OPTIMIZATION OF THE EFFLUENT TREATMENT SYSTEM (ANAEROBIC/AEROBIC) FOR RUBBER INDUSTRY BY KINETIC MODELING

Indika Upuli Hettiarachchi

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Department of Chemical & Process Engineering

University of Moratuwa

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Declaration

I hereby declare that this submission is a result of work carried out by me & to the best of my knowledge, it contains no material previously written or published by another person nor material which has been accepted for the award of any degree or acceptable qualification of a university, or other institute of higher learning except where the due reference to the material is made.

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Indika Upuli Hettiarachchi.
December, 2003.

Abstract

Raw rubber processing factories generate large amounts of wastewater containing organic pollutants & various process chemicals. Factory effluents exhibit high BOD (Biochemical Oxygen Demand) & COD (Chemical Oxygen Demand) concentrations, ammonia & suspended solids that are amenable to biological treatment methods.

Rubber Research Institute (RRI) of Sri Lanka developed a novel & cost effective biological effluent treatment technique for rubber-processing effluents discharged by crepe rubber & centrifuged latex factories. Treatment system, based on high rate anaerobic digestion coupled with aerobic stabilization also consists of settling & sand filtration. The main feature of this technique is the use of a low cost, septic tank type anaerobic digester filled up with coir fibres for the attachment of useful microorganisms for effective biological conversion. Biological kinetic expressions have been derived for the design & control of effluent treatment plants where aerobic digestion is used commonly as the only treatment method. The kinetic coefficients in these expressions are widely used in design calculations. For a specified waste, a given biological community & a particular set of operating conditions the kinetic coefficients are fixed. Kinetic coefficients used for the design of domestic effluent treatment plants cannot be applied for the design of industrial effluent treatment plants as the waste composition & biological communities involved are different. Also kinetic coefficients for the anaerobically pretreated wastewater could be very different to those of the raw wastewater even for the same type of waste. No kinetic study has been carried out yet for the RRI developed treatment process for making possible improvements & modifications for optimal operation & performance of the aerobic treatment system to reduce capital, operational & maintenance costs under low loading conditions.

The objective of this study is to find out the kinetic coefficients required for the design of activated sludge process from anaerobically pretreated rubber industry

wastewater. The obtained values of kinetic coefficients were used to model an existing treatment system.

A pilot-scale continuously aerated stirred tank was used as a model reactor. Reactor was operated without a recycle stream & fed with a steady flow of anaerobically pretreated wastewater obtained from a full-scale rubber industry effluent treatment plant. Samples were taken for five different runs at five different mean-cell residence times (θ_c). BOD & MLVSS (Mixed Liquor Volatile Suspended Solids) of each sample for each run were measured according to Standard Methods for the Examination of Water & Wastewater.

The following kinetic coefficients were estimated by a graphical method using measured data & the standard kinetic expressions.

- Y = cell yield coefficient
- k_d = cell decay coefficient
- K_s = half-velocity constant
- k = maximum substrate concentration per unit mass of microorganisms
- μ_m = maximum specific growth rate).

The obtained kinetic coefficients show significant differences to those of domestic wastewater reported in literature. Maximum substrate concentration per unit mass of microorganisms (k) is less than one-half of the corresponding value for domestic wastewater. This implies more than double the concentration of microorganisms is required to be maintained in the aeration tank than that for domestic wastewater. Half-velocity constant (K_s) is more than double the concentration of the corresponding value for domestic wastewater. It implies that the microorganisms have high affinity to anaerobically digested substrate. This could be expected because most anaerobically digested intermediate products & end products are considered good substrates for heterotrophic organisms. The cell yield coefficient (Y) is comparatively higher & the cell decay coefficient (k_d) relatively lower than those for domestic wastewater leading to a higher μ_m, maximum specific growth rate. Therefore a richer microorganism concentration could be expected in the aeration tank.

Obtained kinetic coefficients were used to model an existing activated sludge treatment system. The minimum mean-cell residence time calculated with the obtained kinetic coefficients lead to a value of 0. 9 (d) with a safety factor of 3.33 & is within the accepted range for plant operation (2 – 20). Sludge washouts are very unlikely due to the fulfillment of the condition $\theta_c > 1/\mu_m$ indicating a good waste stabilization. Calculations revealed significant difference between the predicted & operated condition of the plant. The obtained kinetic coefficients were used to optimize the plant operation by estimating sludge recirculation rate, aeration rate & sludge production rate. The findings will help improve the treatment system design & reduce the associated costs.

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List of symbols & acronyms

d = day
d^{-1} = day^{-1}
dX/dt = rate of change of microorganism concentration in the reactor measured in terms of mass(VSS), mass VSS/(volume.time)

E = process efficiency

K_s = half-velocity constant, mass/volume
k = μ_m/Y, maximum rate of substrate utilization per unit mass of microorganisms, $time^{-1}$
k_d = endogenous decay coefficient, $time^{-1}$

N_0= influent TKN, mass/volume
N = effluent TKN, mass/volume

P_x = net weight of activated sludge produced each day, measured in terms of VSS, lb/d (kg/d)

Q = flow rate, volume/time
Q'_w = cell wastage rate from recycle line, volume/time
Q_e= flow rate of effluent from the solids separation unit, volume/time

r_g = rate of bacterial growth, mass/volume.time
r_{su} = substrate utilization rate, mass/volume.time
r'_g = net rate of bacterial growth, mass/volume.time
r_T = reaction rate at T
r_{20}= reaction rate at 20^0C

S = concentration of growth limiting substrate in solution or substrate concentration in effluent, mass/volume
S_0 = substrate concentration in influent, mass/volume
S_0-S = mass concentration of substrate utilized, mass/volume

t = tonne
T = temperature,°C

U = specific substrate utilization rate, $time^{-1}$

V_r = volume of the reactor
V_s = volume of the settling tank
V_T = volume of reactor plus volume of settling tank

X_0 = concentration of microorganisms in the influent, mass VSS/volume
X = concentration of microorganisms in the reactor, mass VSS/volume

X_r = microorganism concentration in return sludge line, mass VSS/volume
X_e = microorganism concentration in effluent from the solids separation unit, mass VSS/volume

Y = maximum yield coefficient, mg/mg (ratio of the mass of cells formed to the mass of substrate consumed, measured during any finite period of logarithmic growth)
Y_{obs} = observed yield,

θ = hydraulic retention time
θ_c = mean cell-residence time
θ_{ct} = mean cell- residence time based on the total system
$1/\theta_c$ = net specific growth rate
'θ' = temperature activity coefficient

μ = specific growth rate, $time^{-1}$
μ_m= maximum specific growth rate, $time^{-1}$
μ' = net specific growth rate, $time^{-1}$

ASP = Activated Sludge Process
BOD = Biochemical Oxygen Demand
COD = Chemical Oxygen Demand
DO = Dissolved Oxygen
DRC = Dry Rubber Content
IRRDB = International Rubber Research Development Board
MLSS = Mixed Liquor Suspended Solids
MLVSS = Mixed Liquor Volatile Suspended Solids
OUR = Oxygen Uptake Rate
RAS = Return Activated-Sludge
RCCSR = Rubberized Coir Carrier Septic Tank Reactor
RRI = Rubber Research Institute
RRIM = Rubber Research Institute of Malaysia
RSS = Ribbed Smoked Sheet
SBR = Sequencing Batch Reactor
SOUR = Specific Oxygen Uptake Rate
TKN = Total Kjeldal Nitrogen
TMTD = Tetra-Methyl-Thiuram-Disulphide
TOC = Total Organic Carbon
TSR = Technically Specified Rubber
WAS = Waste Activated-Sludge