MODEL BASED ON-LINE SYSTEM IN ACTIVATED SLUDGE PROCESS TREATING PULP AND PAPER WASTEWATERS

S.Halttunen
Tampere University of Technology, Tampere, Finland

Corresponding Author: S. Halttunen, Tampere University of Technology,
Department of Chemistry and Bioengineering
P.O.Box 541, 33101 Tampere, Finland; sakari.halttunen@tut.fi

Abstract. The management of activated sludge in dynamic conditions in space limited process requires knowledge and expertise. Activated sludge process treating nutrient poor wastewaters are controlled with following: return sludge flow, excess sludge flow, air flow, dosage of phosphorous and nitrogen. The procedure of model based on-line system is based on three levels: 1 selection of process status target, 2 set point estimation of devices and 3 control loops of devices. In level 1 steady state model of activated sludge process is used. The formation of biomass is based on models of growth, degradation and accumulation. Activated sludge distribution and behaviour is modelled in both basic unit processes: aeration tank and secondary settling tank. Results are given as a function of sludge age. Results are used to select limits and target values in level 2. Following three factors should be considered in selection: safe operation, high effluent quality and low costs. In level 2 process status is calculated from the last possible measured data. Part of the status variables are exponentially filtered during calculation. Result variables are compared with set of limits and target values. Comparison produces new set point values, which are then used in low level control loops on level 3. During the last ten years the above-mentioned procedure is used on several activated sludge plants in Finland. Experiences have been promising, when the personnel of the wastewater treatment plant are motivated and the measured data is accurate enough.

1 Introduction

Activated sludge is mainly composed of continuously growing micro-organisms able to rapidly adapt to changes of the environment and wastewater to be treated. Mistakes in control of the activated sludge process often necessitate to poorly settling sludge, which will lead to insufficient clarifier capacity. The management of activated sludge in this dynamic environment in a limited process space requires knowledge and expertise.

Expert systems have been considered as one option to ease the control of activated sludge already twenty years ago, when feasible alternatives were even the subject of many academic research programs. In Finland pulp and industry started to use activated sludge processes in waste water treatment during years 1985 – 1995 in twenty mills. In the early stages problems related to dimensioning and implementation a large research program (MEBITE) on pulp and paper waste water treatment with activated sludge process was started [3] The outcome of this program was utilized as software of dimensioning and later as process control systems.

However it is hard to find references in literature where expert systems or advanced model based control systems are described in biological treatment of industrial wastewaters. That is one of the main reasons to produce this paper.

This paper describes the method how the activated sludge process of pulp and paper industry is optimally regulated. The details are given only if they have not been described earlier in the literature. A typical feature for forest industry wastewaters is the high carbon content in relation to nitrogen and phosphor thus giving no need to remove either biologically or chemically nutrients from the wastewaters.

2 System procedure

Suspended solids separation in clarifier often is the limiting factor. Effluent quality of treated water depends on effluent suspended solids (SS) amount because solids carry other commonly used quality criterions like biological oxygen demand (BOD), chemical oxygen demand (COD), phosphorus (P) and nitrogen (N). Activated sludge process treating nutrient poor wastewaters are controlled with following: return sludge flow, excess sludge flow, air flow, dosage of phosphorous and nitrogen. The control of temperature and pH can be done easier with high-low limits or fixed set points.

The procedure of model based on-line system is based on three levels: 1 selection of process status target, 2 set point estimation of devices and 3 control loops of devices. Details of the properties of system levels are shown in Table 1.

	1 selection of process status target	**2 set point estimation of devices**	**3 control loops of devices**
Operational principle	Steady state mass balance models	Expert system	Automatic control loops
Operation frequency	Once a month	Once a day	Continuously
Operator	AS-process expert	AS-process operator	AS-process control system

Table 1. Operational properties of the procedure based on three levels.

2.1 Selection of process status target (level 1)

When choosing the process status target a model based mass balance calculation is used, and it is performed by an expert on activated sludge process. These models are based on well known, simple enough facts established by experience and solved using differential equation referring on steady state.

Model structure. The formation of biomass is based on models for growth, degradation and accumulation. The input of organic as well as inorganic suspended solids originating from the incoming waste water cumulates. To describe the biomass growth simple Monod's equation is used. The following Figure 1 describes the mass balance of activated sludge.

Activated sludge distribution and behaviour is modelled in both basic unit processes: aeration tank and secondary settling tank. For more detailed descriptions see references [1] and [2].

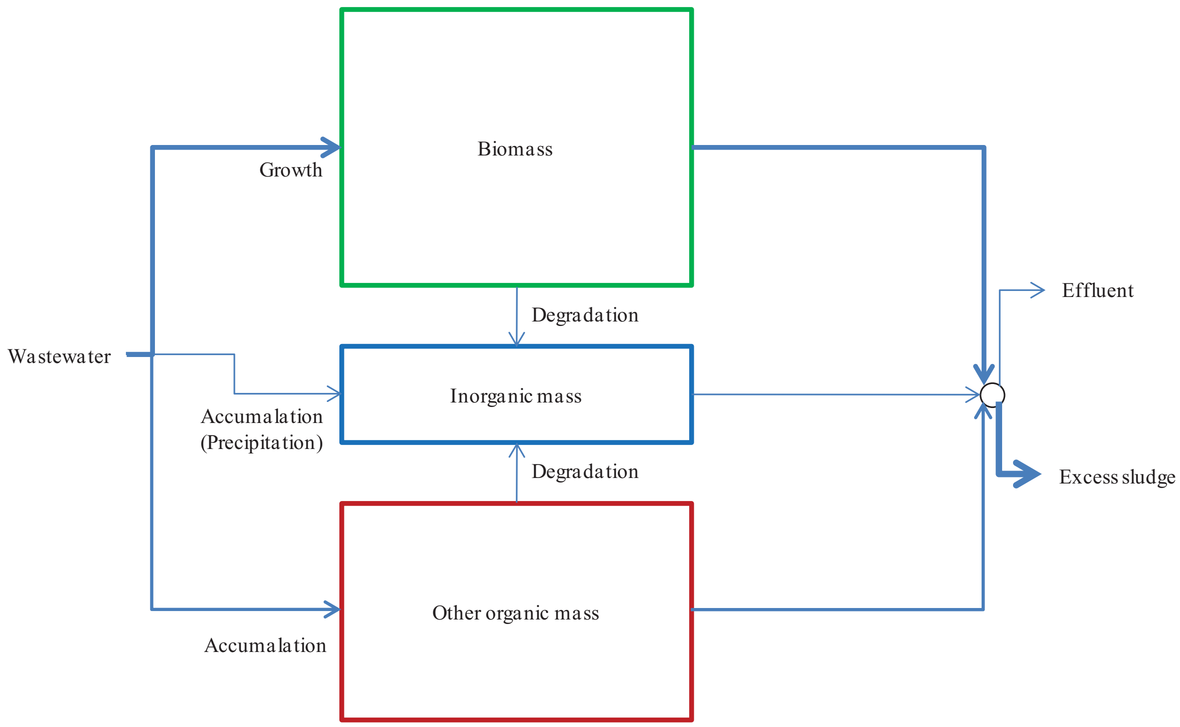

Figure 1. Activated sludge mass balance.

Input. In level 1 the loading figures, process circumstances and process dimensions are the input of steady state model of activated sludge process. The following Table 2 shows the used parameters with numerical examples.

Loading to the process		Status of the process		Dimensions of the process	
Flow m³/d	80000	Return flow m³/d	80000	Aeration m³	35000
COD kg/d	120000	Temperature °C	35,0	Sludge aeretion m³	0
BOD kg/d	50000	DSVI ml/g	150	Clarifiers pcs	3
Suspended solids kg/d	10000	P in sludge %	0,70	Volume of a clarier m³	13586
Ash in SS %	20	P min soluble g/m³	0,20	Area of a clarier m²	3019
P kg/d	160	N in sludge %	7,0	Inlet area of a clarier m²	50
N kg/d	500	N min soluble g/m³	2,0		

Table 2. The input variables used for model selection describing the process status target.
These values have been used for the example.

Results. Results as function of sludge age are: sludge amount in aeration and clarification, effluent BOD, COD, N, P and effluent suspended solids, excess sludge as well as the required oxygen, phosphorus and nitrogen.

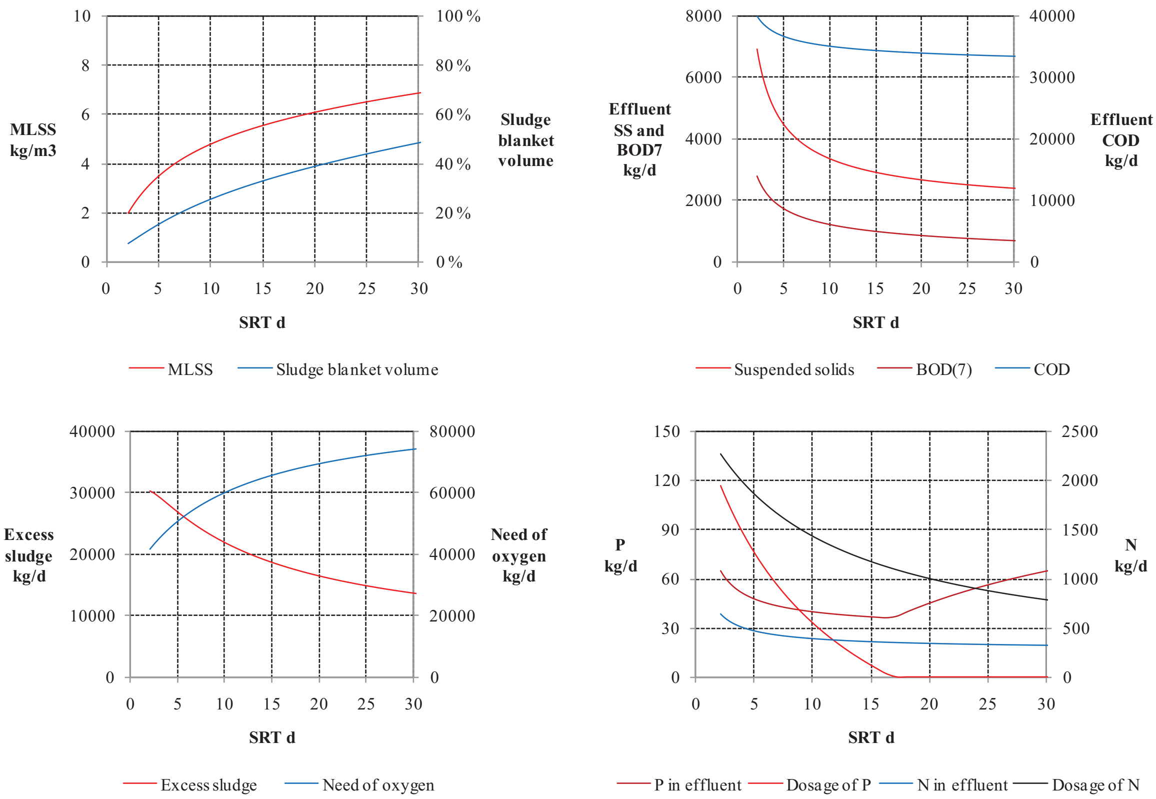

Figure 2. Results of the model used for selection of process status target.
Numeric values are those used in the example.
Results are shown as a function of sludge retention time.

Aspects on the use of the model. These results are used to select limits and target values in level 2. Following three factors should be considered in selection: safe operation, high effluent quality and low operational costs. These factors form a triangle, where each one is in the corner of triangle (Figure 3). If one of the factors is emphasized then the others are understated.

To operate safely it is required to maintain circumstances to meet the requirements for suitable sludge growth environment for optimal settling and condensing. The growth conditions are naturally highly affected with pH and temperature, and are easily regulated with simple control loops for dosing biomass neutralisation chemicals and for cooling tower. Optimal growth conditions in aeration assure with proper oxygen and soluble nutrients. Overloading of secondary clarification creates a marked risk. This can be minimised with low sludge concentration and with optimally settling and condensing sludge.

Low discharge of treated wastewater is generally obtained when using high sludge concentration in aeration and recycling resulting in low suspended solids in treated effluent when the capacity of secondary clarifier is not the limiting factor. In order to maintain the activity of the sludge to remove organic matter oxygen concentration should be kept on a reasonable level. Also the levels of soluble nutrients in the treated water should be minimized.

Main costs for plant operation are energy, chemicals and manpower. Energy is mainly required for oxygen production in aeration; less energy is needed for pumping. To minimize the energy costs it is wise to maintain quite low oxygen concentration and to avoid sludge degradation in the aeration base. Chemical costs are mainly formed from the added phosphorous and nitrogen in addition to polymers and to metal salts possibly needed during sludge drying. To minimize these costs, it is justified to use the lowest possible amount of nutrients and sludge drying chemicals resulting in the lowest possible amount of surplus sludge. In order to maintain the chemical costs at a reasonable level is recommended to use the lowest possible limit value for the soluble nutrients. Manpower is needed to follow and maintain the operation of plant procedure. During the plant procedure the labour cost is kept on low level when the number of laboratory samples and analyses are kept on a reasonable level and by performing only the necessary automated studies.

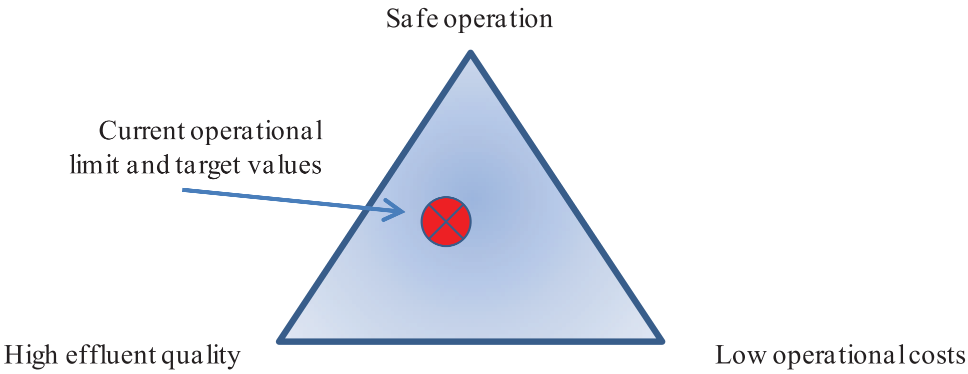

Figure 3. The triangle formed by the critical three factors affecting the selection of target values.

2.2 Set point estimation of devices (level 2)

AS-process operator uses daily expert system giving analyses of the process status as well as instructions to operator in addition to estimating set points of plant devices. Operator instructions explain the situation of the process, whether the limits have been neglected and how the process should further carried on. Set point estimated devices are: return sludge pumping, excess sludge pumping, dosage of phosphorus, dosage of nitrogen and possibly air flow to aeration or dissolved oxygen concentration (Figure 4).

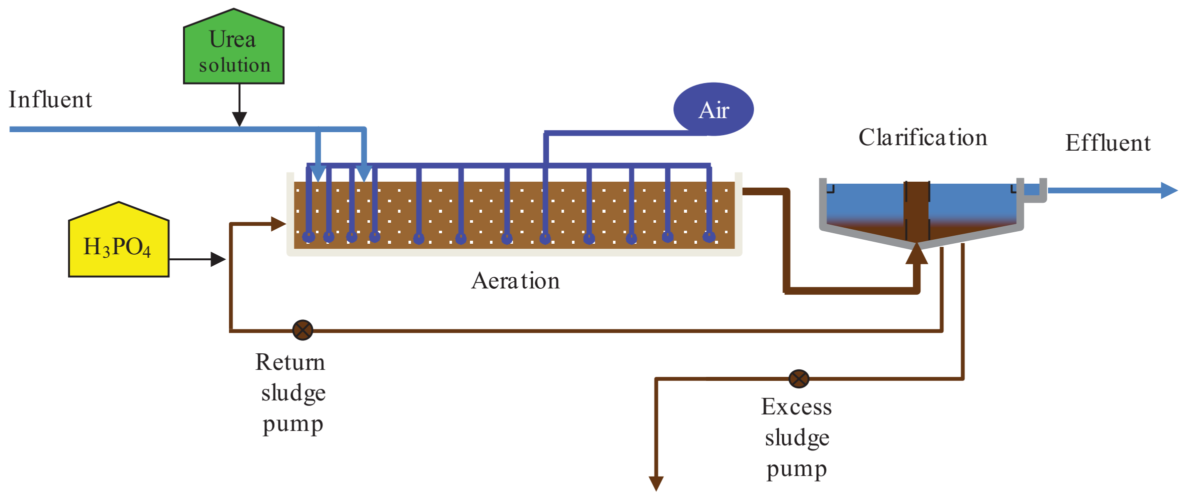

Figure 4. Diagram of activated sludge process and devices used in operation.

Measurements. To obtain data from different stages of the process about 30 samples are collected. Part of the data is daily averages generated by automatic equipments which for certain reasons may be replaced by manual measurements. Part of the measurement data originates from laboratory analyses of composite and grab samples. Part of the data from activated sludge process status is based on indirect measurements Often data of laboratory analysis is sparse in time scale.

Calculated variables. Process variables are calculated from the last possible measured data. Some of these altogether 40 variables are exponentially filtered during calculation. Mathematical description for the exponential filtering in the active sludge processing will be described on next paragraphs.

The important variables for following the proceedings of activated sludge processing might change dramatically and even turn to insignificant during this dynamic and active process. Therefore it has been a generally accepted rule to use numerical filtering in order to increase the usefulness and significance of these variables. For this purpose a general formula for numerical filtering is used, emphasizing the calculated value (α) at the previous time point and the measured value obtained between these two time points (1-α) as follows

$$\hat{x}_t = \alpha \cdot \hat{x}_{t-\Delta t} + (1-\alpha)\, x_t \qquad (1)$$

where

$\hat{x}_t$ = filtered value of variable on moment of examination

$\hat{x}_{t-\Delta t}$ = filtered value of variable on previous moment of examination

α = filtering factor [0<α<1]

x_t = average value of variable between moments of examination

Appropriate numerical filtering of variables in activated sludge process are variables connected to sludge, for example: the average value of excess sludge, phosphorous and nitrogen balance, the average biosludge content as well as flock load. In the equation (1) when applied with the active process the filtering coefficient (α) is not stable, and it is convenient to use sludge retention time in the equation. Thus the filtering factor is calculated with the following equation

$$\alpha = \frac{\hat{\theta}_{t-\Delta t}}{\hat{\theta}_{t-\Delta t} + \Delta t} \qquad (2)$$

where

$\hat{\theta}_{t-\Delta t}$ = filtered sludge retention time on previous moment of examination

Δt = time difference between moments of examination

The average amount of removed sludge is on the other hand the inverse of the sludge retention time. Based on this, numerical filtering can also be used for sludge retention time calculation. The filtered reverse value for sludge age from the active process can be obtained using measured values from the previous time point using exponential numerical filtering as follows

$$\frac{1}{\hat{\theta}_t} = \frac{\alpha}{\hat{\theta}_{t-\Delta t}} + \frac{1-\alpha}{\theta_t} \qquad (3)$$

where

$\hat{\theta}_t$ = filtered sludge retention time on moment of examination

θ_t = average sludge retention time between moments of examination

When (2) is substituted in (3), the equation for filtered sludge age is given as follows

$$\hat{\theta}_t = \frac{\hat{\theta}_{t-\Delta t} + \Delta t}{1 + \dfrac{\Delta t}{\theta_t}} \qquad (4)$$

Average sludge retention time between moments of examination is calculable when using the sludge content of the process and dividing it with the sum of passed sludge flows. Then all sludge presentations and flows have been taken into account.

$$\theta_t = \frac{\sum_i M_i}{\sum_j F_j} = \frac{\sum_i V_i \cdot X_i}{\sum_j Q_j \cdot X_j} \qquad (5)$$

where

M_i = sludge mass in process basin i
F_j = sludge mass outflow j
V_i = volume of process basin i
X_i = sludge average concentration in process basin i
Q_j = outflow j of sludge
X_j = sludge average concentration in outflow j

Limits Measures and calculated result variables are compared together with a set of limits and target values, selected from process status target (level 1). There are altogether about twenty target values and limit values to be used in the different stages of the process. Comparison of these produces a new set of point values, to be further used in the low level control loops (level 3). Changes in set points will be performed damped to avoid high unregulated effects.

2.3 Control loops of devices (level 3)

Set points of control loops from five devices will be transferred from expert system to automatic control system of the activated sludge process. The automatic control loop follows the set up values unless they are changed. The earliest possible time point to change the starting values occurs after 24 hours.

3 Practical experiences

During the last ten years the previous procedure has been used on several activated sludge plants mainly in Finland. The procedure is run either using normal workstation individually with data transfer or fully integrated on the data and control system of the mill. The commercial version of the procedure is available as Biosim and Biopert® software package (Biosim Networking Group Ab, Finland).

Thus far experiences with this procedure have been promising, especially when the personnel of the wastewater treatment plant are motivated and the measured data is accurate enough. Motivation to use the procedure is not sufficient in cases, when effluent quality of treated water meets the requirements of the authorities with lower effort.

4 References

[1] Halttunen S.: *Clarifier performance in activated sludge process treating pulp and paper mill effluents*. Wat. Sci. Tech. Vol. 29. No. 5-6. pp. 313-328, 1994.

[2] Halttunen S.: *Thickening in an activated sludge process clarifier*. Wat. Sci. Tech. Vol. 33. No. 12. pp. 171-180, 1996.

[3] Hynninen P. Halttunen S., Vuoriranta P.: *MEBITE: improved biological purification of forest industry wastewaters: final report.* KCL, Espoo. 1991.