Prediction of self-diffusion coefficients of ions from various livestock antibiotics in water at infinite dilution

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Abstract. The development of antibiotic-resistant bacteria due to the existence and fate of Pharmaceutically Active Compounds (PHAC) used to treat bacterial diseases in humans as well as veterinary medicine to prevent disease in animals such as poultry, cattle, swine, and fish during animal food production and as growth promoters like antibiotics entering the environment turned out to be a problem when not removed in a normal wastewater treatment plant as it has increased effects on the disturbance of the natural bacterial ecosystem, presence of it in the effluent of sewage treatment plants as well as to surface and groundwater, and concerns for human health. Fate and transport of particles is an important matter that describe their physical form and behavior in different media with primary concern of determining the transport speed and combined effects of the chemicals in their discharge environments. In order to predict the fate and transport in the environment, one important parameter that indicates how individual molecules and ions move through a medium under a concentration gradient at a certain pressure and temperature is the diffusion coefficient. In relation to the previously published work on diffusion coefficient of various livestock antibiotics at infinite dilution, the present work extended the calculation to determine the self-diffusion coefficient of constituent ions from the studied antibiotics using the Nernst-Einstein Equation. Other parameters such as activation energy, pre-exponential factor, and hydrodynamic radius needed in describing the infinite dilution diffusion behavior were also calculated using Arrhenius-type equation and Stokes-Einstein Equation, respectively. The results may provide an adequate understanding of the mobility and behavior of these constituent ions from these livestock antibiotics when present in environmental water system, which may be of help for future studies for the removal of these antibiotics which can lead to the microbial resistance bacteria.

1. Introduction

According to Cunningham et al [1], the existence and fate of Pharmaceutically Active Compounds (PHAC) entering the environment turned out to be a problem as it has increased impacts on the disruption of the natural bacterial ecosystem and concerns for human health. Antibiotics for example, are among the frequently prescribed drugs used in modern medicine to treat bacterial diseases in humans as well as veterinary medicine to prevent disease in animals such as poultry, cattle, swine, and fish during animal food production and as growth promoters. The manufacturing process, disposal of unused antibiotics, manure, and non-metabolized antibiotics excreted by the user largely attributes to its presence in sewage system and in ground water. In therapeutic doses, 25% to 75% of the drug is excreted unchanged in urine [2]. Often, these compounds are not commonly removed in a normal wastewater treatment plant because they are not equipped to detect or remove these drugs from...
wastewater. In such cases, antibiotics may further be exposed to the effluent of sewage water treatment plants as well as to surface and groundwater, which can eventually enter the drinking water supply. Ultimately, the presence of these antibiotics in municipal sewage waters and aquatic environment spreads to the microbial communities, which then results to the development of antibiotic-resistant bacteria leading to a serious threat to human health.

One important physiochemical property called diffusion coefficient specifies how individual molecules, ions, or metabolites transport through a medium under a concentration gradient at a certain pressure and temperature must be taken into consideration to properly detect, evaluate, and remediate the risk, the effects, and the potential effects of these antibiotics in the aquatic environment [3-5]. Thus, in relation to the previously published work on diffusion coefficient of various livestock antibiotics at infinite dilution [6], the present work extended the calculation to find out the self-diffusion coefficient of constituent ions from the studied antibiotics using the Nernst-Einstein Equation. Other parameters (such as activation energy, pre-exponential factor, and hydrodynamic radius) needed in describing the infinite dilution diffusion behavior were also calculated.

2. Computational section

From the measured electrolytic conductivity (κ) data obtained from the previous work [6], the calculated molar conductivity data were presented in table 1. In the previous work, the diffusion coefficients of various livestock antibiotics in water at infinite dilution were estimated using the Nernst-Haskell, as in equation (1),

\[
D_{AB}^o = \frac{RT}{F^2} \frac{|z_+| + |z_-|}{|z| |z|} \frac{A_+^o A_-^o}{A_+^o + A_-^o}
\]

where \(D_{AB}^o\) is the diffusion coefficient of the solute, or in this case the antibiotics (A), in water (B) at infinite dilution in m²/s, \(R\) is the universal gas constant in J/mol·K, \(T\) is the absolute temperature in K, and \(F\) is Faraday’s constant. Other parameters in the equation are \(z_+\) and \(z_-\) which designate the charge numbers of the cation and anion, respectively, and \(A_+^o\) and \(A_-^o\) are the molar conductivities of the cation and anion in m²/mol, respectively, at infinite dilution.

| Table 1. Calculated molar conductivities (\(\Lambda\)) at infinite dilution of the various livestock antibiotics at different concentrations and temperatures. |
| --- |
| **Amtyl (amoxicillin + tylosin): [H⁺][AMT]** |
| **C** / (kmol/m³) | 0.0002 | 0.0005 | 0.0008 | 0.0011 | 0.0014 |
| **T / K** | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 |
| \(\Lambda^o / (S·m²/mol)\) | 0.966595 | 1.075675 | 1.168950 | 1.274455 | 1.375390 |
| **Ciproyl (ciprofloxacin): [H⁺][CIP]** |
| **C** / (kmol/m³) | 0.0002 | 0.0005 | 0.0008 | 0.0011 | 0.0014 |
| **T / K** | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 |
| \(\Lambda^o / (S·m²/mol)\) | 0.901360 | 1.075675 | 1.168950 | 1.274455 | 1.375390 |
| **Doxylak Forte (doxycycline tiamulin hydrogen fumarate): [H⁺][DOX]** |
| **C** / (kmol/m³) | 0.0002 | 0.0005 | 0.0008 | 0.0011 | 0.0014 |
| **T / K** | 293.15 | 298.15 | 303.15 | 308.15 | 313.15 |
| \(\Lambda^o / (S·m²/mol)\) | 0.901360 | 1.075675 | 1.168950 | 1.274455 | 1.375390 |
The ions of interest were then correlated using the Nernst-Einstein shown in equation (2) from which the calculated molar conductivity, $\Lambda$, at infinite dilution as shown in table 1 was utilized,

$$D_{\text{ion}}^o = \frac{RTA_{\text{ion}}^o}{|z_{\text{ion}}|^2F^2}$$

where $D_{\text{ion}}^o$ is the self-diffusion coefficient of the ion at infinite dilution in m$^2$/s, $A_{\text{ion}}^o$ designates the infinite dilution molar conductivity of the ion, and $z_{\text{ion}}$ is the charge number of the ion.

In order to observe the behavior of the molar conductivity as a function of concentration, an equation to model the relationship of the two was used. Robinson and Stokes (RS) Equation shown in equation (3) is the common model utilized. The molar conductivity data obtained experimentally are fitted in the model to determine the infinite dilution conductivities. As the researchers fitted the experimental data, the overall average absolute deviation (AAD) shows an average value of 18.52 % which is unacceptable, thus, a new correlation is needed. With this, the RS Equation was modified as shown in equation (4). The modified RS Equation correlated well the present data as shown by an overall average absolute deviation (OAAD) of 5.59 %. The comparison of the calculation results using the original and modified RS Equation is presented in table 2.

$$\Lambda = A^o + (\alpha_1 A^o + \alpha_2)C^{1/2}$$

$$\Lambda = A^o + \alpha_1 C^{1/2} + \alpha_2 \left(C^{1/2}\right)^2$$

In equations (3) and (4), $A^o$ is molar conductivity at infinite dilution and $\alpha_i$ are the determined empirical parameters.

| $T$/K | $A$/ (S·m$^2$/mol) |
|-------|---------------------|
| 293.15 | 1.076675 0.575818 0.432256 0.363294 0.319227 |
| 298.15 | 1.185760 0.632498 0.474816 0.398695 0.352866 |
| 303.15 | 1.287190 0.681224 0.514444 0.433445 0.379006 |
| 308.15 | 1.384540 0.738104 0.558148 0.465971 0.413881 |
| 313.15 | 1.493625 0.789892 0.599689 0.505078 0.442279 |

| $T$/K | $A$/ (S·m$^2$/mol) |
|-------|---------------------|
| 293.15 | 0.885050 0.423390 0.309735 0.258010 0.225453 |
| 298.15 | 0.981900 0.473688 0.342193 0.286804 0.253267 |
| 303.15 | 1.067025 0.514260 0.375704 0.313465 0.277076 |
| 308.15 | 1.164375 0.563130 0.412363 0.341608 0.303215 |
| 313.15 | 1.257150 0.608394 0.448898 0.373433 0.330448 |

Trisullak (contramazine): $[\text{H}^+][\text{TRI}^-]$

| $C$/ (kmol/m$^3$) | 0.0002 | 0.0005 | 0.0008 | 0.0011 | 0.0014 |
|-------------------|--------|--------|--------|--------|--------|

| $T$/K | $A$/ (S·m$^2$/mol) |
|-------|---------------------|
| 293.15 | 0.885050 0.423390 0.309735 0.258010 0.225453 |
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| 313.15 | 1.257150 0.608394 0.448898 0.373433 0.330448 |

Vetracin Gold (doxycycline tiamulin vitamin A + B12): $[\text{H}^+][\text{VET}^-]$

| $C$/ (kmol/m$^3$) | 0.0002 | 0.0005 | 0.0008 | 0.0011 | 0.0014 |
|-------------------|--------|--------|--------|--------|--------|

| $T$/K | $A$/ (S·m$^2$/mol) |
|-------|---------------------|
| 293.15 | 1.076675 0.575818 0.432256 0.363294 0.319227 |
| 298.15 | 1.185760 0.632498 0.474816 0.398695 0.352866 |
| 303.15 | 1.287190 0.681224 0.514444 0.433445 0.379006 |
| 308.15 | 1.384540 0.738104 0.558148 0.465971 0.413881 |
| 313.15 | 1.493625 0.789892 0.599689 0.505078 0.442279 |

$\Lambda$ is molar conductivity at infinite dilution and $\alpha_i$ are the determined empirical parameters.
positive and negative ions migrate without interionic forces in a low concentration [7,8]. Since these ions are assumed to be migrating independently of each other, the total molar conductivity can be calculated by the addition of the cation and the anions as shown in equation (5),

$$A^o = z_+A^o_+ + z_-A^o_-$$

The present work focuses on infinite dilution of antibiotic ions. Using the equation shown in equation (5), the infinite dilution molar conductivities of the anion and cation can be predicted. These positive and negative ions migrate without interionic forces in a low concentration [7,8]. Since these ions are assumed to be migrating independently of each other, the total molar conductivity can be calculated by the addition of the cation and the anions as shown in equation (5),

$$A^o = z_+A^o_+ + z_-A^o_-$$
To evaluate some important parameters pertaining to migration of ions, the molar conductivity of ions, determined using equation (5), was represented by an Arrhenius-type equation, which represents the activated process and is temperature dependent as shown in equation (6),

$$\Lambda_{ion}^o = Ae^{-E_a/RT}$$

(6)

where \( A \) is the pre-exponential factor and \( E_a \) is the activation energy of the ion migrating.

In addition, the effective hydrodynamic radius or Stokes radius is calculated from the diffusion coefficient using the Stokes-Einstein Equation as represented in equation (7). The effective hydrodynamic radius is a measured radius of a hypothetical hard sphere that diffuses at the same rate as the solute particle under examination.

$$D_{ion}^o = \frac{kT}{6\pi\mu BR_s}$$

(7)

where \( k \) is the Boltzmann constant, \( T \) is the absolute temperature, \( \mu \) is the viscosity of solvent (water), and \( r_s \) is the effective hydrodynamic radius.

3. Results and discussion

In using the Nernst-Einstein Equation in the determination of the self-diffusion coefficient of the ion at infinite dilution of the considered systems, the evaluation of the infinite dilution molar conductivity of the ion is the most essential component. Using equation (5), the infinite dilution molar conductivities of the considered ions were evaluated and are presented in table 3. The infinite dilution conductivities of the individual anions namely: [AMT\(^-\)], [CIP\(^-\)], [DOX\(^-\)], [TRI\(^-\)], and [VET\(^-\)], were observed to have a close or almost similar values with each other. The molecular structures of antibiotics are all complex. They similarly show that the independent movement of the negatively charged ions gives a conductivity ranging from 2.0 to 3.2 S·m\(^2\)/mol.

Table 3. Infinite dilution conductivities of the individual ions (\(\Lambda_{ion}^o\)) at different temperatures.

| T / K  | [AMT\(^-\)] | [CIP\(^-\)] | [DOX\(^-\)] | [TRI\(^-\)] | [VET\(^-\)] | [H\(^+\)] |
|--------|-------------|-------------|-------------|-------------|-------------|-----------|
| 293.15 | 2.1806      | 2.0754      | 2.3505      | 2.0634      | 2.2538      | 0.032695  |
| 298.15 | 2.3843      | 2.2774      | 2.5599      | 2.2572      | 2.4566      | 0.034928  |
| 303.15 | 2.5995      | 2.4915      | 2.7801      | 2.4620      | 2.6700      | 0.037232  |
| 308.15 | 2.8261      | 2.7176      | 3.0111      | 2.6777      | 2.8942      | 0.039606  |
| 313.15 | 3.0643      | 2.9562      | 3.2531      | 2.9046      | 3.1291      | 0.042049  |

\(^{\text{f}}\)Data obtained from Apelblat & Bešter-Rogač, 2015 [9].

Table 4. Parameters of Equation (6)\(^{\text{f}}\) for the ions under study.

| Ions   | \(A\) (S·m\(^2\)/mol) | \(10^4 E_a\) (J/mol) | AAD |
|--------|------------------------|-----------------------|-----|
| [AMT\(^-\)] | 448.80                | -1.2983               | 0.4662 |
| [CIP\(^-\)] | 527.66                | -1.3498               | 0.6244 |
| [DOX\(^-\)] | 380.96                | -1.2401               | 0.5166 |
| [TRI\(^-\)] | 436.16                | -1.3048               | 0.4735 |
| [VET\(^-\)] | 383.89                | -1.2522               | 0.4483 |
| [H\(^+\)] | 1.69                  | -9.6019               | 0.2980 |

\(^{\text{f}}\)\(\Lambda_{ion}^o = Ae^{-E_a/RT}\)

The temperature dependency of the infinite dilution conductivities of the ions was correlated by the Arrhenius-type equation shown in equation (6). Table 4 presented the calculations using equation (6).
With an overall AAD of 0.47 %, equation (6) satisfactorily correlated the temperature dependence of the infinite dilution conductivities of the ions. In terms of the activation energy, $E_a$, for the individual ions, $H^+$ has the lowest activation energy and $DOX^{-1}$ has the highest in the order: $H^+ > CIP^{-1} > TRI^{-1} > AMT^{-1} > VET^{-1} > DOX^{-1}$. The low value of the activation energy of $VET^{-1}$ and $DOX^{-1}$ indicates high mobility of ions in the sample. This, in turn, can be associated with the high conductivity data obtained.

Table 5. Calculated self-diffusion coefficients and hydrodynamic radius of the studied antibiotics.

| $T / K$ | $10^9 D_{AB}^{0}$ (Nernst-Haskell Equation) | $10^9 D_{[\text{cation}]}^{0}$ (Nernst-Einstein Equation) | $10^{-8} r_{5}$ (m) (Stokes-Einstein Equation) | $10^9 D_{[\text{anion}]}^{0}$ (Nernst-Einstein Equation) | $10^{-8} r_{5}$ (m) (Stokes-Einstein Equation) |
|--------|-------------------------------------------|--------------------------------------------------|---------------------------------|-------------------------------------------------|---------------------------------|
| 293.15 | 0.084332                                  | 0.085597                                         | 2.472170                        | 5.708840                                        | 3.706944                        |
| 298.15 | 0.091660                                  | 0.093002                                         | 2.619460                        | 6.348777                                        | 3.837121                        |
| 303.15 | 0.099377                                  | 0.100801                                         | 2.742043                        | 7.037693                                        | 3.927419                        |
| 308.15 | 0.107490                                  | 0.108997                                         | 2.863353                        | 7.777408                                        | 4.012859                        |
| 313.15 | 0.116004                                  | 0.117596                                         | 2.969510                        | 8.569706                                        | 4.074851                        |
|        | **Ciproltyl (ciprofloxacin):** $[H^+]$ $[CIP^{-1}]$ |                                             |                                 |                                                 |                                 |
| 293.15 | 0.084269                                  | 0.085597                                         | 2.472170                        | 5.433613                                        | 3.894448                        |
| 298.15 | 0.091598                                  | 0.093002                                         | 2.619460                        | 6.064148                                        | 4.017317                        |
| 303.15 | 0.099316                                  | 0.100801                                         | 2.742043                        | 6.745251                                        | 4.097693                        |
| 308.15 | 0.107431                                  | 0.108997                                         | 2.863353                        | 7.478983                                        | 4.172980                        |
| 313.15 | 0.115947                                  | 0.117596                                         | 2.969510                        | 8.263700                                        | 4.223868                        |
|        | **Doxylak Forte (doxycycline tiamulin hydrogen fumarate):** $[H^+]$ $[DOX^{-1}]$ |                                             |                                 |                                                 |                                 |
| 293.15 | 0.084422                                  | 0.085597                                         | 2.472170                        | 6.153753                                        | 3.438702                        |
| 298.15 | 0.091751                                  | 0.093002                                         | 2.619460                        | 6.816195                                        | 3.574077                        |
| 303.15 | 0.099469                                  | 0.100801                                         | 2.742043                        | 7.526610                                        | 3.673200                        |
| 308.15 | 0.107582                                  | 0.108997                                         | 2.863353                        | 8.286588                                        | 3.766284                        |
| 313.15 | 0.116095                                  | 0.117596                                         | 2.969510                        | 9.097677                                        | 3.838373                        |
|        | **Trisullak (contramazine):** $[H^+]$ $[TRI^{-1}]$ |                                             |                                 |                                                 |                                 |
| 293.15 | 0.084261                                  | 0.085597                                         | 2.472170                        | 5.402113                                        | 3.917156                        |
| 298.15 | 0.091585                                  | 0.093002                                         | 2.619460                        | 6.010353                                        | 4.053273                        |
| 303.15 | 0.099299                                  | 0.100801                                         | 2.742043                        | 6.665426                                        | 4.146767                        |
| 308.15 | 0.107408                                  | 0.108997                                         | 2.863353                        | 7.369094                                        | 4.235208                        |
| 313.15 | 0.115918                                  | 0.117596                                         | 2.969510                        | 8.123083                                        | 4.298895                        |
|        | **Vetracin Gold (doxycycline tiamulin vitamin A + B12):** $[H^+]$ $[VET^{-1}]$ |                                             |                                 |                                                 |                                 |
| 293.15 | 0.084373                                  | 0.085597                                         | 2.472170                        | 5.900502                                        | 3.586292                        |
| 298.15 | 0.091699                                  | 0.093002                                         | 2.619460                        | 6.541133                                        | 3.724370                        |
| 303.15 | 0.099414                                  | 0.100801                                         | 2.742043                        | 7.228705                                        | 3.823641                        |
| 308.15 | 0.107525                                  | 0.108997                                         | 2.863353                        | 7.964813                                        | 3.918441                        |
| 313.15 | 0.116037                                  | 0.117596                                         | 2.969510                        | 8.751012                                        | 3.990428                        |

Table 5 was taken from the previous work of Soriano et al 2017 [6].

Using the Nernst-Einstein Equation shown in equation (2), the infinite dilution self-diffusion coefficient of the ions from various antibiotics was evaluated. Nernst-Einstein Equation relates the molar conductivity of an electrolyte to the diffusion coefficients of its constituent ions. Such equation further illustrates that when ions dissociate and move independently within the system, they diffuse at a unique rate. Correlated values for self-diffusion coefficients of the studied ions are presented in table 5 along with the diffusion coefficients of the studied livestock antibiotics in water at infinite dilution. Figure 1 graphically shows these values. As seen in this figure, temperature increase causes rise in the

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![Image of Figure 1](image_url)
diffusion coefficient of the ions. This may indicate that at high temperatures, ions move faster as vibrational energy is increased and ionic migration is at its highest.

Figure 1. Infinite dilution self-diffusion coefficients ($D_{\text{ion}}^0$) as function of temperature: ▲, [AMT$^-$]; ○, [CIP$^-$]; ●, [DOX$^-$]; □, [TRI$^-$]; ■, [VET$^-$]; and lines, guide for the eyes.

Figure 2. Infinite dilution self-diffusion coefficients at 298.15 K: hollow shapes represents self-diffusion of anions, ▲, [AMT$^-$]; ○, [CIP$^-$]; ●, [DOX$^-$]; □, [TRI$^-$]; ■, [VET$^-$]; solid shapes represents self-diffusion of cation H$^+$; and the dotted lines are guide for the eyes.

The self-diffusion coefficients of the anions and the cation were representatively ($T = 298.1$ K) compared through graphical representation as shown in figure 2. As shown in this figure, the anion [DOX$^-$] has the highest mobility in water based on diffusion coefficients, with the least being [TRI$^-$]. Same trend applies for all the other considered temperatures for this study. It was shown that [DOX$^-$] travels the longest in the solution. The observation was consistent with the expected behavior with consideration to its ionic radius (as seen in table 5) since it has the smallest radius amongst the five
antibiotics. The least hydrodynamic radii have the largest mobility [10].

The Stokes-Einstein Equation [11], as presented in equation (7), is a model which associates the self-diffusion coefficients as a function of the solvent’s viscosity. Using this equation, the effective hydrodynamic radius or Stokes radius of small molecules in dilute aqueous solution can be determined. Some researchers stated that the diffusion of the solvent governs the linear relationship between the diffusion of the ions [12,13]. The hydrodynamic radius obtained from the diffusional properties of the particle is indicative of the apparent size of the dynamic hydrated particle [14]. The equation also indicates that the ratio of diffusion coefficient of the solvent to the diffusion coefficient of ion is a measure of hydrodynamic diameter.

Figure 3. Determined ratios of Stokes radii of the investigated ions at 298.15 K: hollow shapes represent $R_{\text{cation}}$ values relative to the solvent of the cation, H$^+$; and solid shapes {▲, [AMT$^-$]; ●, [CIP$^-$]; ▼, [DOX$^-$]; ■, [TRI$^-$]; ◆, [VET$^-$]} represent $R_{\text{anion}}$ values relative to the solvent; and the dotted lines are guide for the eyes.

Figure 3 shows the ratio of the solvent diffusion coefficient ($D_B^0$) to those of the ($D_{\text{cation}}^0$) and anion ($D_{\text{anion}}^0$) at a representative temperature of 298.15 K. It is shown from the trend that the ratio of diffusion coefficient and the ratio of hydrodynamic radius remain constant. The trend formed from all the temperature under study is similar to the representative temperature. This ratio is represented as $R_{\text{cation}} = D_B^0/D_{\text{cation}}^0$ for the hydrogen cation and $R_{\text{anion}} = D_B^0/D_{\text{anion}}^0$ for the antibiotic anion.

Figure 4 represents the variation of hydrodynamic radii and the diffusion coefficient of antibiotic anions under this study. It is further understood that the relationship between these parameters are isotherms depicted by the inverse relationship in the graph. Such relationship of inverse proportionality is found in the Stokes-Einstein Equation for hydrodynamic radius.
Figure 4. Self-diffusion coefficients of antibiotics anions at infinite dilution as function of hydrodynamic radius at different temperatures: △, [AMT\textsuperscript{-}]; ●, [CIP\textsuperscript{-}]; ◀, [DOX\textsuperscript{-}]; □, [TRI\textsuperscript{-}]; ●, [VET\textsuperscript{-}] and dotted lines are guide for the eyes.

4. Conclusion
The fate and transport of antibiotics infiltrating the aquatic environment has raised many threats regarding the possible effects of antibiotic-resistant bacteria. While limited information is available for the detection, evaluation, and remediation of these antibiotics in the aquatic environment, the physical form, behavior in different media, transport speed, and combined effects of these Pharmaceutically Active Compounds (PHAC) are needed to be determined. The prediction of the transport property, significantly the estimation of diffusion coefficients of antibiotics was illustrated in this study through a simple, yet a well-established method involving the electrolytic conductivity. Models and correlations available were utilized in order to calculate and correlate the measurable data to parameters that might help describe the infinite dilution behavior of these antibiotics in water. The results may provide an adequate understanding of the mobility and behavior of these constituent ions from these livestock antibiotics when present in environmental water system, which may be of help for future studies for the removal of these antibiotics which can lead to the microbial resistance bacteria.

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References
[1] Cunningham V L, Binks S P and Olson M J 2009 Regul. Toxicol. Pharmacol. 53 39-45
[2] Boxall A B 2004 EMBO Rep. 5 1110-6
[3] Segura P A, García-Ac A, Lajeunesse A, Ghosh D, Gagnon C and Sauvé S 2007 J. Environ. Monit. 9 307-13
[4] Sczechowski J G 1997 ENVE 436: Fate and Transport (Retrieved: 1 February 2016 from http://ceenve3.civeng.calpoly.edu/cota/env436/fate.html)
[5] Atkins P and De Paula J 2011 Physical Chemistry for the Life Sciences (USA: Oxford University Press)
[6] Soriano A N, Adamos K G, Bonifacio P B, Adornado A P, Bungay V C and Vairavan R 2017 EDP sciences EPJ Web of Conferences 162 01083
[7] Soriano A N, Agapito A M, Lagumbay L J L I, Caparanga A R and Li M-H 2011 *J. Taiwan Inst. Chem. Eng.* **42** 258-64
[8] Soriano A N, Entrolizo R V, Era C M A, San Diego J S H and Li M-H 2014 *P.I.Ch.E. J.* **15** 54-63
[9] Apelblat A and Bešter-Rogač M 2015 *J. Mol. Liq.* **211** 417-24
[10] Grimes C A and Mor G K 2009 *TiO$_2$ Nanotube Arrays: Synthesis, Properties, and Applications* (Springer Science & Business Media)
[11] Robinson R A and Stokes R H 2002 *Electrolyte Solutions* (Courier Corporation)
[12] Hayamizu K, Aihara Y, Arai S and Martinez C G 1999 *J. Phys. Chem. B* **103** 519-24
[13] Hayamizu K, Aihara Y, Nakagawa H, Nukuda T and Price W S 2004 *J. Phys. Chem. B* **108** 19527-32
[14] Malvern Instruments 2017 *Dynamic Light Scattering* (Retrieved: 16 January 2017 from [www.imbb.forth.gr/people.aeconomou/pdf/hydrodynamic_radius.pdf](www.imbb.forth.gr/people.aeconomou/pdf/hydrodynamic_radius.pdf))