieves a five year payback. During the ten year period the automated plant (option 3 and 4) costs $36,000-$43,000 less to operate. This is without the benefit of operator labor savings. Assuming that automated control saved four hours of operator time per week, an added savings of $3,000 per year would be realized. Factored into the financial analysis the payback would be reduced to three and one-half years. This would also bring the ten year savings up to the range of $66,000-$73,000. Therefore, the automated aerator control system is cost effective even for plants smaller than 1 MGD.

Automated control for the 5 MGD plant has a two year payback, while the 10 MGD plant pays for itself in one and one-half years. During the ten year life, over a one quarter of a million dollars reduction in operating costs is achieved for the 5 MGD plant. For the 10 MGD plant this figure exceeds $600,000. The savings in electrical power alone justify the investment. The labor saving benefits are not necessary to establish the merit of microprocessor controls. The impact on operator labor could significantly increase the savings of operating costs for the automated aeration system.

Automated control of the aeration system saves 50% on power. A major part of this energy saving is the ability to respond to the continual changes in waste load. The energy savings has a much broader significance than just the reduced operating expenses. As long as the

United States is an importer of energy resources, any reduced usage improves our trade balance. In the long term, energy is a nonrenewable resource, which is too valuable to use inefficiently.

AERATOR

The surface aerator, Figure 2, is an intermediate speed radial flow device. It pumps the mixed liquor up at the center and throws an umbrella of water radially outward parallel to the liquid surface. Oxygen transfer to the liquid occurs at the impeller, during its air-borne flight, and upon splashing back into the basin. The oxygen en-riched fluid is pumped to the remote regions of the basin and then returns to the aerator for another cycle. The aerator has two key features for this application:

1. High transfer efficiency.
2. Wide range of operation (power).

The greater the operating range of the aerator the more efficiently the plant can operate. The aerator in this paper can operate with an 8:1 turndown. Power can be varied either by changing the aerator speed, the liquid level, or a combination of both.

The variation in STE due to speed control is shown in Figure 6. (STE is the clean water standard oxygen rate per shaft power.) The aerator STE is nearly independent of rotating speed. Three common ways to vary speed are:

1. Motor speed controller.
2. Reducer change gears.
3. Two speed motor (1800/1200).

Speed controllers are quite expensive. In the near future (7) we can expect these prices to be reduced by a factor of 15-20. That price reduction would make motor speed controllers preferable. At todays costs, change gears and two speed motors are far more cost effective. The squares plotted on Figure 6 show incremental power levels available by using the reducer change gear feature and an 1800 RPM motor. The gear change requires two to four hours and is only done to accommodate long term trends. The arrows show speeds available with these same gear ratios using the low speed, 1200 RPM, of a two speed motor. Over the entire operating speed range efficiencies vary from 1.8-2.2 Kg/KW-HR. These aerators therefore fall into the group of highest efficiency units presently available.

A second method to control aerator power is by adjustment of the liquid level. The principal advantage of this approach is infinitely variable power draw between the minimum and maximum submergences. Figure 7 shows the impact of liquid level on power at three different aerator speeds. These speeds are available with standard change gears. Transfer efficiencies for this mode of operation as shown in Figure 8 are also quite high.

The aerator cannot operate at power levels less than 12% of design. Both mass transfer and basin circulation drop quite rapidly. This observation is substantiated by the corresponding rapid decrease in transfer efficiency. Operation above this 12% point provides both mass transfer and sufficient mixing to disperse the oxygen enriched fluid throughout the basin. However, the aerator must also supply adequate mixing for suspending the biomass. At lower power levels the bottom scouring velocity is reduced. At the lowest operating power the velocity must be high enough to prevent solids from settling and becoming anaerobic. Operation at power levels between 12-25% will therefore depend on the solids settling characteristics.

PROBE

Existing probes have proven unreliable for monitoring basin D. O. to achieve automated control of aerators. The standard Clark probe, Figure 9, consumes oxygen at the cathode. Because of this consumption, oxygen must continually diffuse through the membrane. The membrane must not foul, and the liquid film adjacent to the membrane must be continually replenished. If fouling or film stagnation occurs, Figure 10, the rate of oxygen diffusion to the cathode is interrupted. This results in an erroneously low reading of dissolved oxygen. The fouling characteristics and stirring dependence of conventional electrochemical dissolved oxygen monitors has necessitated frequent maintenance plus cumbersome and expensive designs.

A new oxygen sensor overcomes the limitations of the traditional approach while maintaining all of its advantages. This patented (8) probe is unique both in configuration, Figure 11, and operation. The new probe consumes oxygen at a multiplicity of cathodes, similar to the Clark probe. But differs by simultaneously generating oxygen at a multiplicity of annodes. Since oxygen is generated and consumed within the probe an equilibrium oxygen level exists between the electrolyte, membrane and the sample.

Several advantages result from this development:

1. Nearly independent of fouling.
2. Thick membrane for rugged construction.
3. No oxidation of the electrode.
4. No depletion of the electrolyte.
5. Does not require stirring action.

These factors are discussed at length in reference (8).

A number of trials have been conducted during the development phase of this program. The results of one recent industrial effluent trial are presented in Figure 12. This test was selected because of the wide excursions of D. O.. The test started by monitoring and calibrating, as necessary, during the first week. After this period the probe was left submerged in the process water, monitoring continually. Daily readings were compared to a frequently calibrated portable unit (referee) which was briefly placed in the waste liquor close to the test probe. The Leeds & Northrup probe was not cleaned, calibrated, removed from the process, or otherwise altered during the test.

The plotted data covers a 50 day period. Both the referee and the new probe have an uncertainty of 0.2 mg/l. On fifteen occasions the difference between the probe and the referee was greater than 0.4 mg/l. On five occasions the difference exceeded 1.0 mg/l. The test included a wide range of ambient temperature and precipitation conditions during the February thru March period. Combining the variable weather factors with the wide excursions in basin conditions, the results demonstrate that this is a reliable and accurate probe. Field data from other tests show better agreement because of the more favorable conditions.

CONTROLLER

The microcomputer-based aeration controller accepts inputs from 1-5 dissolved oxygen monitors. Output signals control either a motorized positioner for level control or a group of two speed aerators to achieve a controlled level of dissolved oxygen. The goal is to vary aerator power to maintain the dissolved oxygen level as the waste load varies.

The controller (Figure 13) provides three sequential functions: weighted averaging, control and output. The first function involves combining the several dissolved oxygen inputs through some mathematical or logical algorithm to achieve a single value which is representative of the degree of aeration in the process. A probable algorithm would be one like that shown below:

$$O_{AVE} = K_1O_1 + K_2O_2 + K_3O_3 + K_4O_4 + K_5O_5$$

Where: O_{AVE} is the computed value representative of the process.

O_n are the various dissolved oxygen inputs measured at various positions in the process.

K_n are various weighting factors.

The second function involves comparing the average value (O_{AVE}) with the desired value known as the set point (S.P.) and computing an output signal which will manipulate the process in such a way as to keep O_{AVE} equal to S.P.. The algorithm used provides for proportional plus integral gain (reset in repeats/min.) adjustable so that the controller can be tuned to the specific process.

The third block converts the control to a form which is capable of driving the particular final control element which will be used. In this case, two variations are shown: one for positioning control and the second to sequence a group of up to eight two speed motors. The controller can be set up to provide either output.

The motor positioning logic compares the position of the motor as measured by a slidewire feedback signal with that of the control signal, U. It then drives the motor in one direction or the other until the motor position corresponds to the control signal U.

The sequential control output provides for switching motors from low speed to high speed as a function of the control variable U, Figure 5. In addition to providing motor sequencing as shown in the diagram, the logic has the capability of preventing excessive motor cycling by either introducing a dead zone between the value of U, at which the motor goes to high and value at which it goes to low, or a minimum time during which the motor must stay in either the high or low speed mode before switching to the other mode.

CONCLUSIONS

Other papers (6) have addressed the subject of aerator control to optimize plant efficiency. Typical cost justifications have been based on long term benefits. The results presented in this paper demonstrate a payback time of one and one-half to five years depending on the plant size. The larger the plant (10 MGD) the quicker the payback.

The cost analysis did not include the labor savings associated with automated control. A rough estimate of the cost of labor for the 1 MGD plant, reduced the payback from five to three and one-half years.

Over a ten year period the aeration system energy consumption can be cut in half.

The system is suitable for retrofitting to existing plants. Key elements; the aerator, probes and controller can be installed with minimum interruption to an existing plant.

The aerator used in this system has been proven to have high efficiencies over a wide range of input power.

The oxygen probe is a new patented device with documented field experience. The probe is suitable for long term operation in waste providing the D. O. signal for a microprocessor controller.

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1 MGD	-	2-25 HP Aerators 2 Basins 35' x 35' x 12' SWD
5 MGD	-	4-60 HP Aerators 2 Basins 50' x 100' x 15' SWD
10 MGD	-	8-60 HP Aerators 2 Basins 100' x 100' x 15' SWD

TABLE I

AERATION DESIGN FOR

THREE MUNICIPAL PLANTS

1. No Aerator Power Control -

One basin operation first three years.

Each basin operated at full power.

2. Manual Power Control -

Probes monitor basin D. O. level. Power based on peak loads (manual wier/or reducer gear change).

Time between power adjustments, 6 months$^+$

1 MGD	5 MGD	10 MGD
$10,750	$19,000	$34,000

3. Controller and Probes -

Diurnal changes per two-speed motor.

Reducer change gears for long term growth.

1 MGD	5 MGD	10 MGD
$26,500	$42,900	$70,700

4. Controller and Probes -

Diurnal changes per liquid level control. A reducer gear change once during plant life.

1 MGD	5 MGD	10 MGD
$30,000	$51,000	$85,000

TABLE II

DESIGN OPTION DEFINITION

INCREMENTAL CAPITAL COSTS

PLANT AND BASE POWER	OPERATING COST AND POWER SAVINGS		
	#2	#3	#4
1 MGD	$11,400	$36,400	$43,400
2.72(10^6 KW-HR)	0.4(10^6 KW-HR)	1.22(10^6 KW-HR)	1.38(10^6 KW-HR)
5 MGD	$117,000	$276,000	$300,000
13.3(10^6 KW-HR)	2.76(10^6 KW-HR)	6.42(10^6 KW-HR)	7.06(10^6 KW-HR)
10 MGD	$280,000	$593,000	$622,000
26.6(10^6 KW-HR)	6.3(10^6 KW-HR)	13.4(10^6 KW-HR)	14.1(10^6 KW-HR)

TABLE III

TEN YEAR OPERATING COSTS AND POWER SAVING

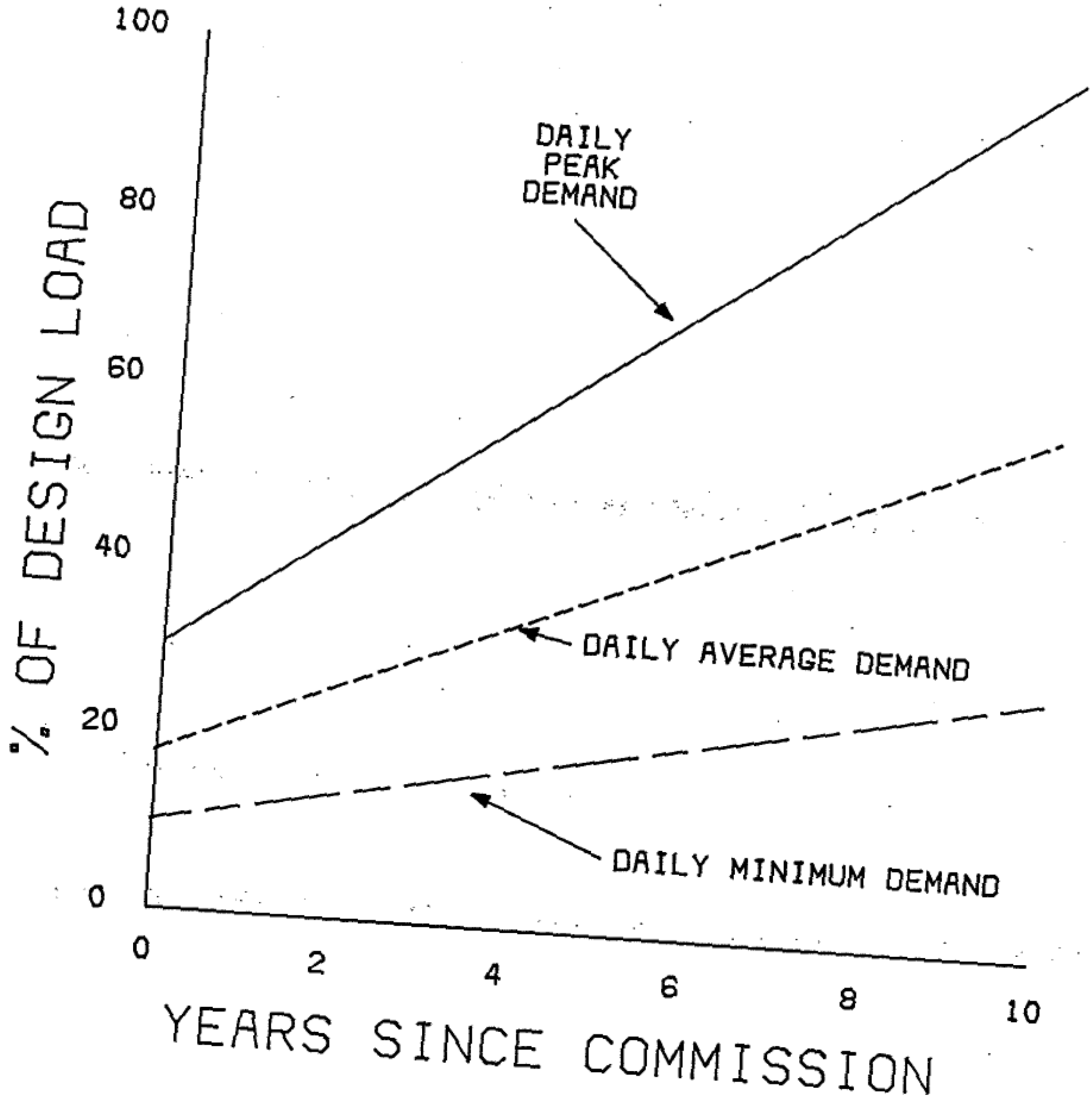

FIGURE 1
PLANT OPERATING CONDITIONS

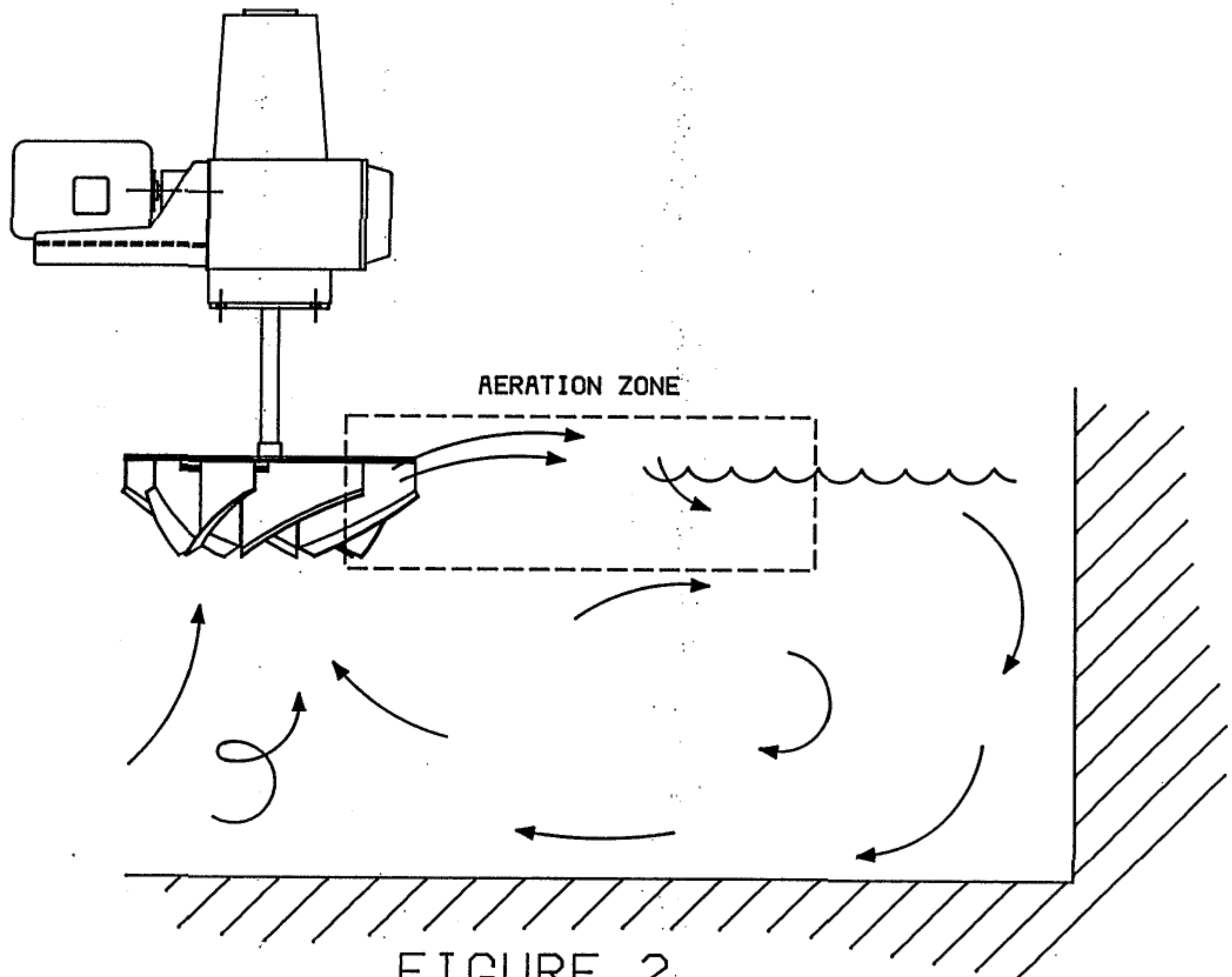

FIGURE 2

RADIAL FLOW SURFACE AERATOR

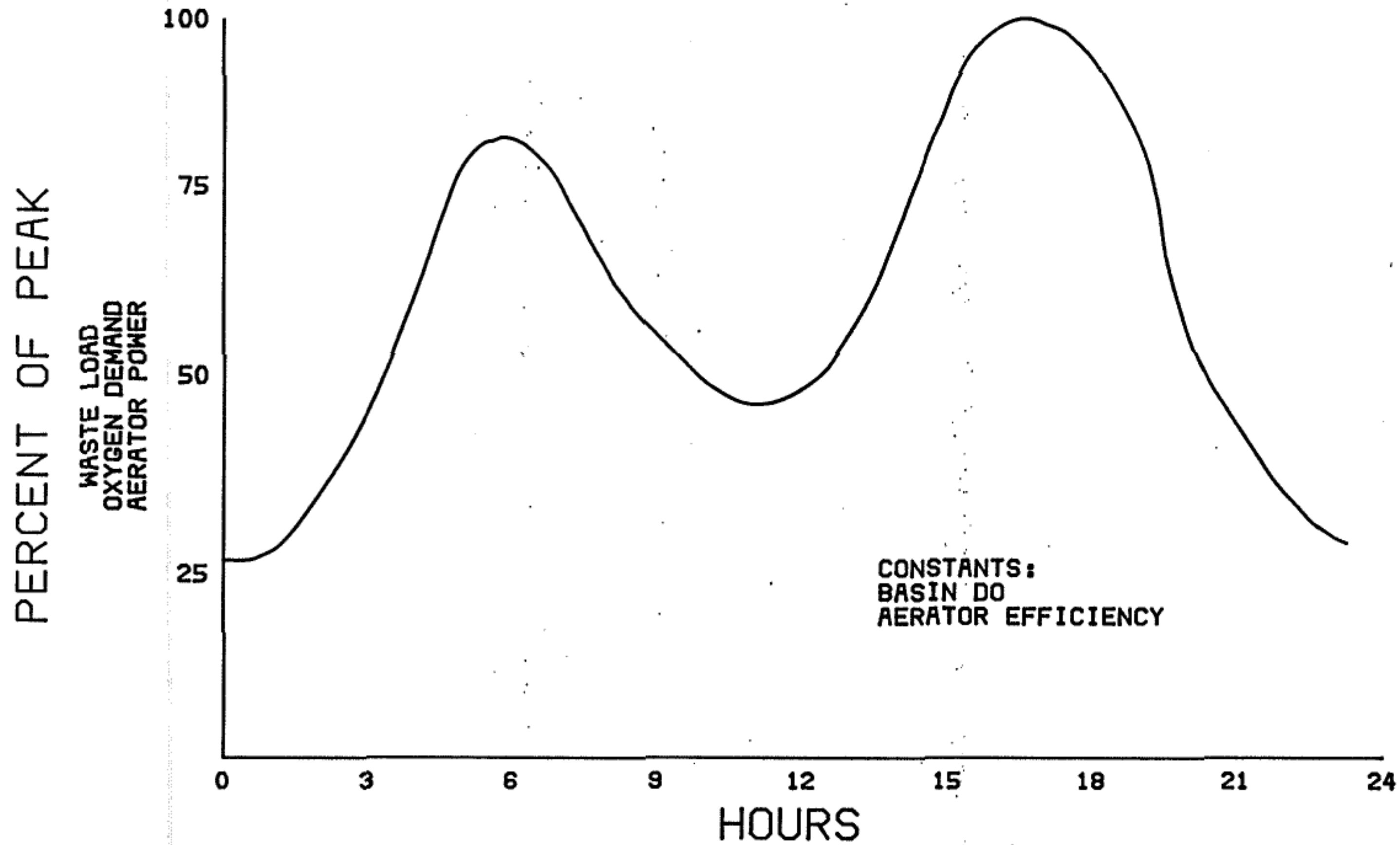

FIGURE 3

DIURNAL VARIATION
OF
AERATION PROCESS

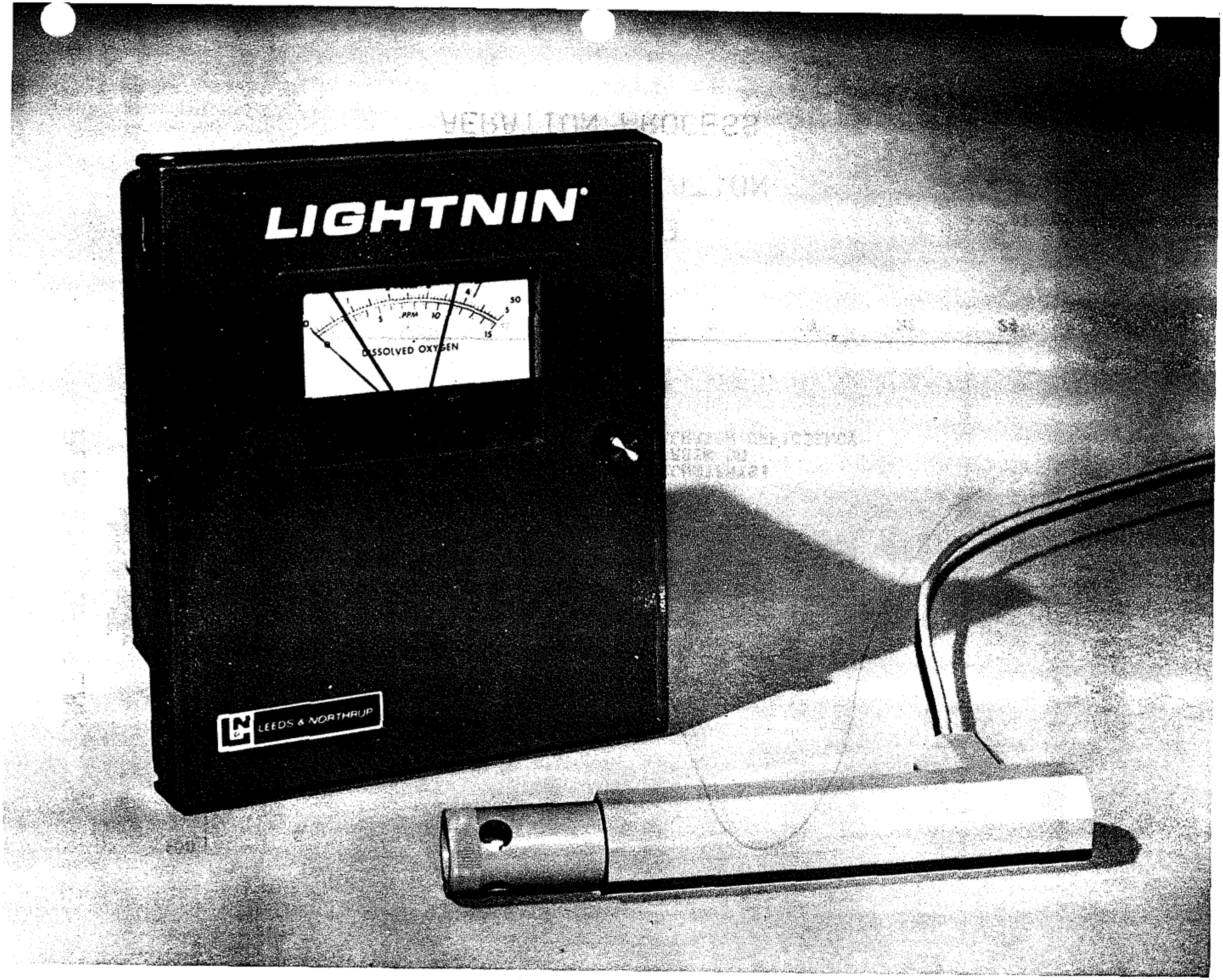

FIGURE 4

LEEDS & NORTHRUP PROBE AND MONITOR

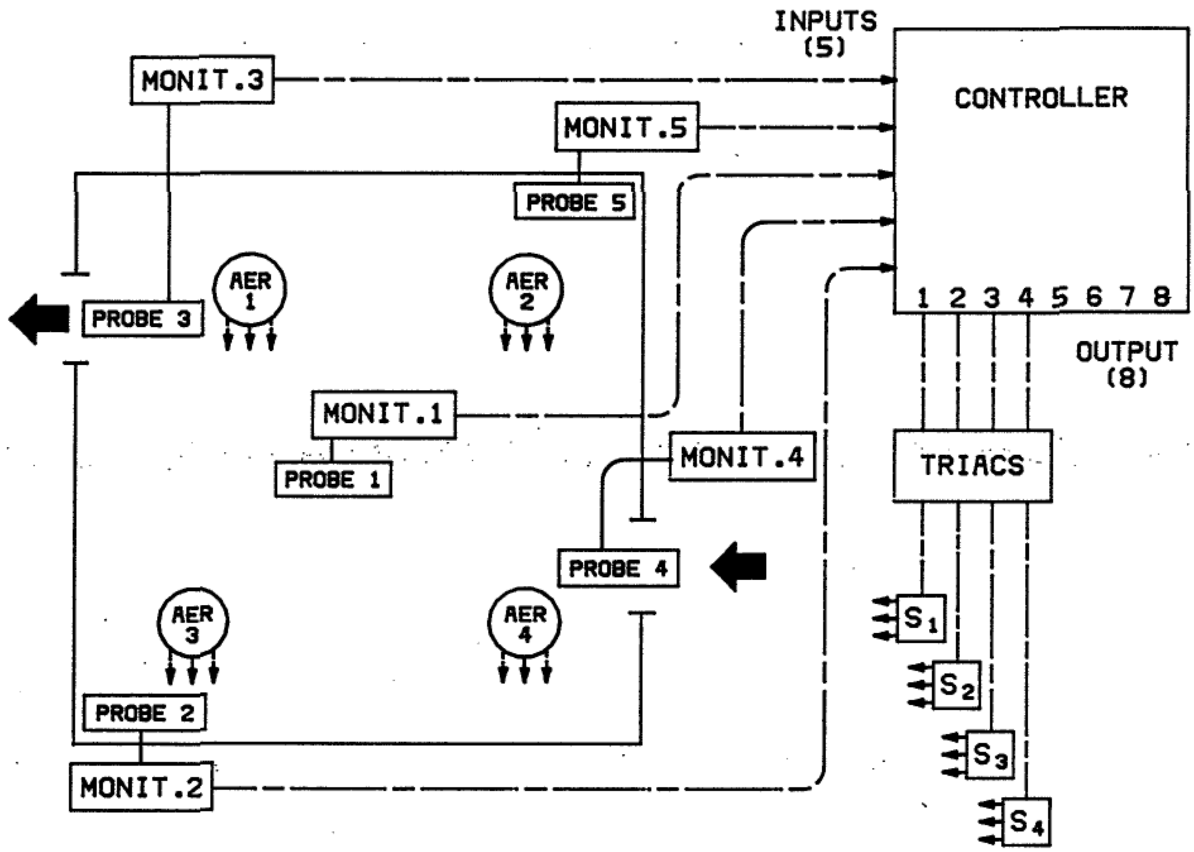

FIGURE 5

LIGHTNIN AERATION SYSTEM

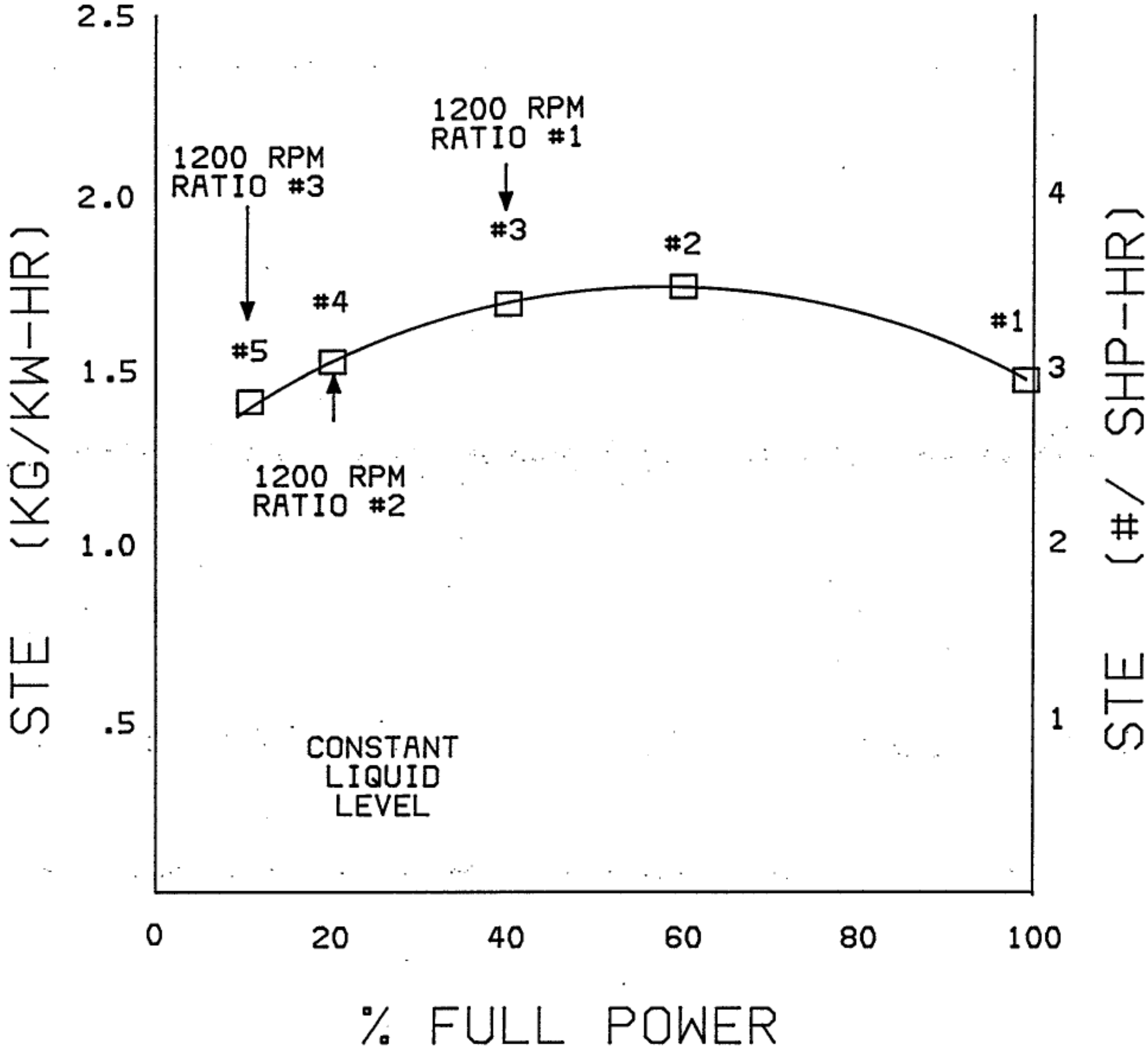

FIGURE 6

EFFECT OF SPEED CHANGE ON AERATOR EFFICIENCY

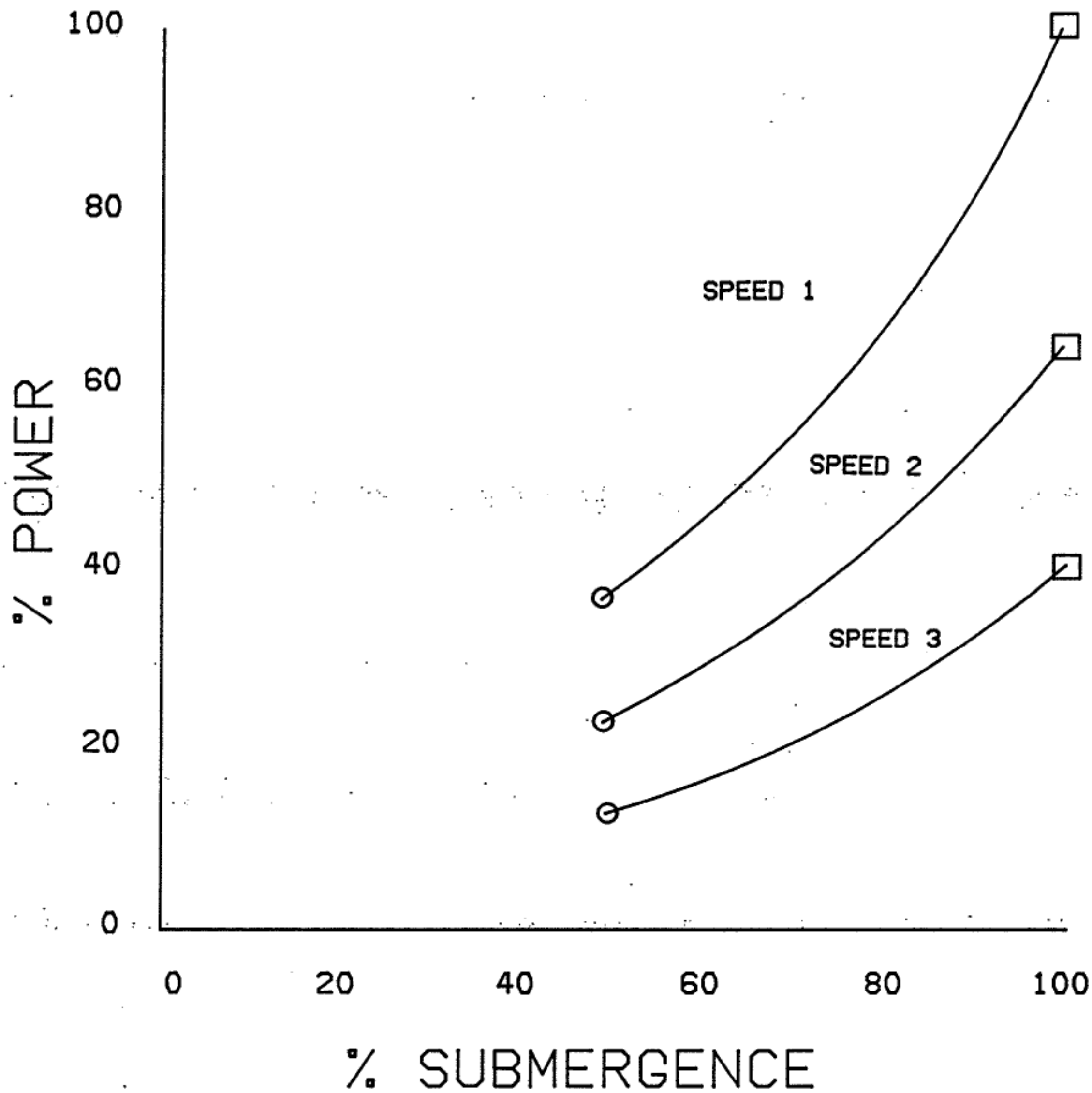

FIGURE 7

EFFECT OF IMPELLER SUBMERGENCE ON AERATOR POWER

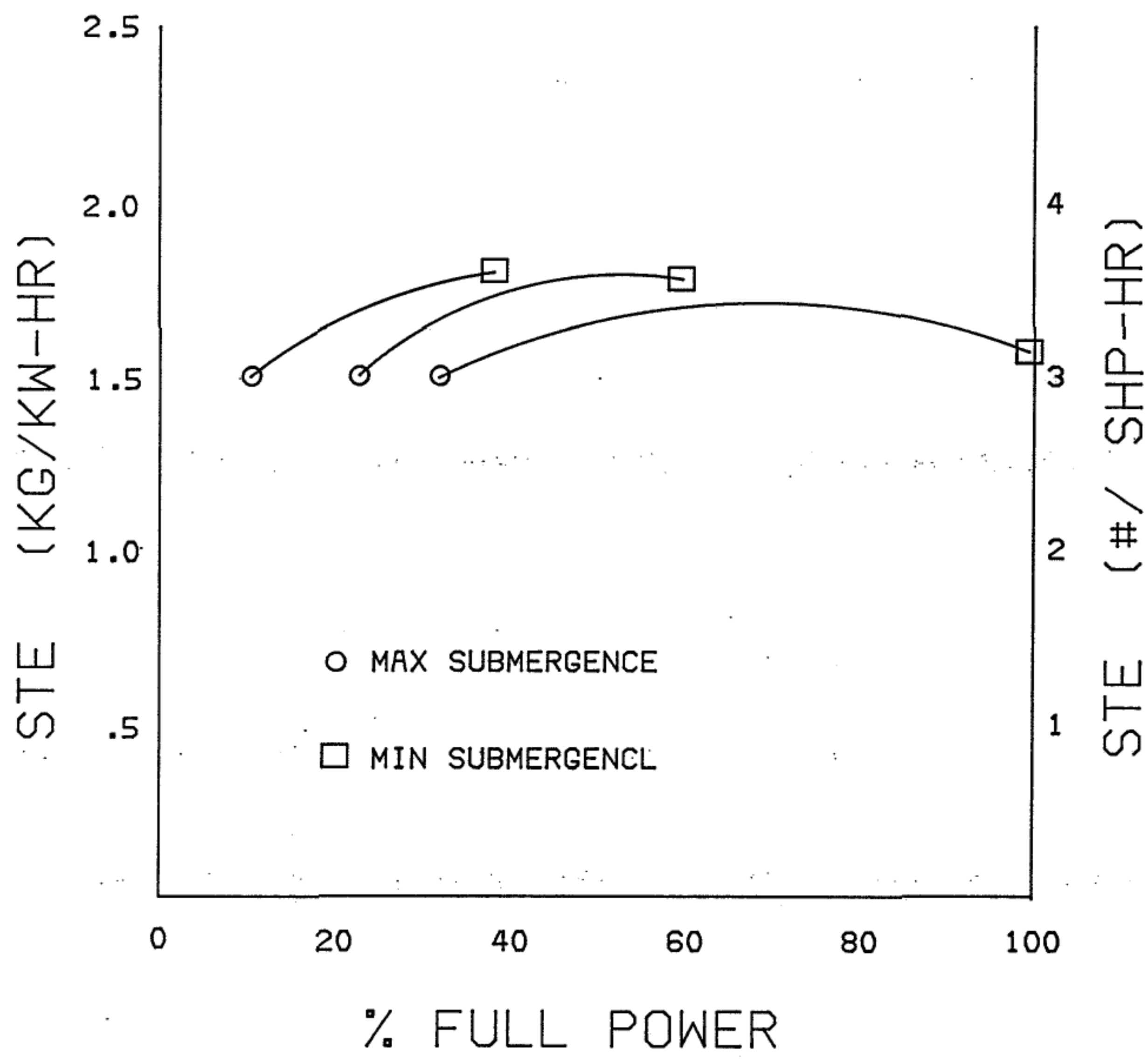

FIGURE 8

EFFECT OF IMPELLER
SUBMERGENCE ON
AERATOR EFFICIENCY

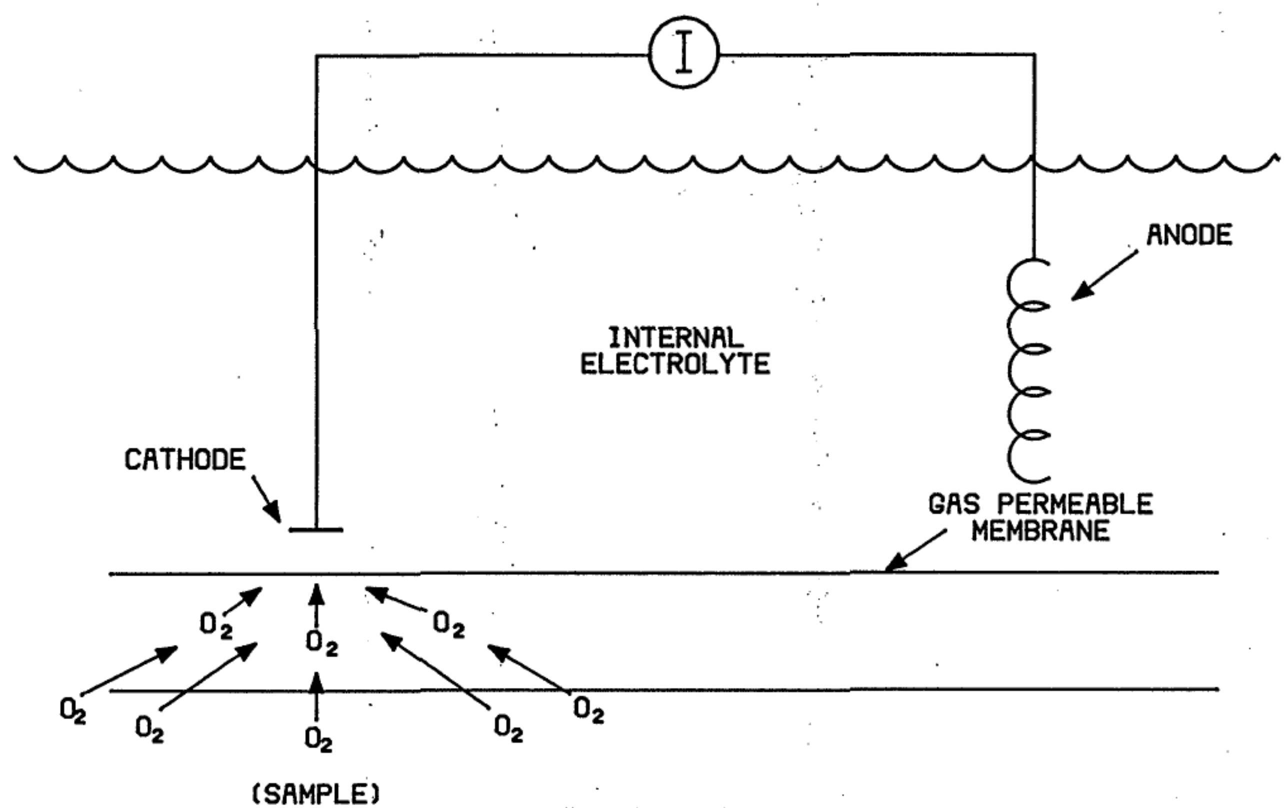

FIGURE 9

SCHEMATIC OF A CLARK OXYGEN SENSOR

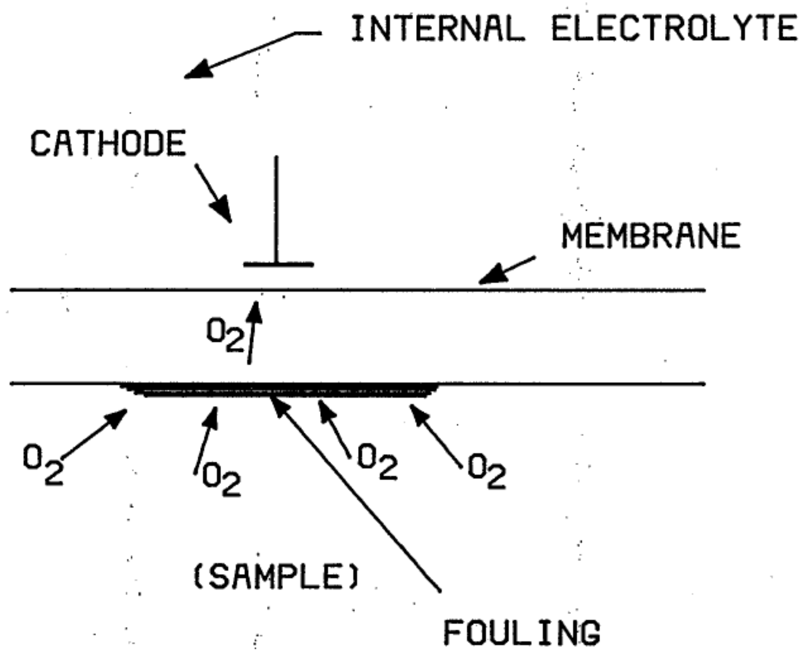

FIGURE 10
SCHEMATIC OF SENSOR WITH FOULED MEMBRANE

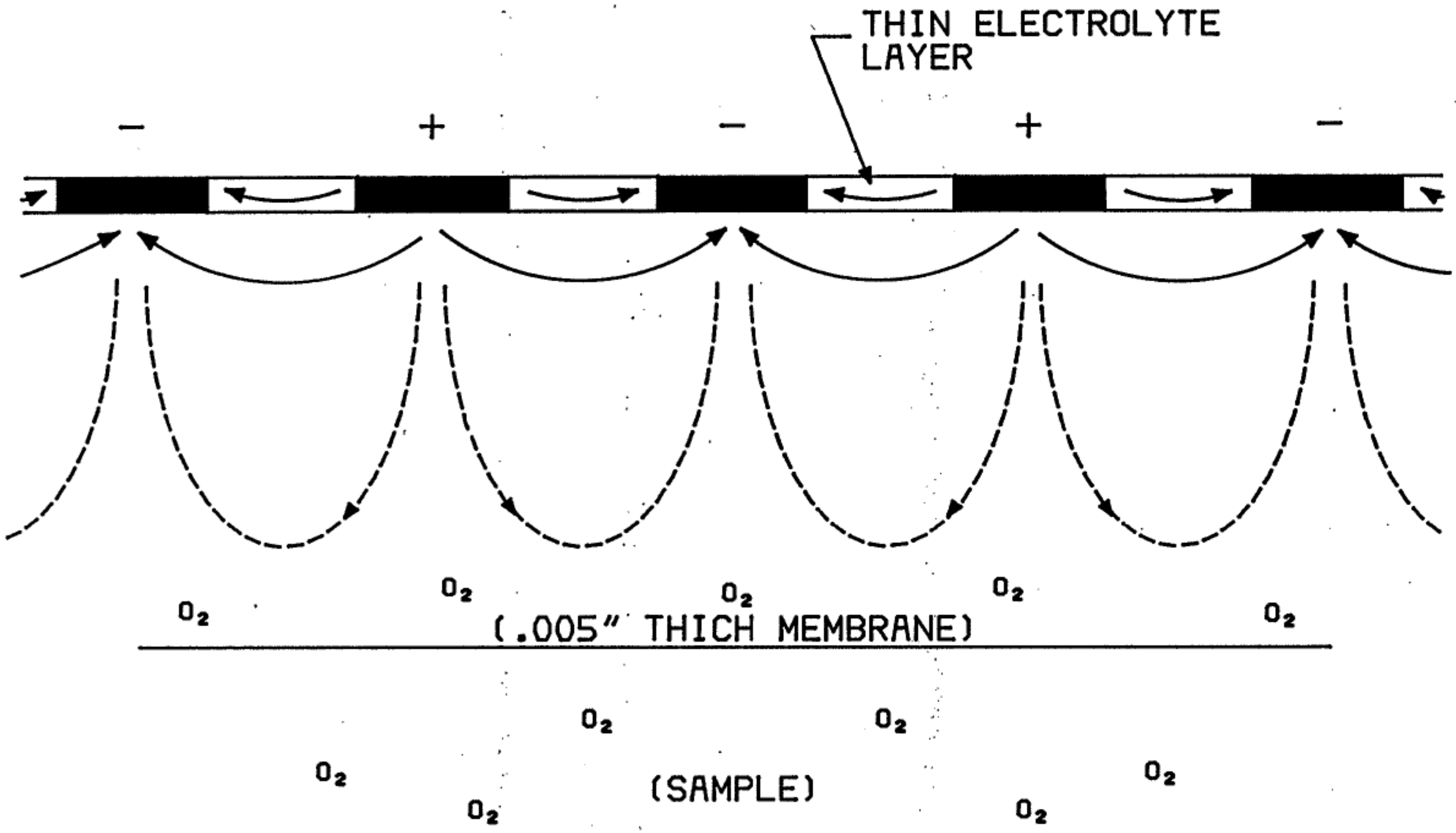

FIGURE 11
SCHEMATIC OF
THE LEEDS & NORTHRUP OXYGEN SENSOR

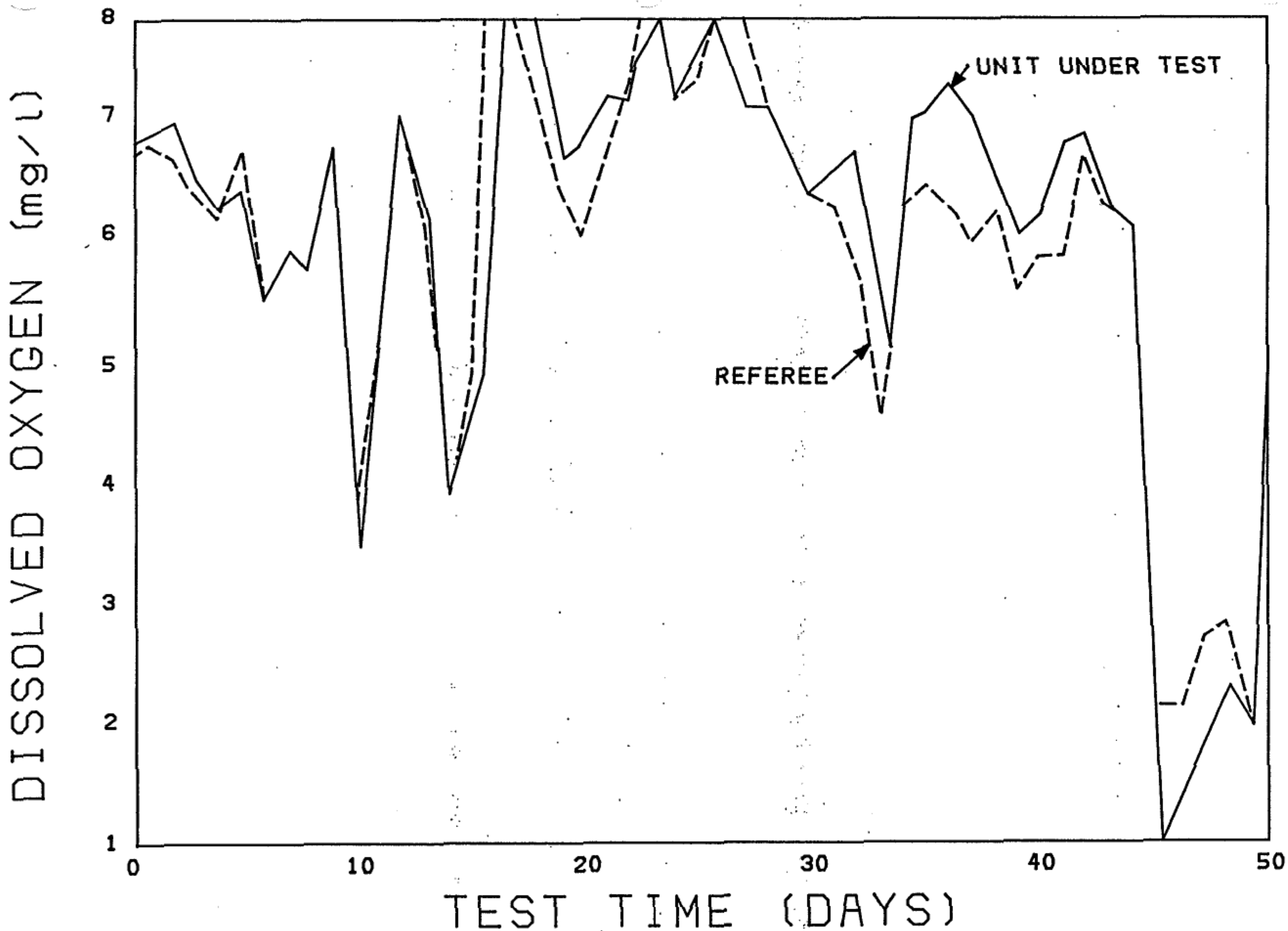

FIGURE 12
FIELD TEST DATA

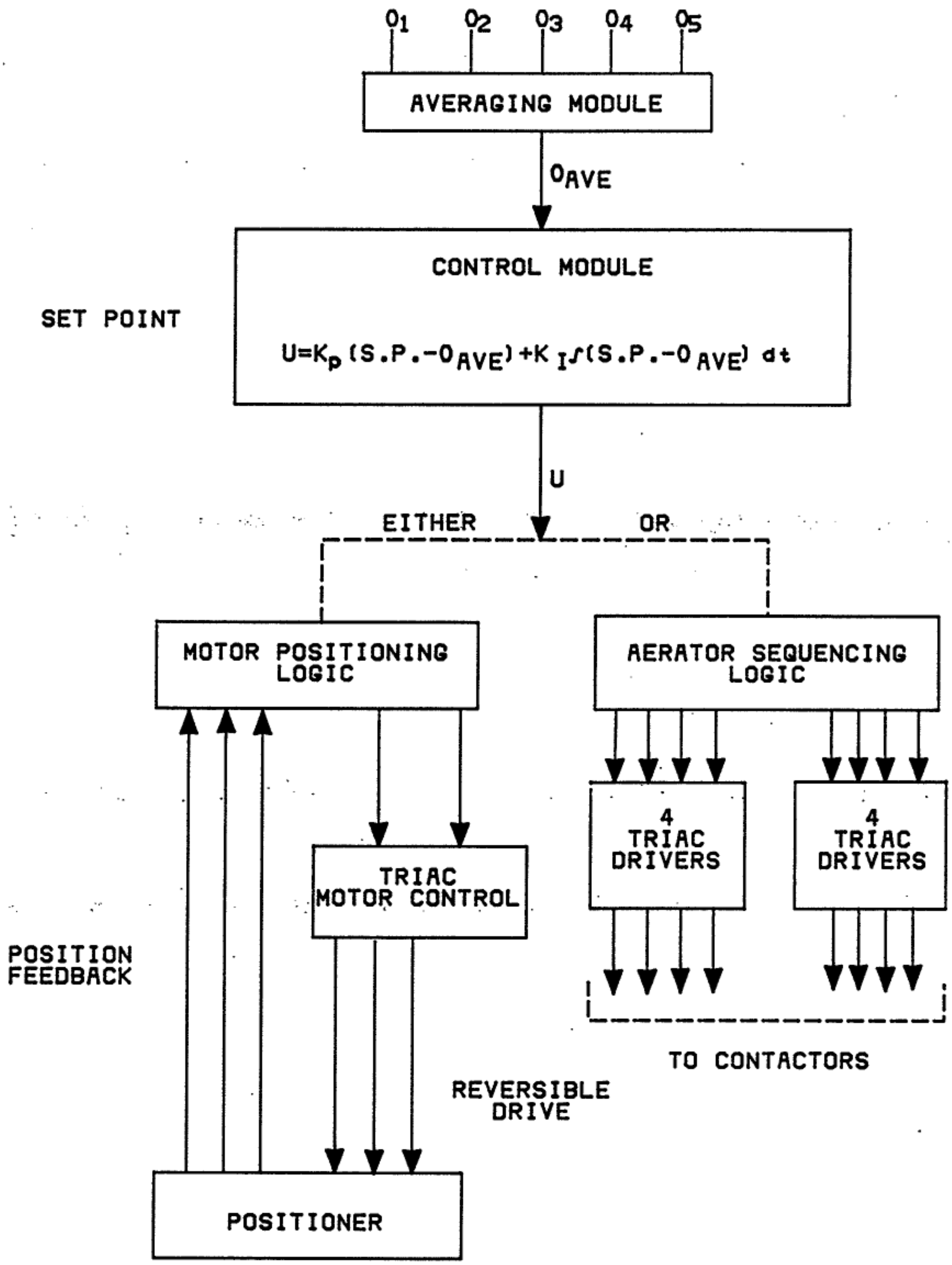

FIGURE 13
CONTROLLER SCHEMATIC