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Comparative assessment of influent wastewater organic fractions

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Abstract
Organic fractions assessment in influent wastewater is essential for designing the biological wastewater treatment plant. The characteristics of the influent organic load (readily biodegradable, biodegradable or inert) and form of distribution (soluble/suspended) may induce the design and operational parameters of primary settlers and biological treatment step. The current work presents the comparative assessment of organic fractions in three wastewater samples evaluated experimentally through three different fractionation methodologies, respectively modified ATV-A131 guidelines, IWA methodology and the Łomotowski-Szpindor methodology. The wastewater samples were collected from the influent of two municipal wastewater treatment plants. In all wastewater samples tested the biodegradable fractions, both soluble and suspended had the highest share in the total organic load. This is consistent with the biodegradable character of municipal influents and the suitability for organic and advanced nutrient removal through biological processes. The amount of non-biodegradable fractions SI and XI, varied from 18 to 54% of total organic load, on momentary grab samples of studied influents.

Keywords: *wastewater, fractions, organic load*

INTRODUCTION

Nowadays, many research efforts focus on delivering best wastewater treatment performances with lowest capital and operational costs either by optimization of existing treatment processes [1-3] either by developing alternative biological wastewater treatment technologies [4-6].

Microorganisms play an essential role in the biological treatment of wastewater and are responsible, for the removal of organic compounds and nutrients. In order to achieve high efficiencies through biological treatment, it is essential that the main pollutant constituents (organics, nitrogen and phosphorus compounds) are present in wastewater in assimilable forms that can be easily processed by microorganisms. Global analytical parameters such as biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) are usually used to assess the organic load of wastewaters. COD is a global indicator that provides information on the total organic load, while BOD_5 represents the total biodegradable organic fraction (both soluble and suspended). Either of these parameters does not provide specific data on the quantitative ratios between the fractions of readily biodegradable and non-biodegradable organic load. Their assessment is advised prior to choosing the wastewater treatment system, designing the treatment steps and defining of the operating conditions to ensure optimum biological processes conditions for organics and nutrients removal. Experimental organic load fractionation methodologies allow to quantify fractions depending on the state of organic load (soluble/suspended) and the specific behavior during biochemical degradation under the microbial activity of activated sludge [7-9]. Thus, the main outcome of organic load fractionation is the

specific ratio of easily and heavily biodegradables from the total organic load of the wastewater.
The fraction of heavily/non-biodegradable organics in wastewater is a key characteristic that directly influences the achievable treatment efficiencies of the biological treatment step in wastewater treatment plants. Therefore, when designing wastewater treatment systems or when modelling biological treatment processes for organic load removal, it is preferable to have detailed information on the specific characteristics of organic load fractions in raw wastewater for both soluble and suspended organics. This assessment also allows detailed subsequent evaluation of the nitrogen forms load in the studied wastewater influent. The constituent fractions of the total organic load are as follows: Ss – soluble readily biodegradable organic load, S_I - soluble inert organic load, X_S – suspended slowly biodegradable materials, X_I – suspended inert organic load, X_H – heterotrophic microorganisms, X_A – autotrophic microorganisms, X_P - decay products. For this study, the fractionation model is simplified by neglecting the biomass fractions.
The S_S fraction is usually biodegraded to mineralization by heterotrophic bacteria. This fraction offers information on the readily available sources of organic carbon in wastewater. The ratio of each organic fraction in influent wastewater is used to assess through mathematical modeling the kinetic parameters of the biodegradation process and define the operation parameters necessary for an efficient treatment. Even though the readily biodegradable fraction is a source of energy for the heterotrophic bacteria, the constituent organic compounds are subjected to complex biochemical transformation under the enzymatic system of the microorganisms before they can diffuse and be absorbed and used subsequently. The fraction of soluble readily biodegradable organics influences greatly the success of biological phosphorus removal and denitrification steps in specific operating conditions.
Similar to the soluble biodegradable fraction S_S, the X_S has a considerable influence on the activated sludge process being one of the main parameters used for designing biological systems for nutrients removal. The fraction of suspended slowly biodegradable organics is represented by compounds that are easily susceptible to be biodegraded by the complex extracellular enzymatic system of microorganisms and hydrolyzed into simple assimilable compounds [10]. This fraction offers valuable information on the potential dynamic behavior of the activated sludge biological process parameters including oxygen consumption. Part of this fraction can be removed through primary settling as primary sludge [10-12].
The fraction of soluble inert organics (S_I) is represented by the organic pollutants that do not undergo any changes during the wastewater treatment process and are discharged in the receiving waters once with the effluent. The S_I fraction offers valuable information on the potential suitability of one influent wastewater to be treated in a biological treatment system, If the ratio of S_I in wastewater is high, is advisable to use physical-chemical pre/treatment steps prior to any biological process [13]. Moreover, it should also be assessed weather the soluble inert organic fraction has an inhibitory/toxic effect for microbial activity.
Fraction X_I is composed of suspended inert particles [14]. This fraction is usually adsorbed/trapped in the activated sludge mass and accumulates in the bioreactor, thus influencing the efficiency of wastewater treatment and the quality of the effluent. The high concentration of fraction X_I can create difficulties in maintaining the age of the sludge with potential consequences on nitrification performances. It is considered that this fraction does not change under biological processes in any way and is discharged with the excess sludge [10,13]. The non-biodegradable fraction can be determined based on mass balance analysis, ie the product between the mass of influent and the sludge age parameter. We may say that a significant part of the sludge dry matter may consist of fraction X_I [13].
The current study focused on the comparative evaluation of organic fractions in three grab samples of raw wastewater from two wastewater treatment plants in order to assess the variability in composition and ratio regarding the soluble/suspended and easily biodegradable/non-biodegradable organic load in municipal wastewaters.

MATERIALS AND METHODS

The methodologies used to evaluate the organic load fractions were developed based on: the modified ATV-A131 guidelines [15], the methodology proposed by the IWA [16] and the Łomotowski-Szpindor methodology [17]. The modified ATV-A131 and the Łomotowski-Szpindor methodologies for the comparative assessment of S_S, S_I, X_S and X_I fractions involves the analytical determination of COD and BOD_5 in filtered and unfiltered samples of raw influent and treated wastewater. Each of the fractions were determined for wastewater samples collected from two wastewater treatment plants according to the methods presented below.

The methods used for evaluating the organic fractions differ considerably in complexity and and resources needed - as well in necessary lab work and time.

For the adapted ATV-A131 methodology inert soluble organic material is determined as residual soluble COD in filtered treated (0.45 μm) wastewater sample. Soluble readily biodegradable substrates are determined as the difference between the soluble COD in the influent (determined on the filtered sample) and the concentration of the non-biodegradable soluble fraction. The XS fraction is defined as the difference between the BOD5 of unfiltered influent wastewater to which the biochemical decomposition coefficient is applied (k1 = 0.6) and the soluble readily biodegradable substrates. The inert particulate organic material is calculated as the difference between the total concentration of organic suspensions and particulate slowly biodegradable substrates.

Łomotowski - Szpindor methodology provides the fastest results and relies on the following relations among the different organic fractions, COD and BOD 5 (rel. 1-4):

$$Si = COD\ b - 1.47\ BOD_{5b}, \quad (1)$$

where COD b and BOD5b are values obtained by analyzing filtered effluent samples

$$S_S = BOD_5 \quad (2)$$

where *BOD5* values are obtained by analyzing filtered influent wastewater sample

$$Xs = 0.47\ BOD5 \quad (3)$$

$$X_I = COD - 1.47\ BOD - S_I \quad (4)$$

According to the IWA Methodology soluble readily biodegradable fraction is calculated using relation (5):

$$S_S = (\Delta OUR * V) / (Q * (1 - Y_H)) \quad (5)$$

ΔOUR - variation of oxygen absorption rate at the end of feeding (ML-3T-1)
V - reactor volume (L3)
Q- influent flow (L3T-1)
Y_H - heterotrophic yield.

In order to determine the inert soluble organic fractions, small aliquots are periodically sampled, filtered and used for COD determination. COD values either decrease over time or remain constant. The last option appears if Ss is negligible, and the first if not. The final residual value of soluble COD is given by inert soluble organic compounds, equal to the concentration of the influent S_I. For this methodology inert particulate organic material is evaluated as fractionation calibration parameter, in accordance with Xs. According to the literature hypotheses [18,19], XI is initially assumed 50% of the suspensions COD, the value being adapted during the simulations. Xs is determined from equation (6)

$$COD = S_S + S_I + X_S + X_I + X_H \quad (6)$$

RESULTS AND DISCUSSION

The study was conducted for the municipal wastewater treatment plants of Focsani and Buftea. These are mechanical-biological treatment plants designed for enhanced biological nutrients removal (organic load, nitrogen and phosphorus removal).

The average values of the organic load indicators for the raw wastewater and the treated wastewater in the treatment plants are presented in Table 1. The results showed similar values of the organic load in the influent wastewater of the two treatment plants. For all wastewater samples tested, the

COD / BOD_5 ratio for raw unfiltered wastewater ranged from 1.7 to 3.2, demonstrating a moderate content of biodegradable organic loading. In the unfiltered treated effluent, COD values ranged from 35.2 g O_2/m^3 (Buftea) to 158 g O_2/m^3 (Focsani), while BOD_5 was less than 10 g O_2/m^3. The efficiency of global organic load removal, expressed as COD for the studied wastewater treatment plants varied from 65% (Focsani) and 92% (Buftea).

Table 1. Organic loadings in influent and treated wastewater

Raw wastewater

Wastewater treatment plant	COD [g O_2/m^3]		BOD_5 [g O_2/m^3]	
	homogenous	filtered	homogenous	filtered
Focsani	448.8	369.6	266.3	158.3
Buftea	457.6	158.4	194.5	39
Buftea	308	167.2	96.2	38.6

Treated wastewater

Wastewater treatment plant	COD [g O_2/m^3]		BOD_5 [g O_2/m^3]	
	homogenous	filtered	homogenous	filtered
Focsani	158.4	79.2	9.1	4.3
Buftea	35.2	26.4	7.45	5.56

The values of the specific organic load fractions in total COD for the studied samples, determined according to the adapted ATV-A131 methodology, the Łomotowski and Szpindor methodology and respectively the methodology proposed by IWA can be seen in table 2.

Table 2. Organic fractions loadings in influent and treated wastewater

Wastewater treatment plant	X_S [g O_2/m^3]	X_I [g O_2/m^3]	S_S [g O_2/m^3]	S_I [g O_2/m^3]	Fractions sum - % of the total COD
Adapted ATV-A131 methodology					
Focsani	153.43	0	290.4	79.2	133
Buftea 10	192.17	107.03	132	26.4	100
Buftea 11	19.53	121.27	140.8	26.4	100
Łomotowski and Szpindor methodology					
Focsani	125.16	0	266.3	72.88	107
Buftea 10	91.42	153.46	194.5	18.23	100
Buftea 11	45.21	148.36	96.2	18.23	100
IWA methodology					
Focsani	139.2	39.6	200	70	100
Buftea	198.57	149.6	39.42	17.8	88

The results show that the SS fraction, constitute the largest fraction of the Focsani wastewater samples, inert soluble organic material having values between 18% (Focsani) and 4% (Buftea).

According to the results obtained with the adapted ATV-A131 methodology for Focsani wastewater, the soluble biodegradable fraction is predominant, representing approximately 65% of the total influent organic load, this being followed by the biodegradable suspensions fraction. For Buftea wastewater the results for the biodegradable fraction have values between 52 and 71%, while the lowest values were obtained for to the soluble inert fraction SI. For this wastewater, the considerable differences in characteristics of the organic load fractions can be attributed to the sampling strategy - two momentary samples were analyzed, which further highlights the quality parameters variability in the wastewater treatment plant influent.

The results obtained according to the methodology proposed by Łomotowski and Szpindor are presented in Table 4. From the calculations performed resulted that the largest share of organics is represented by soluble biodegradable fraction biodegradable suspended organics, SS + XS fractions, in all tested wastewaters. For Focsani treatment plant, the influent has a cumulative value of the two fractions representing 87% of the total influent organic load. The SI - non-biodegradable soluble fraction has values of 16% for the influent of Focsani treatment plant and 4 to 6% for Buftea.

The level of difficulty in determining the component fractions of the organic load is similar for the adapted ATV-A131and Łomotowski and Szpindor methodologies and the resulting values are comparable, the error determined by reporting the fractions sum to the total influent COD is lower for the second methodology.

The values calculated according to the adapted methodology for the biodegradable COD fraction (XS + SS) varied between 339 g O_2 / m^3 and 443 g O_2 / m^3 for the Focsani treatment plant and 141 g O_2 / m^3 and 324 g O_2 / m^3 for Buftea wastewater treatment plant influent wastewater. The inert fractions (X_I + S_I) varied between 18 and 25% for the wastewater from Focsani treatment plant and 29 and 54% for the samples form Buftea wastewater treatment plant.

CONCLUSIONS

Currently, there is no unanimously accepted methodology for determining the characteristics of organic fractions in wastewater. As demonstrated, the results obtained by different experimental methodologies may vary considerably. Usually, especially for municipal wastewater, average data on fractions ratios from literature are used, but this estimation method leads sometimes to errors. In all wastewater samples tested, the biodegradable fractions SS or XS had the highest share in the total organic load. This translates in a confirmation of the possibility of organics removal through biological processes. For the non-biodegradable fractions SI and XI, the values obtained were in accordance with those found in literature and are specific to a municipal type wastewater.

Based on the results obtained, the differences between the sum of fractions and the total organic load, as well as the complexity of fractions evaluation methodologies, the Łomotowski - Szpindor fractionation method resulted as being the optimal for the studied cases and samples.

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