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CONVERGENCE OF ACTIVATED SLUDGE AND TRICKLING FILTER DESIGN FORMULAS

It has recently been proven that activated sludge substrate removal mechanism of the first order type is analogous to the kinetic representation of the biodegradable organic load removal across high-rate trickling filters. The paper illustrates further convergence of the removal mechanisms in the two basic aerobic biological processes, based on the excess sludge production. The presented hypothesis suggests that the performance of trickling filters can be represented by excess sludge accumulation diminished by the magnitude of endogeneous respiration against the specific surface area of biological slime exposed to wastewater flow.

1. INTRODUCTION

The popularity of trickling filters had ups and downs in the last three decades and frequently lost ground to activated sludge. Recent years have lifted the popularity to new high levels and several new companies in Europe have profited from introduction of plastic media [5]. It occurs that one of the major factors in deciding against trickling filters had been the difficulty in actual design of full scale units and problems in running and interpreting pilot studies data.

Based on author's work on modelling removal mechanisms in biological systems an attempt will be presented here to show the distinct similarities existing in interpreting data and designing the biofilters and activated sludge units.

2. ORGANICS REMOVAL CHARACTERISTICS

Completely mixed, homogeneous activated sludge reactor (CMR) traditionally has been modelled by a simple first order relationship of the type:

$$\frac{S_0-S_e}{X_v \cdot t} = k \cdot S_e = \frac{S_r}{X_v \cdot t} \tag{1}$$

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where:

S_0, S_e — influent and effluent soluble BOD, COD or SOC concentration, respectively,

and $S_r = S_0 - S_e$,

X_v — the mixed liquor volotile suspended solids concentration (dry weight),

t — the aeration time,

k — rate removal coefficient in units corresponding to S_r

For a plug — flow PFR activated sludge reactor the equation is:

$$S_e/S_0 = \exp(-Kt) \tag{2}$$

where

$K = k \cdot X_v$ — the volumetric substrate removal coefficient

k — the specific substrate removal coefficient.

Recently introduced the so-called substrate removal mechanism [1] [3] has provided an additional dampening effect on the variability of the rate coefficient. The forms used now for completely mixed and for plug flow activated sludge reactors account for influent concentration variability:

$$\frac{S_0 S_r}{t} = K S_e, \qquad \text{CMR}, \tag{3}$$

$$\frac{S_e}{S_0} = \exp\left(-\frac{Kt}{S_0}\right), \qquad \text{PFR}, \tag{4}$$

Taking into account the fact that the food to microorganism ratio, F/M, is equivalent to load — L (mg/mg·h) then

$$F/M = L = \frac{S_0}{X_v \cdot t}, \tag{5}$$

and thus PFR equation (4) takes the form

$$S_e/S_0 = \exp\left(-\frac{k}{F/M}\right) = \exp\,(-k/L). \tag{6}$$

Author's studies on trickling filter substrate removal mechanism [4] have proved that heavily loaded, oriented plastic media biofilter responds to loading according to the mechanism:

$$S_e/\,S_0 = \exp\left(-\frac{kAH}{QS_0}\right) \tag{7}$$

assuming there is no recycle and the temperature is constant.

In case of recycle — mixed influent concentration S_a is substituted for S_0, while temperature correction can be made by the standard Arrhenius equation. Mathematical transformations have lead to another convenient trickling filter design formula proposed by the author:

$$S_e/S_0 = \exp(-K/L) \tag{8}$$

apparently identical to equation (6); and it assumes that the product of specific surface area $A(m^2/m^3)$ and rate coefficient k is equal to $K = kA$ and represents the fixed biomass solids in the filter; and that H/Q is proportional to time, t. One has to state here, however, that detailed studies [4] have proved irrelevance of residence time in evaluation of trickling filter performance. This is the single most significant difference between highly loaded mixed — homogeneous reactors and heterogeneous reactors such as biofilters. Naturally, equation (7) can be transformed to show the food to microorganisms F/M ratio concept as in equation (6).

3. SLUDGE PRODUCTION

3.1. ACTIVATED SLUDGE

Sludge settling and recycle is inherent to activated sludge process performance. Sludge production and wasting of excess sludge is a measure of process stability and activity of the microbial population. The exact mathematical relationship for daily sludge accumulation (i.e. excess sludge X_v — kg/d) involves at least four elements:

1. Sludge build-up due to influent suspended solids which are not degraded in the process;
2. Increase in biological volatile solids (VS) due to cell synthesis;
3. Decrease in biological VS due to endogenous respiration;
4. Decrease of sludge mass due to solids lost in the effluent.

To simplify the reasoning let us assume that influent is totally soluble and final clarification is 100% efficient (i.e. disregarding elements 1 and 4), then the resulting equation is:

$$\Delta X_v = aS_r - bX_v \tag{9}$$

where:

a — sludge synthesis coefficient, (kg VSS produced/kg organics removed),

b — sludge endogenous respiration coefficient (kg VSS oxidized/kg MLVSS·day); and where it is assumed that X_v represents 100% biodegradable fraction coefficient — as used by ECKENFELDER [1], i.e. $x = 1$.

The design values for a and b coefficients are obtained from the plot of net sludge production versus activated sludge loading, as shown in fig. 1.

3.2. TRICKLING FILTERS

In case of trickling filters — with proper hydraulic regime i.e. where no sludge deposits are retained in the media — the active sludge is retained in the media in form of biological slime. The sludge removed from the final clarifier should then be considered as excess

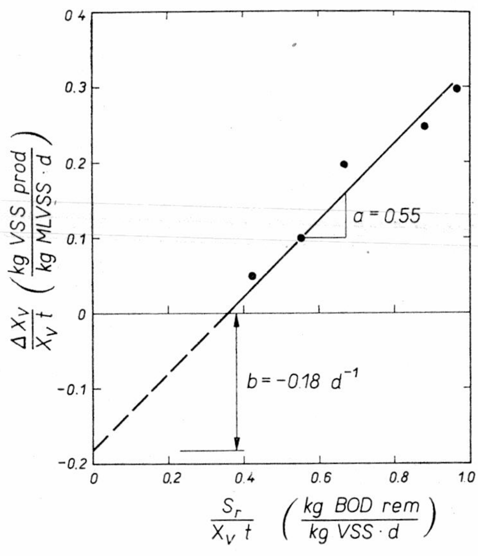

Fig. 1. Example of excess activated sludge productionc oefficients calculation — municipal wastewater

Rys. 1. Przykład obliczenia współczynnika nadmiernej produkcji osadu czynnego — ścieki miejskie

sludge i.e. ΔX_v, proportional to the load removed S_r and to the active slime mass. The latter is directly proportional to the specific surface area A. It should be stressed here that sludge recycle, sometimes advocated, is without substantiation and may only be used for start-up acclimation. In active biological filter sludge that is removed (unloaded) has no further treatment potential.

Results of studies on six parallel biofilters published by Bruce and Merkens [2] have been utilized here to show that sludge production in trickling filters can be accurately related to the applied and removed organic loadings. From the published data on average values of unit BOD removal and average quantity of wet film the values of kg BOD removed per kg of wet film-day were calculated and plotted in fig. 2.

The resultant equation is

$$\Delta X = a\, S_r - bX = 0{,}59\, S_r - 0.016\, X \tag{10}$$

where X denotes total sludge, since VSS were unknown and thus the relationship is approximate.

4. SUMMARY AND CONCLUSIONS

Further data is needed to verify the hypothesis that the classic excess activated sludge approach to sludge mass balance in trickling filters is adequate. Data is needed also to prove that the unit oxygen uptake rates and consumption by biofilter slimes can be used in a manner similar to activated sludge oxygen requirements formula.

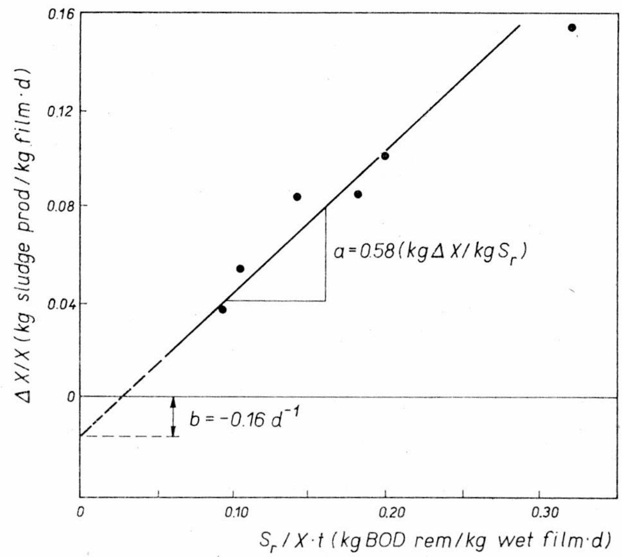

Fig. 2. Trickling filter excess sludge production versus removed BOD load — municipal wastewater

Rys. 2. Zależność nadmiernej produkcji osadu czynnego złoża biologicznie zraszanego od usuniętego obciążenia BZT — ścieki miejskie

The information presented, proves however, that the design models for the two biological processes are similar in nature and that pilot studies should be aimed at determining the sludge production and characteristics since it does play a significant role in biofiltration technology and the role is measurable.

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MODELE PROJEKTOWANIA ZŁÓŻ BIOLOGICZNYCH I PROCESU OSADU CZYNNEGO

W pracy przedstawiono zbieżności nowego modelu kinetyki osadu czynnego w układzie tłokowym i modelu empirycznego złoża biologicznego. Oba urządzenia da się modelować podobnym wzorem

$$S_e/S_0 = \exp(-K/L),$$

gdzie S_e, S_0 są stężeniami BZT_5 odpływu i dopływu, L obciążeniem objętościowym s. m. osadu lub jednostki powierzchni właściwej. Praca dowodzi więc roli, jaką w tych procesach biologicznych odgrywa obciążenie ładunkiem organicznym osadu lub powierzchni błony biologicznej. W dalszym ciągu, na przykładzie dokładnych pomiarów produkcji osadu w złożach biologicznych zaproponowano interpretację złóż na podstawie przyrostu osadu, ponieważ udało się zastosować wzór analogiczny do podstawowej zależności na przyrost osadu czynnego, tj. $\Delta X = aS_r - bX$. Hipoteza ta oparta jest na badaniach pilotowych oczyszczania na złożach z tworzyw sztucznych ścieków miejskich i wymaga potwierdzenia dla innych rodzajów ścieków oraz dla wypełnień konwencjonalnych.

GEMEINSAME PROJEKTIERUNGSRUNDLAGEN FÜR TROPFKÖRPER UND BELEBUNGSANLAGEN

Der Verfasser erläutert im vorstehenden Beitrag die Konvergenz eines neuen kinetischen Modells des Belebtschlammes und des als Propfenströmungsreaktor arbeitenden Tropfkörpers. Beide Einrichtungen lassen sich mit der gleichen Formel

$$S_e/S_0 = \exp(-K/L)$$

beschreiben, wobei S_e und S_0 die Abfluß- und Anfangskonzentrationen des BSB_5 und L die Belastung des Schlammes bzw. der spezifischen Filterfläche sind.

Der Beitrag beweist also die grundlegende Tatsache, daß im biologischen Reinigungsverfahren die spezifische Belastung des Schlammes oder des biologischen Rasens des Tropfkörpers von ausschlaggebender Bedeutung ist. Anhand von genauen Messungen des Rasenswuchses im Tropfkörper, ist es dem Verfasser gelungen, die bekannte Formel der Schlammzuwachsrate $\Delta X = aS_r - bX$ auch als Zuwachsrate für den Tropfkörperrasen anzuwenden.

Die vorgeschlagene Hypothese wurde im Reinigungsverfahren städtischer Abwässer im Pilot-Tropfkörper mit Kunststoffüllung erstellt. Sie soll demnächst mit anderen Abwasserarten und am anderen Füllmaterial erprobt bzw. bestätigt werden.

МОДЕЛИ ПРОЕКТИРОВАНИЯ БИОФИЛЬТРОВ И ПРОЦЕССА АКТИВНОГО ИЛА

В работе представлено совпадение новой модели кинетики активного ила в поршневой системе эмпирической модели биофильтра. Оба устройства могут моделироваться подобной формулой:

$$S_e/S_0 = \exp(-K/L),$$

где S_e, S_0 — концентрации BZT_5 стока и притока, L — объемная нагрузка осадка или единицы удельной поверхности. В работе доказана основная зависимость, какой в этих биологических процессах является нагружение органическим веществом осадка (ила) или поверхности биопленки. На основе точных измерений осадка в биофильтрах предложен расчет фильтров по приращению осадка, так как удалось применить формулу, аналогичную основой формуле для приращения активного ила, то есть $AX = aS_r - bX$. Эта гипотеза основана на проведенных в полузаводском масштабе исследованиях по очистке городских сточных вод с помощью фильтров из пластмасс; она нуждается в подтверждении для других видов сточных вод, а также для конвенциональных заполнителей.