# A RESPIROMETRIC VERIFICATION OF THE KINETIC SELECTION THEORY FOR THE CONTROL OF FILAMENTOUS BULKING IN ACTIVATED SLUDGE PROCESS

**Kamal T. Ewida**
Department of Engineering Physics and Mathematics, Faculty of Engineering,
Zagazig University, Zagazig, EGYPT.

ABSTRACT

A simple respirometric approach has been used for the determination of the maximum substrate removal rates, $r_{x,m}$,and half velocity coefficients, $K_s$ of excess biomass to control bulking in conventional activated sludge systems. Feeds of multicomponent substrate were cultivated and continuously fed to a laboratory, completely mixed (filamentous) activated sludge unit. The results verified the kinetic selection theory experimentally, and demonstrated the low values of $r_{x,m}$ and $K_s$ in mixed cultures, cultivated in completely mixed reactors.

## INTRODUCTION

Bulked sludge is one that has poor settling conditions and poor compactability.One of the principal causes of sludge bulking is the growth of filamentous organisms, growing under adverse conditions of respiration in a multicomponent substrate. The theory presented by Chudoba et al (1), developed a selection approach to mixed cultures which is based on Monod equation (2), and presumed several growth constants $k_s$, and $u_m$, for different organisms. This has consequently suggested different relationships between the specific growth rate and substrate concentration.

For a batch culture the rate of organisms growth is described by the following equation

$$\frac{dx}{dt} = \mu x \qquad (1)$$

The Monod equation for the substrate limited growth is in the form.

$$\mu = \mu_m \frac{S}{K_s+S} \qquad (2)$$

From equations(1) and (2) we can deduce that

$$\frac{dx}{dt}\frac{1}{x} = \mu_m \frac{S}{K_s+S} \qquad (2)$$

Where x is the concentration of biomass, mass/Unit volume, S is the concentration of growth limiting substrate mass/unit volume, $\mu$ and $\mu_m$ are actual and maximum biomass growth rates. respectively 1/time, and $K_s$ is the saturation or half velocity constant, mass/unit volume.

In equations (2) and (3) the overall growth constants $u_m$ and $K_s$ for mixed cultures are usually represented by mean values of the growth constants of individual organisms and their frequencies in the culture. Therefore variations in culture population are always reflected on the overall growth constants changes as described by Peil and Gaudy (3) and Ghosh and Pohland (4).

Accordingly microorganisms with low values of $K_s$ and $u_m$ should prevail in aeration systems with low values of S and vice versa. Hence in mixed cultures cultivated in completely-mixed activated sludge systems with high purification efficiencies, that is with very low values of, S, in effluent, one supposed to have overall growth constants lower than those cultivated in systems with high values in the inlet part such as plug flow systems.

Verification of the above theoretical conclusions through experimental means of measuring the biomass growth is quite difficult because all methods known for the determination of $K_s$ and $\mu_m$ are not sensitive enough especially for low values of $K_s$ (below 20 mg/L) as prescribed by Williamson and Mccarty (5). However, since biomass growth is always associated with substrate removal according to the equation

$$\frac{dx}{dt} = -Y_{obs}\frac{ds}{dt} \qquad (4)$$

Where $Y_{obs}$ is the observed biomass yield coefficient. Equations (3) and (4) were combined to give

$$-\frac{ds}{dt}\frac{1}{x} = \frac{\mu_m}{Y_{obs}}\frac{S}{K_s+S} \quad (5)$$

substituting $r_x$ for -(ds/dt)/X,and $r_{x,m}$ for $u_m/ Y_{obs}$, we get

$$r_x = r_{x,m}\frac{S}{K_s+S} \quad (6)$$

where $r_x$ and $r_{x,m}$ are the actual and maximum substrate removal rates 1/time.Hence the biomass growth rate equation (4), has been transferred to a substrate removal one.

A rapid method for the determination of $K_s$ and $r_{x,m}$ has been developed by Williamson and Mccarty (5). However the disadvantage of their method is the need of a simple, sufficiently specific and accurate analytical methods for the determination of the tested substrate.

The objective of this work is to determine the values of $K_s$ and $r_{x,m}$ for the substrate of a completely mixed activated sludge, using the respirometric technique developed by Cech et al(6)

## MATERIALS AND METHOD

A laboratory activated sludge used for respirometric measurements was cultivated in an 8 liters completely mixed reactor which was continuously fed, while the temperature was maintained at 25 °C. The technological parameters of the activated sludge unit are shown at Table (1).

**Table 1.** Technological Parameters of Activated Sludge Unit.

| Parameter and Characteristic | Value |
|---|---|
| Aeration Volume (L) | 8 |
| Volume of Settlers(L) | 2 |
| Retention Time (h) | 24 |
| Sludge age(day) | 2 |
| Recirculation Ratio | 1 |
| MLSS ($gL^{-1}$) | 2.24 |
| SVI ($mLg^{-1}$) | 120__ 1000 |
| Volumetric loading ($Kgm^{-3}$ $day^{-1}$) | |
| BOD basis | 1.2 |
| COD basis | 1.8 |
| Sludge loading ($KgKg^{-1}$ $day^{-1}$) | |
| BOD basis | 0.94 |
| COD basis | 1.4 |

A multi component substrate solution was dosed to the reactor by means of a peristaltic pump. Its composition was frequently changed during the course of experiment as shown in Table (2). All componenents were dissolved in distilled water and balanced with nutrients.

### *Respirometric Measurements*

The respirometer adapted and used for measurements is the one developed by Lambetal (8), and Vernimmen et al.(9), and shown at Figure (1).

For the respirometric measurement, unwashed biomass was used and diluted with effluents when necessary.Initial concentrations of biomass varied from 0.20 to 2.2 g/L. A dose of 1.2 mg/L of allylthiourea was used for the total suppression of nitrification. The suspension of biomass was aerated prior to measuring for about 1.5 h, without the exogeneous substrate.

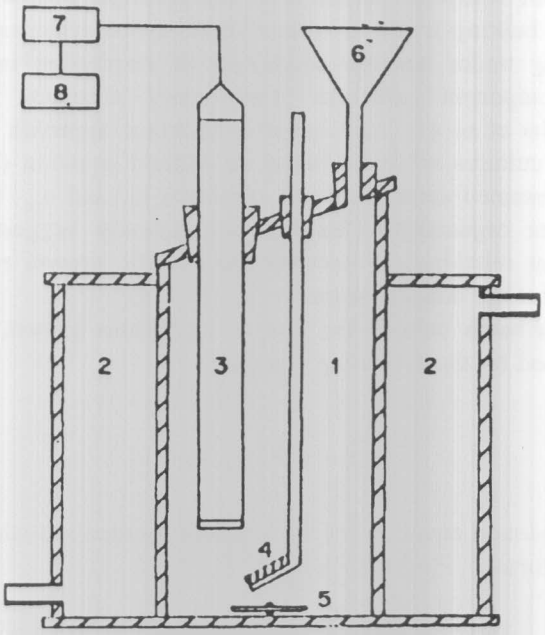


**Figure 1.** Scheme of the respirometer used.
1- Respirometric cell, 2- Water Jacket,
3- Oxygen electrode, 4- Aeration frit,
5- Magnetic mixing bar, 6- Expansion funnel,
7- Oxymeter, 8- Recorder.

The suspension of activated sludge microorganisms was latter transferred into the respirometer and aerated to increase the dissolved oxygen to 6-8 mg/L. After reaching that concentration aeration was stopped. A respirogram was then plotted as shown in Figure (2). The

respirogram shows in all cases a slow decrease in oxygen concentration, which was due to heterotrophic endegenous respiration.

While in the endegenous phase of respiration, heterotrophic microorganisms utilize oxygen at a constant rate,over a relatively long period of time as demonstrated by line A-B-C.

**Table 2**. Composition of the multi-component substrate used for feeding the activated sludge unit.

| Fixed components | Variable components | Period during 1991day/month | Concentration mgL $^{-1}$ |
|---|---|---|---|
| Glutamic acid | | 15/3 - 25/10 | 500 ** |
| Tyrosine | | 15/3 - 25/10 | 500 ** |
| Valeric acid | | 15/3 - 25/10 | 500 ** |
| Methyl alchol | | 15/3 - 25/10 | 500 ** |
| | Glucose | 10/5 - 5/7 | 500 ** |
| | Citric acid | 5/7 - 30/9 | 500 ** |
| | Phenol | 30/9 - 25/10 | 500 ** |
| $NaHCO_3$ | | | 65.8 |
| $KH_2PO_4$ | | | 46.5 |
| $CaCl_2$ | | | 31.6 |
| $Fecl_3 . H_2O$ | | | 0.38 |
| Trace elements * | | | 0.002 |

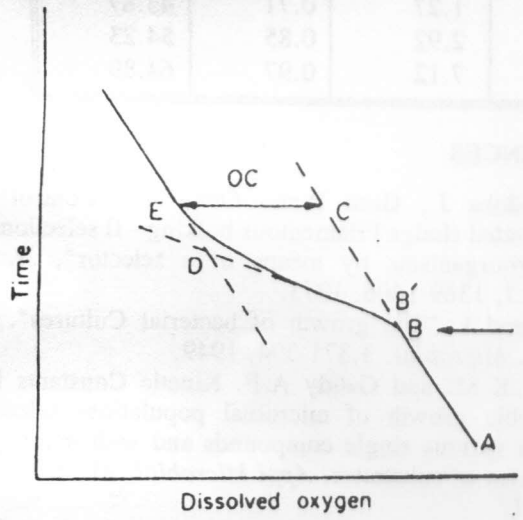


**Figure 2**. Recorder chart of a typical respirogram.

At time B,a calculated, small volume of concentrated substrate solution was injected to the respirating sludge by means of hypodermic syringe.The concentration of this substrate is obviously representing the initial substrate concentration S.

This addition of a limited amount of substrate into the suspension of activated sludge causes a temporary change in the respiration rate. as shown by the B-E curve of the respirogram. The maximum value tangent to this curve line (B-D) represents constant total respiration rate at the substrate concentration S. As the substrate concentration decreases with time, the respiration rate also decreases, being at low concentrations, substrate dependent. The substrate was then removed at point E. This removal caused the respiration rate to return to point D.

When the measurement with one concentration is finished, a new dose of substrate is injected to the respiratometer and a new respirogram is recorded. New rearation must take place when the dissolved oxygen drops below 2 mg/L.

Having been able to construct a respirogram for the substrate of concentration S, the specific rate of substrate removal $r_x$, was determined.

Determination of $r_x$ from the respirogram involves, calculating (i) endogenous respiration rate,$r_{xe}$, (ii) the total $r_{xt}$, respiration rate and (iii) measurement of the net oxygen consumption, OC.

The following rates and coefficients were then computed:

(a) Specific rate of substrate oxidation at concentration S:

$$r_{x,ox} = r_{x,t} - r_{x,e} \tag{7}$$

(b) Specific rate of substrate removal at concentration S:

$$r_x = \frac{r_{x0x}}{OC/S} \tag{8}$$

(c) Coefficient of substrate oxidation:

$$1 - Y = \frac{OC}{S}$$

(d) Coefficient of biomass yield:

$$Y = 1 - \frac{OC}{S} \tag{9}$$

A numerical differentiation computer program has been used for calculating $r_{x,e}$, and $r_{x,t}$ directly from the respirograms data output. A computer program was also developed so as to calculate the $K_s$ and $\mu_m$ coefficients for any substrate of concentration S and the kinetic constants were incorporated in a linearized equation of the form.

$$r_x = r_{x,m} - K_s \frac{r_x}{S} \tag{10}$$

**Table 3.** Summery of the obtained results.

| Sludge Type | S(as COD) (mg/L) | $r_x$ $h^{-1}$ x $10^3$ | $r_{x,m}$ $h^{-1}$ x $10^3$ | $K_s$ mg/L | Y | u $h^{-1}$ x$10^3$ |
|---|---|---|---|---|---|---|
| Glucose | 0.8 | 30.2 | 45.3 | 0.4 | 0.12 | 5.40 |
| | 2.1 | 39.8 | 68.1 | 1.4 | 0.18 | 12.25 |
| | 3.6 | 50.7 | 78.7 | 1.9 | 0.23 | 18.10 |
| | 5.5 | 61.7 | 92.4 | 2.7 | 0.26 | 24.00 |
| | 8.2 | 64.9 | 96.2 | 3.9 | 0.34 | 32.70 |
| | 10.7 | 65.7 | 99.1 | 5.4 | 0.41 | 40.60 |
| Citric-acid | | | | | | |
| | 0.6 | 10.4 | 31.7 | 1.2 | 0.60 | 19.02 |
| | 2.6 | 18.2 | 40.6 | 3.2 | 0.68 | 27.60 |
| | 3.9 | 22.6 | 54.4 | 6.1 | 0.73 | 39.70 |
| | 5.7 | 30.4 | 58.7 | 4.5 | 0.81 | 47.5 |
| | 9.4 | 32.6 | 60.3 | 7.9 | 0.88 | 53.00 |
| Phenol | 11.6 | 36.1 | 66.7 | 9.8 | 0.94 | 60.70 |
| | 0.9 | 25.8 | 27.3 | 0.05 | 0.55 | 15.00 |
| | 1.6 | 41.1 | 46.5 | 0.21 | 0.56 | 23.00 |
| | 2.4 | 46.9 | 57.6 | 0.54 | 0.59 | 27.67 |
| | 4.0 | 58.8 | 68.3 | 0.64 | 0.63 | 37.04 |
| | 5.5 | 61.8 | 67.1 | 1.27 | 0.71 | 43.87 |
| | 7.9 | 63.8 | 87.4 | 2.92 | 0.85 | 54.23 |
| | 16.0 | 66.9 | 96.7 | 7.12 | 0.97 | 64.89 |

## RESULTS AND DISCUSSION

The results of respirometric measurements of different activated sludges with variable substrate concentrations are summarized in Table (3). The results demonstrated the low values of the coefficients $r_{x,m}$ and $k_s$, for the completely-mixed activated sludge unit within the specified range of substrate concentrations.It also emphasized the importance of respirometric evaluation for optimum efficiency and avoidance of filamentous bulking in the conventional activated sludge units.

## CONCLUSION

Respirometric measurements have been used for the determination of the maximum removal rates $r_{x,m}$ and the half velocity coefficients, $K_s$. Completely mixed (filamentous) activated sludge substrates were tested: glucose, Citric acid, and phenol. The respirometric experiments also verified the kinetic selection theory of mixed cultures. The obtained results clearly emphasized the low values of $r_{x,m}$ and $K_s$,at this type of activated sludge units.

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