A Simple Scheme for Controlling Dissolved Oxygen and Measuring Oxygen Utilization Rate in Lab-Scale Activated Sludge Units

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Abstract

The concentration of dissolved oxygen in laboratory experiments involving biological growth in a completely-mixed aerator may be controlled by the use of a simple electronic circuit in conjunction with a standard dissolved oxygen (DO) meter. The system is easily incorporated into an existing experimental set-up; it operates by shutting off the air supply when DO rises above an upper set value and re-admitting air when DO falls below a lower set point. By additionally recording the resultant DO signal and measuring the rate of decrease during periods when the air supply is off, the rate of oxygen utilization in the aerator may be determined.

Introduction

When aerobic biological growth systems such as the activated sludge process are studied in the laboratory, it is frequently desirable to control the concentration of dissolved oxygen (DO) in the growth medium. In many cases, however, air is simply supplied to the reaction vessel continuously, with no attempt at DO control, because a suitable control system is not available.

This paper describes a simple electronic controller which has been successfully employed in conjunction with a standard DO meter to regulate DO concentration in a completely-mixed aeration vessel. By adding a chart recorder the system will furthermore permit the determination of the oxygen utilization rate (OUR) in the aerator on a regular basis.

DO Control

The controller, details of which are discussed in a subsequent section, acts upon the output signal from a DO meter having a probe inserted into the aerobic reaction vessel. It operates on the principle of switching off the source of air supply when DO concentrations rises above an (adjustable) upper set point, and switching air on again once DO drops below a lower set point. On-off operation of the air supply is typically accomplished by actuating a small air pump, or a solenoid valve on a compressed air supply line. In experimental systems which rely on the air supply to provide mixing in the process, a subsidiary means of mixing must be arranged. Adequate agitation will be essential for satisfactory operation of the DO probe.

As a result of the control action, DO concentration in the aerator will oscillate between the upper and lower set points. By choosing these values close together, effectively constant DO may be achieved. In general, however, variations over a slightly wider range (typically 1 to 3 mg/ℓ for activated sludge), will be quite acceptable, and in this case it becomes feasible to determine the oxygen utilization rate. The OUR is directly related to the rate of decrease of the DO concentration during periods when the air supply is off.

Oxygen Utilization Rate

Unless the biological growth rate in the aerobic system is changing rapidly, the DO concentration in the growth medium may be expected to drop off at an essentially constant rate during the "air off" period, as oxygen is consumed by the biological reaction. By registering the DO signal on a chart recorder it should therefore be possible to calculate the OUR from the slope of the recorded signal, as oxygen consumed in mg/ℓ of reactor volume per unit time. There are, however, two possible sources of error which should be examined. These are the dynamic response of the DO probe, and the rate at which oxygen will diffuse into the system through the exposed surface.

A DO probe will not respond instantaneously to changes in the system DO concentration, but will exhibit a certain amount of dynamic lag. Assuming, however, that the probe dynamics may be approximated as a first-order system, it is easily shown by ordinary methods of process dynamics (Ceaglske, 1956) that, for an input variable which changes at a constant rate with time, i.e.,

$$\triangle DO = Kt, \qquad (1)$$

the output signal will have the following special characteristics: the recorded output will lag behind the input, but will assume the same slope as the input, after initial transients have died away. The rate of oxygen utilization, K, may therefore be confidently determined by measuring the slope of the recorded DO trace, ignoring only the initial transient period (where this is noticeable). Of course, it must be recognised that the system may not give accurate results when the oxygen utilization rate is unusually high and the switching period correspondingly short. The minimum acceptable switching period will be about ten times the probe time constant. For practical purposes, the time constant for a particular probe is readily estimated experimentally as the time taken for the output to reach 63% of the final reading following a step change in input.

The second factor to be considered is the amount of oxy-

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gen diffusing into the system through the free surface. The rate of mass transfer may be represented by the standard driving force — resistance concept, viz.,

$$\text{Rate of transfer} = (DO^* - DO)/R, \qquad (2)$$

where DO* is the maximum achievable (equilibrium) concentration of DO in the liquid (for the air/water system this is approximately 9 mg/ℓ), and R is the resistance to mass transfer through the surface. This rate should be added to that obtained by monitoring the drop in DO concentration of the liquid, to obtain the true biological OUR. Since the rate of transfer depends on the changing DO concentration (eq. 2), the rate will not be constant with time, and will theoretically cause the DO-time curve to deviate from the straight line of eq. (1). In most cases encountered in practice, however, the rate of transfer will be small relative to the biological OUR and its effect will be negligible.

In general it would be advisable to minimize the amount of oxygen entering through the free surface by avoiding excessively vigorous agitation. The amount of oxygen transfer may be evaluated in a blank run under identical mixing and mean DO conditions, and added to all oxygen utilization rates determined from the decay of the DO concentration. If curvature of the DO trace is observed at very low total utilization rates, this may be minimized by operating over a narrower DO range.

The Electronic Controller

The circuit diagram for the DO controller is given in Fig. 1. The signal from the DO meter is amplified and then fed to two comparators, one for each of the upper and lower set points.

The resistors R_1 and R_2 as shown will provide a gain of (or, 1 + 100/1,8), to give a recorder output signal of approximately 0,7 V per DO unit, using an input signal from a YSI D meter. Different gain values may be employed, provided the comparator reference resistors R_3 and R_4 are changed accordingly.

The two comparators are designed to switch from the full negative to full positive power rail voltage when the input signal increases above the individual set points. A special feature of the design is the 1MΩ positive feedback resistor which will marginally increase the input to the comparator as soon as the output switches "on", and will thus provide a locking-in facility to prevent chattering. When the input signal exceeds the set point of the upper comparator, the relay is actuated, thereby removing power from the air compressor or solenoid circuit by opening a set of relay contacts. A second set of contacts holds the relay in the active position until DO drops below the lower set point. At this stage the relay is deactivated, and air is switched on, until DO again rises to the upper set point.

Operation of the System

A typical application of the control system is illustrated in Fig. 2, which shows the recorded trace of DO concentration obtained in a laboratory activated sludge process fed on glucose and nutrients.

Upper and lower control points were set at 4 and 1 ppm respectively. In the case considered here, the feed and recycle to

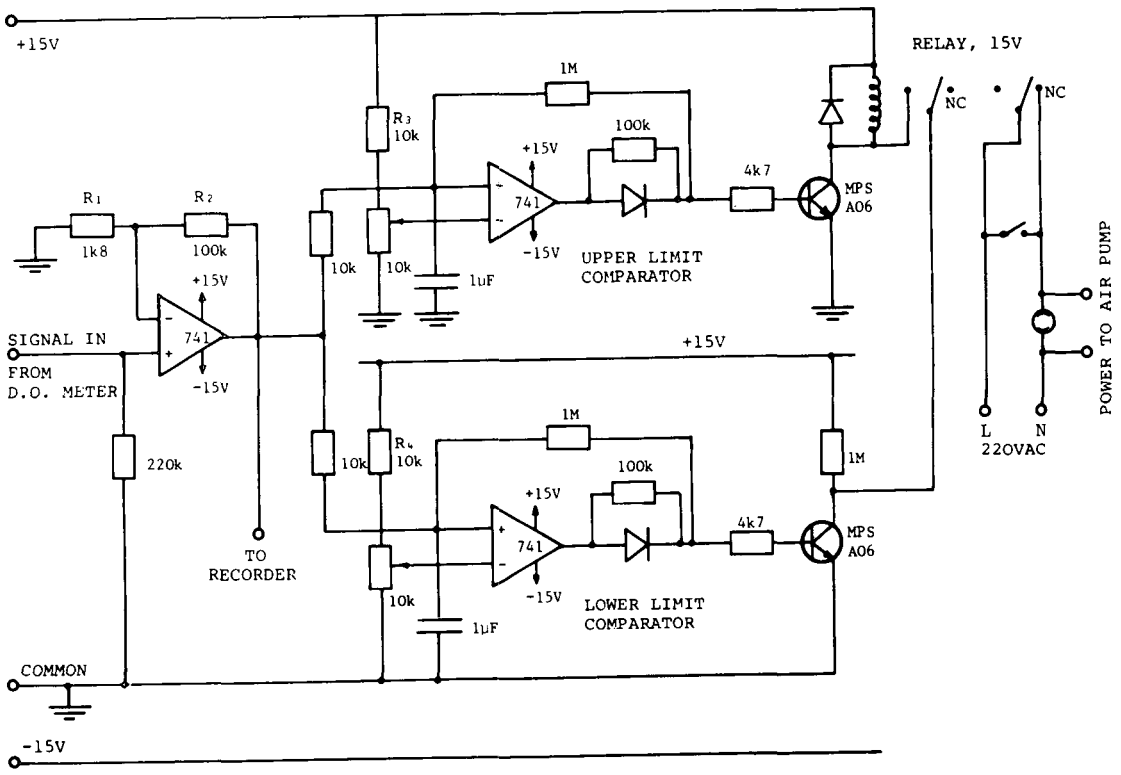

Figure 1
Circuit diagram for DO controller

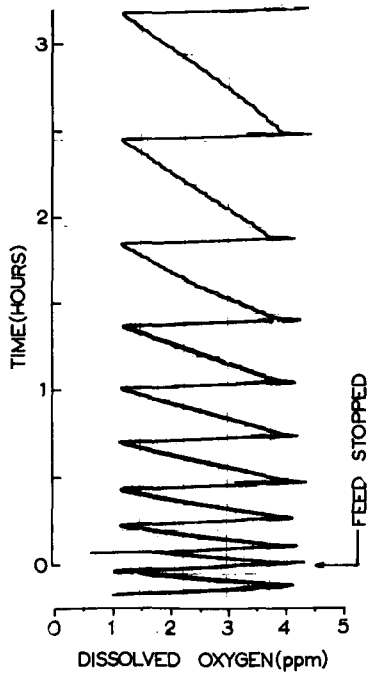

Figure 2
Typical recorder trace obtained in DO control of activated sludge

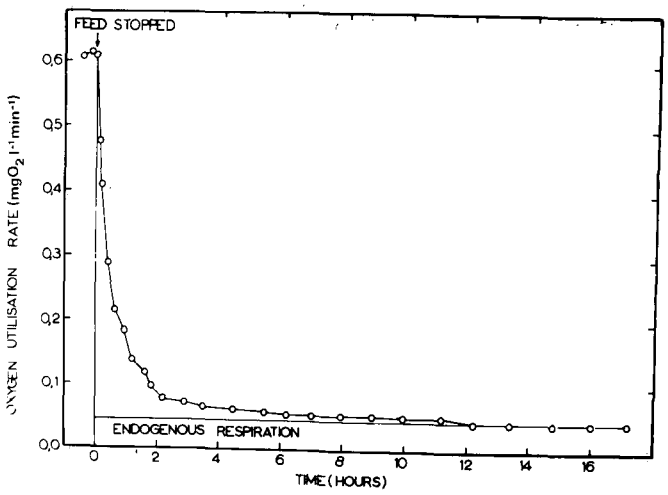

Figure 3
Results obtained from OUR determination, showing variation in OUR in an activated sludge process fed on glucose, after stopping feed at time = 0

the aerator was stopped at time zero, following a period of steady operation. Air was supplied by a small aquarium-type air pump and mixing was provided by a laboratory stirrer. The recorded trace shows the rapid increase in DO from 1 ppm as air is admitted, and the slower decay from 4 ppm as air is switched off and DO is consumed by the biological process. A gradual reduction in oxygen utilization rate, following the feed cut-off, is well illustrated by the lengthening of the periods between successive activations of the air supply system. DO decay curves are generally fairly straight and the slope is easily determined to yield the oxygen utilization rate.

The utility of this method of measuring OUR is illustrated in Fig. 3. Here the change in OUR with time is plotted for the activated sludge process mentioned above, where feed and recycle were stopped at time zero. A sharp drop in OUR, and hence in biomass growth rate, is observed as soon as the feed is removed. This rapid reduction in growth rates is attributed by Dold, Ekama and Marais (1980) to the sudden loss of easily degradable substrate, which is normally metabolized at a high rate. This is followed by a period of slower decay in OUR, where it may be speculated that material stored and entrapped in the sludge floc is being consumed. Finally, OUR settles to an essentially constant value, which should represent endogenous decay of the sludge.

Details of operating conditions relating to Fig. 3 are not given here, since the Figure is only intended to illustrate the application of OUR determinations, and a long-term steady state was not established. It may be mentioned, however, that the rate of oxygen transfer through the surface, which was determined in a blank run and should be added to the OUR values in Fig. 3, amounted to only 0,010 mg $\ell^{-1}min^{-1}$

Conclusions

The control scheme presented provides a simple and convenient method of DO control and OUR determination for experimental completely-mixed activated sludge or other aerobic biological growth processes. The system may be easily added to an existing laboratory set-up, and involves the use of a DO meter, the electronic controller of Fig. 1, and a means of interrupting the air supply. It is also necessary to provide mechanical mixing during periods when air is switched off. In larger systems it is usually inconvenient to shut off the air supply completely, and the method described is therefore most suitable for small-scale systems.

Acknowledgement

The assistance of Mr. E.W. Randall in the design of the electronic control circuit is gratefully acknowledged.

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