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ESTIMATION OF SURFACTANT REMOVAL EFFICIENCY FOR DIFFERENT SLUDGE LOADING RATES

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Abstract: This study presents a theoretical analysis of the elimination of anionic surfactants from wastewater treatment plants using the SimpleTreat model. Sodium dodecyl sulfate (SDS), CAS no. 151–21–3, was chosen as case study because it is widely used in the detergent industry [1]. The model estimates the SDS concentration in effluent and the total elimination from WWTP, that is, the removal efficiency. As this type of chemical is biodegradable in the liquid phase, it is shown that the main removal mechanism is biodegradation in the aeration tank. The estimates are given as a function of seven values of the sludge loading rate, which is one of the most important parameters used to dimension the aeration tank in the WWTP.
Keywords: sodium dodecyl sulfate SDS, removal efficiency, sludge loading rate SLR, SimpleTreat model

1. INTRODUCTION

Biodegradation of organic matter in wastewater, and especially the class of surfactants, is a current topic that is discussed in many studies due to its impact on people and the environment [1–6]. Among anionic surfactants, the most used is the sodium lauryl sulfate (SLS), also known as sodium dodecyl sulfate (SDS), which is the sodium salt of dodecyl hydrogen sulfate [1]. The laboratory procedure to quantitatively determine anionic surfactants using the MBAS test is well described in the literature [5, 6].

In addition, the removal efficiency of anionic surfactants in wastewater treatment plants (WWTP) can be predicted by simulation models [7]. The SimpleTreat model is based on the following three processes that describe the fate, transport, and emission of chemicals in the modelled WWTP: *advection*, *diffusion,* and *biodegradation*. The dependence between these processes and the modelled WWTP compartments is shown in Figure 1 [7].

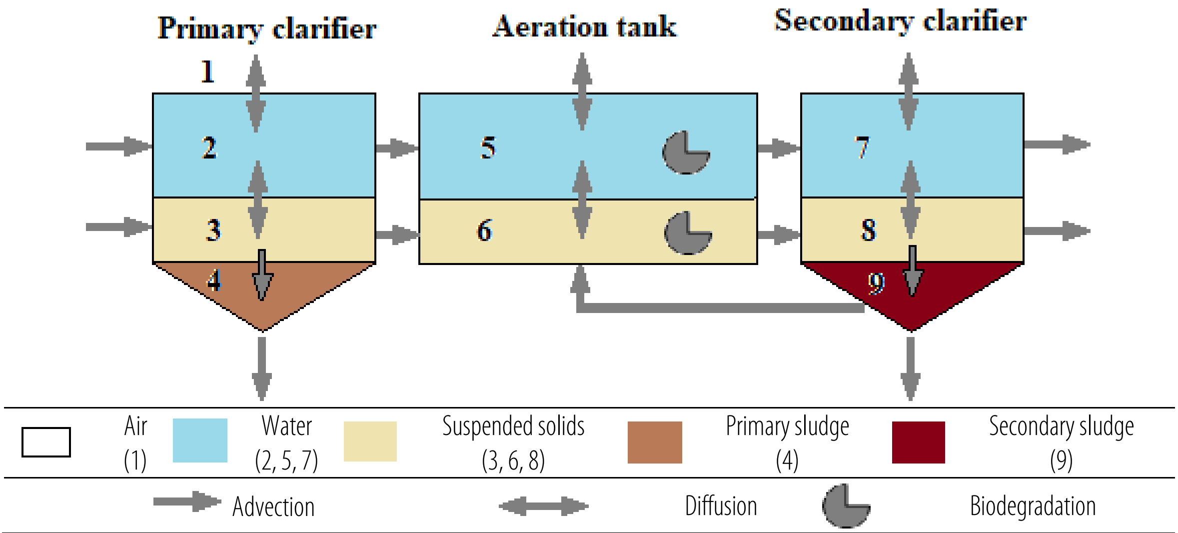

Figure 1. Pollutant processes in the WWTP compartments, reproduction after [7]

Advection is associated with the irreversible mass flow of the pollutant transported by a medium (air, water, or solids) between the WWTP compartments and basins and also the surrounding. At WWTP entry, the pollutant can be distributed in the liquid phase (as a solute in the water) and in

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the solid phase (adsorbed onto the solid sludge particles). *Diffusion* represents the interphase mass transfer of the pollutant between adjacent compartments, driven by concentration gradients [7].
Biodegradation is a process of transformation of the pollutant in the liquid or solid phases in the aeration tank of the WWTP [7–10]. During this process, organic pollutants are decomposed by microorganism activity into new cell mass, CO_2, and H_2O [8, 9]. To complete the process, the microorganism needs a carbon source such as glucose (simple sugar), cellulose (a plant polymer), or a pollutant molecule; a nitrogen source (NH_3); essential nutrients, and oxygen (O_2) [8]. In the case of surfactants, the linear structure that contains the carbon source for the microorganisms may be inaccessible if the substance has other molecular branches. Therefore, linear chain surfactants are more likely to be readily biodegradable than non–linear surfactants [8, 9]. Furthermore, the biodegradation process depends on the number of microorganisms. In 1 gram of surface soil, the bacterial population is generally in the range of 10^6 to 10^9 microorganisms, while the fungal population is between 10^4 and 10^6 [9]. The number of bacteria estimated in 1 gram of dry activated sludge is between 10^8 and 10^{14} cells of 5 to 8 bacteria species [9].
From the sensitivity analyses of the Simple Treat model described in the literature, the most important input parameters that influence the estimated concentration of chemicals in air, receiving water, and soil (through sludge) are: Henry's constant, sewage flow, sludge loading rate SLR, and the biodegradation rates. [11–13].
Sludge loading rate (SLR) or the Food–to–Microorganism ratio (F/M) is one of the most important parameters which is used in the dimensioning of the aeration tank in wastewater treatment plants. The following relation is used to calculate it [7, 9, 14, 15]:

$$\mathrm{SLR} = \frac{\mathrm{BOD_{in}} \cdot \mathrm{Q}}{\mathrm{X_V} \cdot \mathrm{V}} \left(\frac{\mathrm{kg\ BOD}}{\mathrm{kg\ solids} \cdot \mathrm{day}}\right) \quad (1)$$

where: BOD_{in} (kg BOD/m^3) – biochemical oxygen demand (oxygen requirement) at the entrance of the aeration tank; Q (m^3/day) – daily wastewater flow; X_V (kg/m^3) – biomass concentration in the aeration tank; V (m^3) – volume of the aeration tank.
A high SLR value can result in poor pollutants removal efficiency because the food in the aeration tank is in excess and bacterial metabolism is not fully completed [9]. A low SLR value indicates a low–contained food environment in which organic material oxidation may be complete and high removal efficiencies may be obtained [9]. The recommended values are in the range of 0.1 to 0.2 $kgBOD \cdot kg^{-1}_{solids} \cdot d^{-1}$ [9].
This study aims to analyse the influence of the sludge loading rate parameter on the sodium dodecyl sulfate (SDS) anionic surfactant concentration in the effluent and the total elimination from wastewater. In the SimpleTreat model, default values of parameters that describe WWTP functioning were used, while the chemical concentration in the influent was taken as the media value of experimental data collected from 5 municipal wastewater treatment plants in Romania [19].

2. ANALYSIS METHODS

Some parameters used in this study are taken as default values given in references [7, 12, 15]. The ones specific to this case study are further described. The chemical properties of the SDS chemical, which are used as input data in the SimpleTreat model, are given in Table 1 [16, 17].
Knowing the removal of the BOD value required, i.e. the SLR value, the equation (1) can be used to determine the volume of the aeration tank needed. In Table 2 are given the values calculated in this case study, depending on the recommended ones of the SLR and the default values of the wastewater operation mode given in the reference [15]: $\mathrm{Q} = 0.2\ \frac{\mathrm{m^3}}{\mathrm{day \cdot PE}}$, $\mathrm{BOD_{in}} = 0.192\ \frac{\mathrm{kg\ BOD}}{\mathrm{m^3}}$ and $\mathrm{X_V} = 4\ \frac{\mathrm{kg}}{\mathrm{m^3}}$. In calculation, the values were expressed as a function of PE (population equivalent), that is, the default of 10,000 PE with biological oxygen demand (BOD) per PE of 60 g/day [15]. The

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volumes of the aeration tank were calculated to give a detailed view on the WWTP size considering a constant depth of this basin of 3 meters.

Table 1. Chemical properties of SDS, CAS no. 151–21–3 [16, 17]

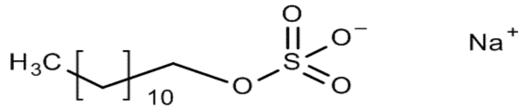
Property	Sodium Dodecyl Sulfate (SDS)
Molecular formula	$C_{12}H_{25}NaO_4S$
Chemical structure	
Molecular weight	288.38 g/mol
Octanol–water partition coefficient, $\log(K_{OW})$	1.6
Dissociation constant in water, pKa	1.31 at 20°C (OECD 112)
Vapour pressure	$2.4 \cdot 10^{-10}$ Pa (at 25 degC)
Water solubility	10^5 mg/L
First order biodegradation constant	1 h^{-1} (readily biodegradable, 95% degradation – based on the evolution of CO_2 after 28 days, OECD 301 B)

Table 2. Calculated aeration tank volumes in function of recommended SLR and HRT

SLR $\left(kg_{BOD} \cdot kg_{solids}^{-1} \cdot d^{-1}\right)$	HRT (h)	Aeration tank volume (m^3/PE)
0.04 (low)	28.7	0.2396
0.06 (low)	19.2	0.1597
0.1 (low –default)	11.5	0.0958
0.15 (medium)	7.7	0.0639
0.2 (medium)	5.2	0.0479
0.3 (high)	3.8	0.0319
0.6 (high)	1.9	0.0160

The hydraulic retention time, HRT in hours, can be determined by dividing the volume of the aeration tank by the wastewater flow, the recommended values in correlation with the SLR parameter are given in Table 2 [2, 15].

The emission input data require the emission rate of chemical, E in (kg/day), estimated with formula [7]:

$$E = \frac{C_0 \cdot Q \cdot N}{1000} \left(\frac{kg}{day \cdot PE}\right) \tag{2}$$

where: C_0 in (g/m^3) is the chemical concentration in the influent, and N in (PE) is the number of inhabitants for which the WWTP is dimensioned.

To give a realistic view of this study, the influent concentration of the modelled chemical was considered from the experimental data collected from 5 municipal wastewater treatment plants in Romania and presented in a paper by Daniel Mitru et al. [19]. From all measurement sites, the authors present a variation in anionic surfactant concentrations in WWTP influents in the range of 0.49 mg/L to 3.60 mg/L, with an average of 1.52 mg/L [19].

This average value of the $C_{SDS\ influent}$ = 1.52 mg/L will be further considered for the anionic surfactant concentration in the modelled WWTP influent. The chemical emission rate in the SimpleTreat model is considered to be 3.04 kg/(day·PE), which was calculated using formula (2).

3. RESULTS AND DISCUSSION

The removal efficiency of the modeled WWTP of the studied chemical is calculated as the ratio between the (influent concentration – effluent concentration) and the influent concentration, which represents total elimination from wastewater [15]. Estimates with the SimpleTreat model for different sludge loading rates are given in Table 3. Taking into account the value given in the regulations of 0.5 mg/L of anionic surfactant emitted in the WWTP effluent [19], except the last case (SLR=0.6), the SDS concentration falls within the regulations.

When analysing the SLR parameter, it was found that it does not affect the fraction eliminated by the primary settler, in which the removal of pollutants is done by adsorption on the surface of suspended solids [11]. In this case study on SDS chemical, the SimpleTreat model gives an estimate of the chemical concentration in the WWTP influent of 1.509 mg/L in the dissolved phase, that is, 99.28%. The presence of SDS in the liquid phase in the influent is expected, as its solubility in water classifies it as 'very soluble', as it is in the range >10,000 mg/L of the general classification [18]. Therefore, the elimination of SDS in the primary settler is predicted to be only 0.5 % for all SLR values considered. Also, the elimination in the secondary clarifier by surplus sludge is insignificant, resulting in the fact that the chemical elimination is done in the aeration tank by biodegradation in the liquid phase.

Table 3. Output values of the SimpleTreat model for different sludge loading rates

SLR (kg BOD/kg_{solids}· day)	$C_{SDS\ effluent}$ (mg/L)	Removal efficiency (%)
0.04	5.100 E–02	96.64
0.06	7.523 E–02	95.05
0.1	1.213 E–01	92.02
0.15	1.750 E–01	88.49
0.2	2.246 E–01	85.22
0.3	3.136 E–01	79.37
0.6	5.193 E–01	65.84

Figure 2 shows a graphical representation of the SDS removal efficiency vs. the sludge loading rate. It may be observed that as the SLR value increases, the removal efficiency decreases. At the default value of 0.1, the total elimination of SDS from wastewater is 92%.

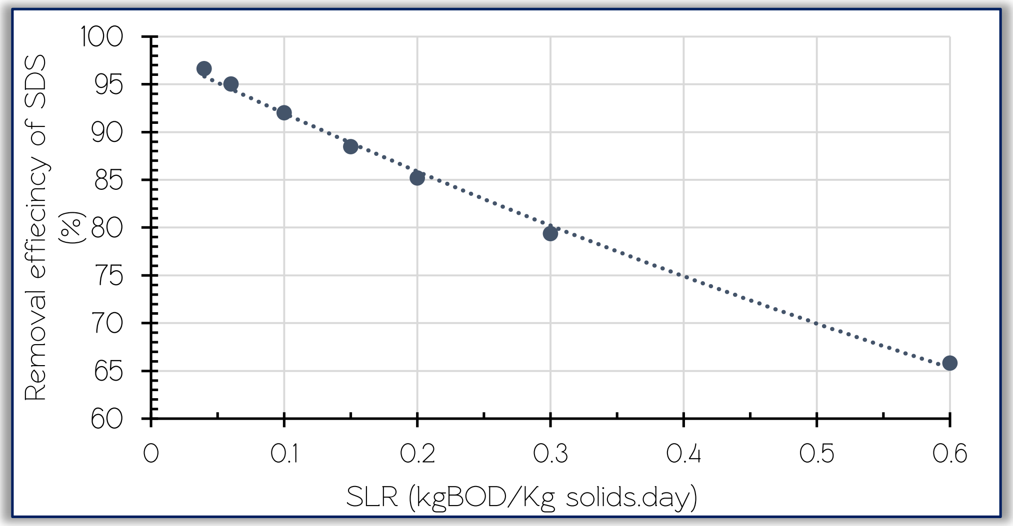


Figure 2. Estimated values of SDS removal efficiency vs. sludge loading rate

Experimental determinations of the removal efficiency of anionic surfactants from wastewater indicate percentages of up to 95 which is obtained in two of the five WWTPs studied [19]. In the presented case study, removal efficiencies above 95% are obtained for the SLR of 0.06 and 0.04 kg BOD/kg_{solids}·day.

4. CONCLUSIONS

The transport and fate of pollutants during WWTP processes should be studied in order to evaluate the environmental risk of contaminants or to evaluate and design depollution methods or those that prevent pollution [8]. Numerical models are reliable techniques through which custom cases may be analysed [7]. In the presented case study, the SimpleTreat model was used to estimate the concentration of sodium dodecyl sulfate (SDS) anionic surfactant in the effluent and calculate the removal efficiency of the modelled WWTP considering different sludge loading rates. The default value of SLR of 0.1 kg BOD/kg_{solids}·day resulted in a removal efficiency of 92.02 %. Taking into account the SLR values of 0.04 and 0.06 kg BOD/kg_{solids}·day, the model gave estimates of removal efficiencies above 95%. Surfactant elimination processes in WWTP can be improved by adding coagulants–flocculants or using adsorption techniques [20–22].

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