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Electronic Supplementary Information

Improved Extraction of Fluoroquinolones with Recyclable Ionic-Liquid-based Aqueous Biphasic Systems

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Experimental Section

Phase Diagrams and Tie-Lines

The composition of each phase in equilibrium was determined using the following four equations (eqs. (1) – (4)) and four unknown values ($[IL]_{IL}$, $[IL]_{salt}$, $[salt]_{IL}$, $[salt]_{salt}$): [1]

$$[IL]_{IL} = A\,exp[\left(B \times [salt]_{IL}^{0.5}\right) - \left(C \times [salt]_{IL}^{3}\right)] \quad (1)$$

$$[IL]_{salt} = A\,exp[\left(B \times [salt]_{salt}^{0.5}\right) - \left(C \times [salt]_{salt}^{3}\right)] \quad (2)$$

$$[IL]_{IL} = \frac{[IL]_M}{\alpha} - \frac{1-\alpha}{\alpha} \times [IL]_{salt} \quad (3)$$

$$[salt]_{IL} = \frac{[salt]_M}{\alpha} - \frac{1-\alpha}{\alpha} \times [salt]_{salt} \quad (4)$$

where IL, salt and M are the IL-rich phase, the salt-rich phase and the mixture, respectively. [IL] and [salt] correspond to the weight fraction percentage of IL and salt, respectively, and α is the ratio between the mass of the IL-rich phase and the total mass of the mixture.

For the calculation of each tie-line length (TLL), the following equation was applied:

$$TLL = \sqrt{([salt]_{IL} - [salt]_{salt})^2 + ([IL]_{IL} - [IL]_{salt})^2} \quad (5)$$

Table S.I. 1. Weight fraction percentage (wt %) of each compound at the coexisting phases of the ABS investigated.

	Weight fraction percentage / wt (%)					
Ionic Liquid	**$[IL]_{salt}$**	**$[salt]_{salt}$**	**$[IL]_{M}$**	**$[salt]_{M}$**	**$[IL]_{IL}$**	**$[salt]_{IL}$**
$[C_2C_1im][CF_3SO_3]$	3.29	40.36	41.94	15.03	63.02	1.21
$[C_4C_1im][CF_3SO_3]$	4.81	22.99	29.24	14.94	73.10	0.49
$[C_4C_1im][Tos]$	0.07	49.95	42.09	14.96	54.48	4.64
$[P_{4441}][CH_3SO_4]$	1.24	41.60	40.21	14.97	58.85	2.16
$[P_{i(444)1}][Tos]$	0.08	37.05	37.95	15.02	58.12	3.29
$[P_{4444}]Br$	0.88	31.98	35.91	15.05	63.55	1.68
$[P_{4444}]Cl$	0.33	46.09	39.91	15.02	55.34	2.91

Table S.I. 2. Tie-line length (TLL), pH of the IL-rich phase (pH_{IL}), and extraction efficiencies of the six studied fluoroquinolones (%EE_{FQs}), and corresponding standard deviations (σ).

Ciprofloxacin				***Norfloxacin***			
Ionic Liquid	**TLL ± σ**	**pH_{IL} ± σ**	**% EE_{FQs} ± σ**	**Ionic Liquid**	**TLL ± σ**	**pH_{IL} ± σ**	**% EE_{FQs} ± σ**
$[C_2C_1im][CF_3SO_3]$	72.4 ± 0.1	2.78 ± 0.01	95.13 ± 0.33	$[C_2C_1im][CF_3SO_3]$	71.4 ± 0.0	2.95 ± 0.01	91.70 ± 0.40
$[C_4C_1im][CF_3SO_3]$	72.4 ± 0.4	2.15 ± 0.01	37.29 ± 0.84	$[C_4C_1im][CF_3SO_3]$	72.6 ± 0.1	2.73 ± 0.01	27.61 ± 0.97
$[C_4C_1im][Tos]$	70.5 ± 0.4	2.72 ± 0.01	87.79 ± 0.49	$[C_4C_1im][Tos]$	70.9 ± 0.1	3.09 ± 0.02	88.23 ± 1.24
$[P_{4441}][CH_3SO_4]$	69.7 ± 0.1	1.71 ± 0.03	36.26 ± 1.49	$[P_{4441}][CH_3SO_4]$	66.5 ± 0.2	3.13 ± 0.02	28.45 ± 3.59
$[P_{i\,(444)1}][Tos]$	66.4 ± 0.1	1.47 ± 0.05	92.85 ± 1.37	$[P_{i\,(444)1}][Tos]$	67.5 ± 0.0	2.66 ± 0.02	84.26 ± 0.75
$[P_{4444}]Br$	67.6 ± 0.0	1.16 ± 0.04	52.62 ± 0.56	$[P_{4444}]Br$	70.6 ± 0.4	1.30 ± 0.03	44.56 ± 2.42
$[P_{4444}]Cl$	70.4 ± 0.1	2.74 ± 0.04	48.26 ± 2.03	$[P_{4444}]Cl$	70.2 ± 0.1	2.88 ± 0.07	37.07 ± 3.35
Enrofloxacin				***Ofloxacin***			
Ionic Liquid	**TLL ± σ**	**pH_{IL} ± σ**	**% EE_{FQs} ± σ**	**Ionic Liquid**	**TLL ± σ**	**pH_{IL} ± σ**	**% EE_{FQs} ± σ**
$[C_2C_1im][CF_3SO_3]$	71.4 ± 0.2	2.95 ± 0.01	95.87 ± 0.35	$[C_2C_1im][CF_3SO_3]$	71.7 ± 0.0	2.92 ± 0.01	91.18 ± 0.50
$[C_4C_1im][CF_3SO_3]$	71.9 ± 0.9	2.73 ± 0.01	57.16 ± 0.37	$[C_4C_1im][CF_3SO_3]$	73.9 ± 2.0	2.70 ± 0.02	34.94 ± 1.43
$[C_4C_1im][Tos]$	70.8 ± 0.1	3.11 ± 0.01	97.18 ± 0.74	$[C_4C_1im][Tos]$	70.9 ± 0.2	3.14 ± 0.08	88.85 ± 1.73
$[P_{4441}][CH_3SO_4]$	69.9 ± 0.4	3.10 ± 0.03	44.83 ± 3.45	$[P_{4441}][CH_3SO_4]$	69.8 ± 0.1	3.08 ± 0.03	35.04 ± 7.07
$[P_{i\,(444)1}][Tos]$	67.1 ± 0.1	2.73 ± 0.06	92.70 ± 0.85	$[P_{i\,(444)1}][Tos]$	67.4 ± 0.3	2.70 ± 0.02	83.19 ± 0.47
$[P_{4444}]Br$	69.6 ± 0.8	1.37 ± 0.04	63.74 ± 0.78	$[P_{4444}]Br$	70.0 ± 0.5	1.39 ± 0.01	43.46 ± 4.24
$[P_{4444}]Cl$	70.0 ± 0.0	2.84 ± 0.05	51.74 ± 2.10	$[P_{4444}]Cl$	70.2 ± 0.2	2.87 ± 0.02	31.08 ± 2.50
Moxifloxacin				***Sarafloxacin***			
Ionic Liquid	**TLL ± σ**	**pH_{IL} ± σ**	**% EE_{FQs} ± σ**	**Ionic Liquid**	**TLL ± σ**	**pH_{IL} ± σ**	**% EE_{FQs} ± σ**
$[C_2C_1im][CF_3SO_3]$	71.7 ± 0.6	2.95 ± 0.01	97.05 ± 0.45	$[C_2C_1im][CF_3SO_3]$	71.7 ± 0.4	2.95 ± 0.01	97.76 ± 0.51
$[C_4C_1im][CF_3SO_3]$	71.0 ± 1.4	2.72 ± 0.01	67.49 ± 0.63	$[C_4C_1im][CF_3SO_3]$	72.8 ± 1.8	2.70 ± 0.01	61.37 ± 2.15
$[C_4C_1im][Tos]$	70.0 ± 1.3	3.14 ± 0.04	96.42 ± 0.46	$[C_4C_1im][Tos]$	71.0 ± 0.1	3.12 ± 0.03	97.39 ± 2.07
$[P_{4441}][CH_3SO_4]$	69.3 ± 0.6	3.13 ± 0.02	61.74 ± 0.71	$[P_{4441}][CH_3SO_4]$	69.5 ± 0.2	3.15 ± 0.04	68.91 ± 0.79
$[P_{i\,(444)1}][Tos]$	67.2 ± 0.1	2.70 ± 0.05	95.86 ± 0.19	$[P_{i\,(444)1}][Tos]$	67.3 ± 0.3	2.69 ± 0.02	96.41 ± 0.30
$[P_{4444}]Br$	69.5 ± 0.4	1.39 ± 0.04	75.92 ± 2.73	$[P_{4444}]Br$	69.6 ± 0.0	1.34 ± 0.03	82.79 ± 2.59
$[P_{4444}]Cl$	70.1 ± 0.0	2.87 ± 0.03	81.74 ± 0.96	$[P_{4444}]Cl$	70.1 ± 0.0	2.88 ± 0.02	77.53 ± 1.82

Table S.I. 3. Comparison of the extraction efficiencies of six studied fluoroquinolones (%EE_{FQs}), and corresponding standard deviations (σ), from separate samples and one mixture sample, using $[C_2C_1im][CF_3SO_3]$ + $Al_2(SO_4)_3$ ABS.

	% EE_{FQs} ± σ	
Fluoroquinolones	**Separate sample**	**Mixture sample**
Ciprofloxacin	95.1 ± 0.3	94.9 ± 0.3
Norfloxacin	91.7 ± 0.4	92.9 ± 0.2
Ofloxacin	91.2 ± 0.5	91.3 ± 0.7
Enrofloxacin	95.9 ± 0.4	95.1 ± 0.7
Sarafloxacin	97.8 ± 0.5	96.9 ± 0.9
Moxifloxacin	97.1 ± 0.5	97.5 ± 0.7

Table S.I. 4. Extraction efficiencies of three studied fluoroquinolones (%EE_{FQs}), and corresponding standard deviations (σ) using phosphonium-based hydrophobic ILs.

	% EE_{FQs} ± σ		
IL	**Ciprofloxacin**	**Norfloxacin**	**Ofloxacin**
$[P_{666(14)}]Br$	60.2 ± 6.5	46.1 ± 3.4	28.0 ± 5.1
$[P_{666(14)}]Cl$	60.2 ± 1.1	68.6 ± 1.9	54.7 ± 5.6
$[P_{666(14)}][NTf_2]$	49.1 ± 3.8	29.7 ± 1.5	20.8 ± 1.7

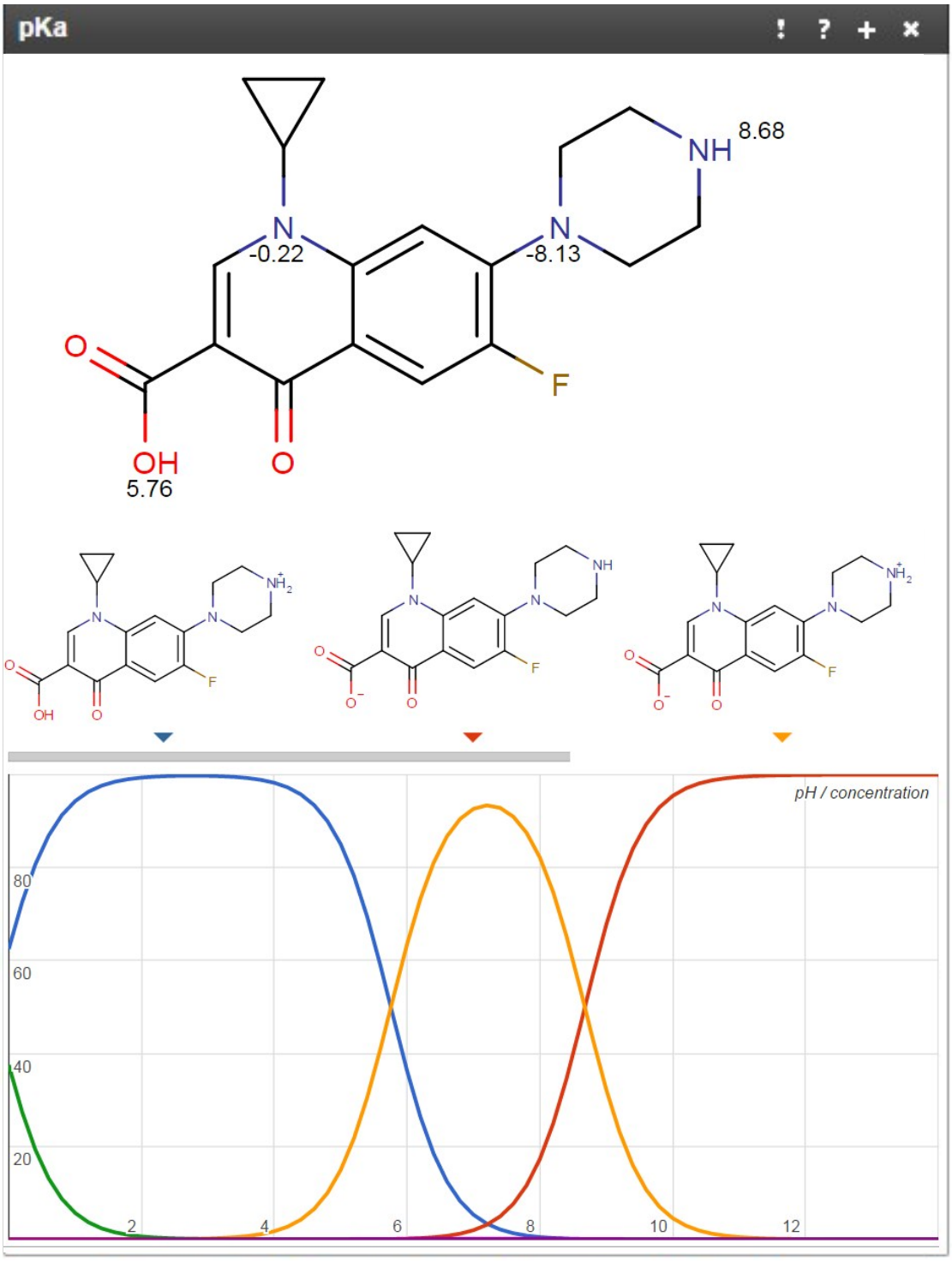

Figure S.I. 1. Acid dissociation constant of ciprofloxacin. [2]

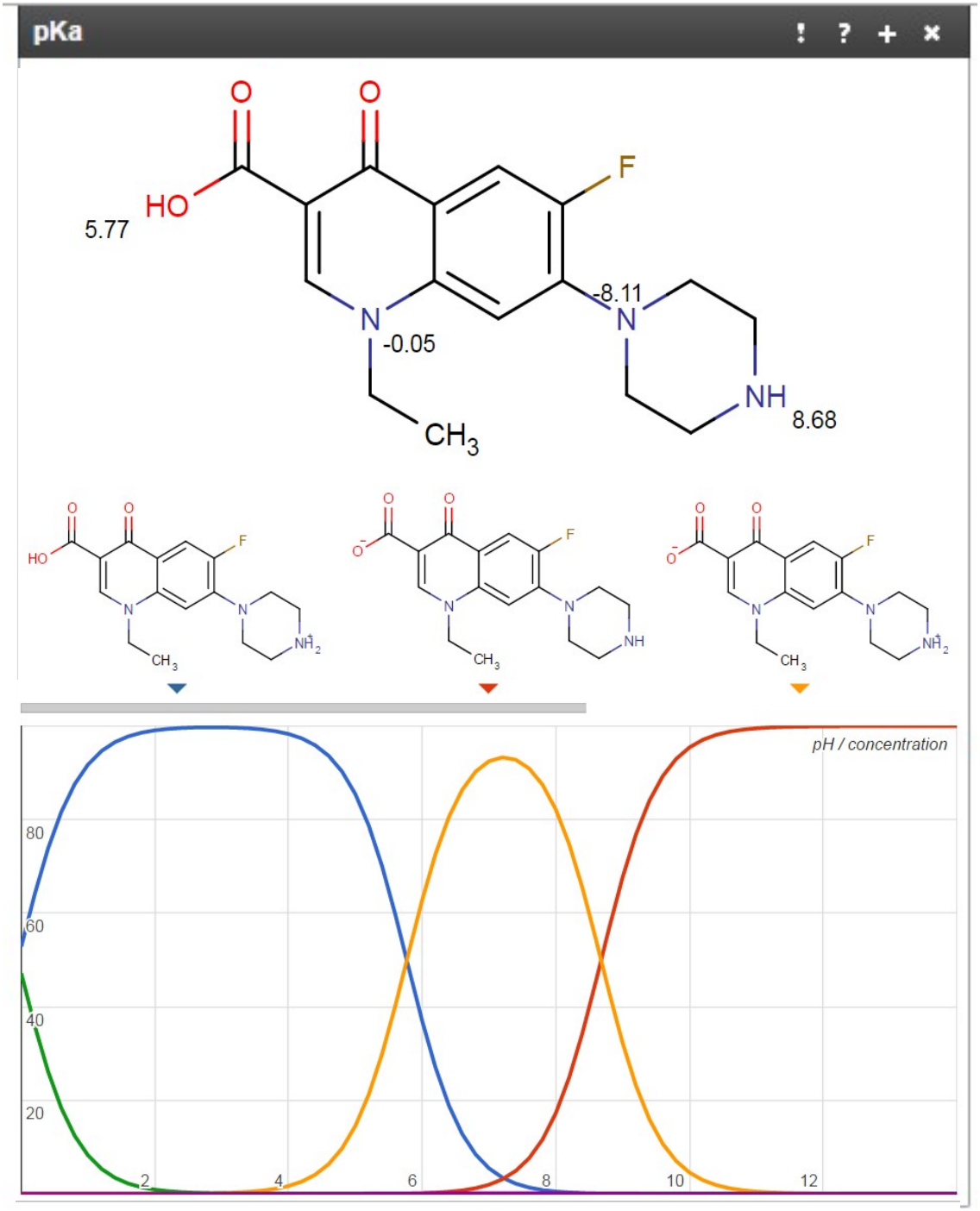

Figure S.I. 2. Acid dissociation constant of norfloxacin. [2]

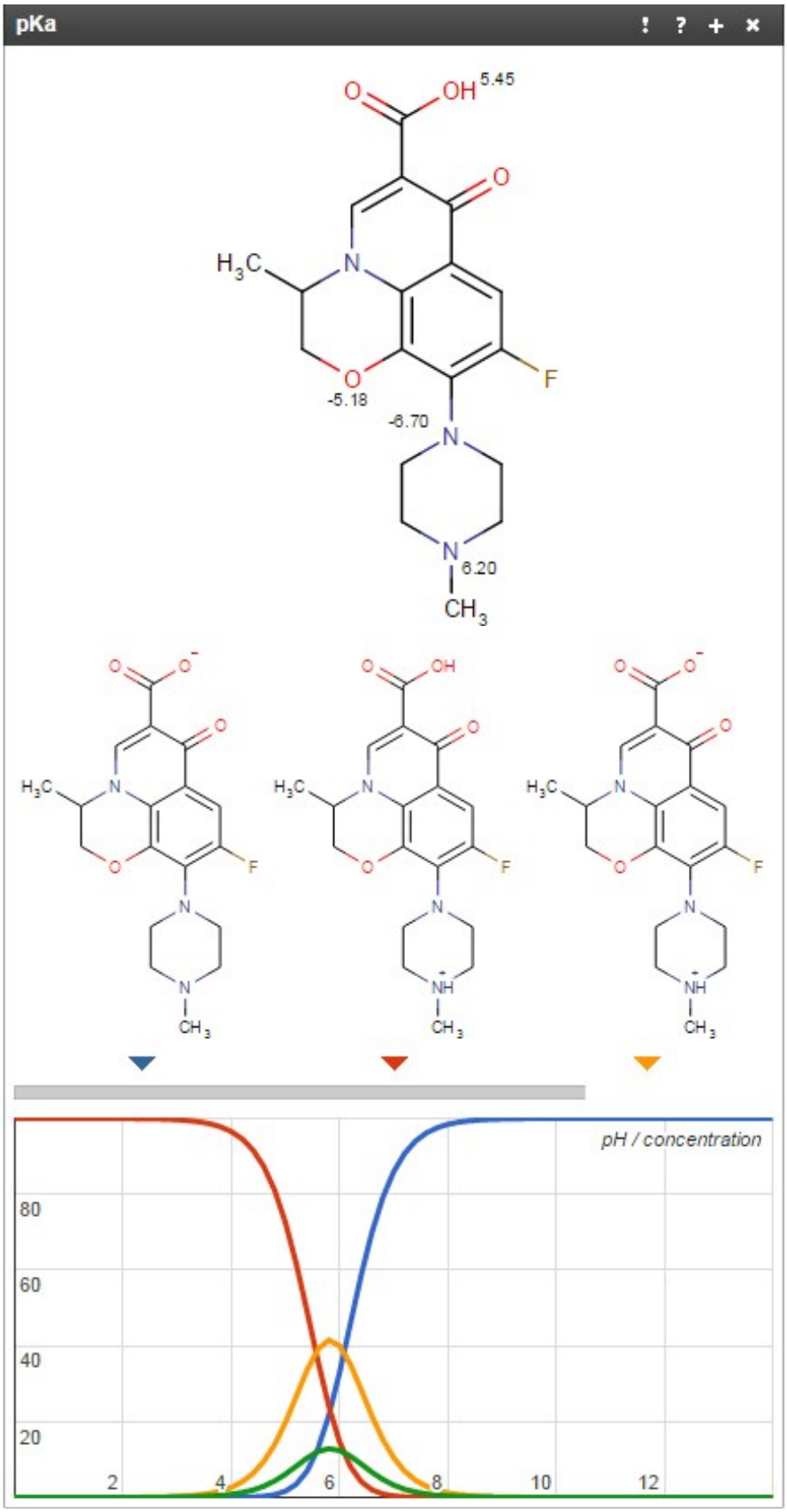

Figure S.I. 3. Acid dissociation constant of ofloxacin. [2]

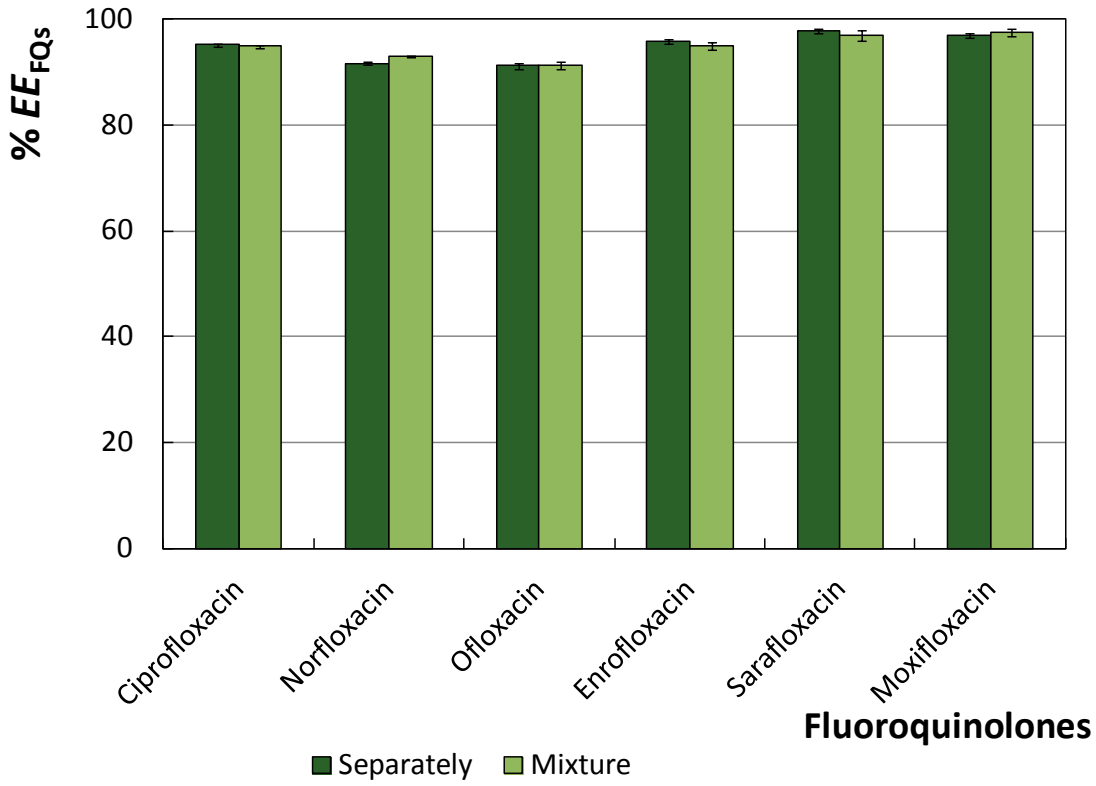

Figure S.I. 4. Extraction efficiencies of six studied fluoroquinolones (%EE_{FQs}) from separate samples and one mixture sample, using $[C_2C_1im][CF_3SO_3]$ + $Al_2(SO_4)_3$ ABS.

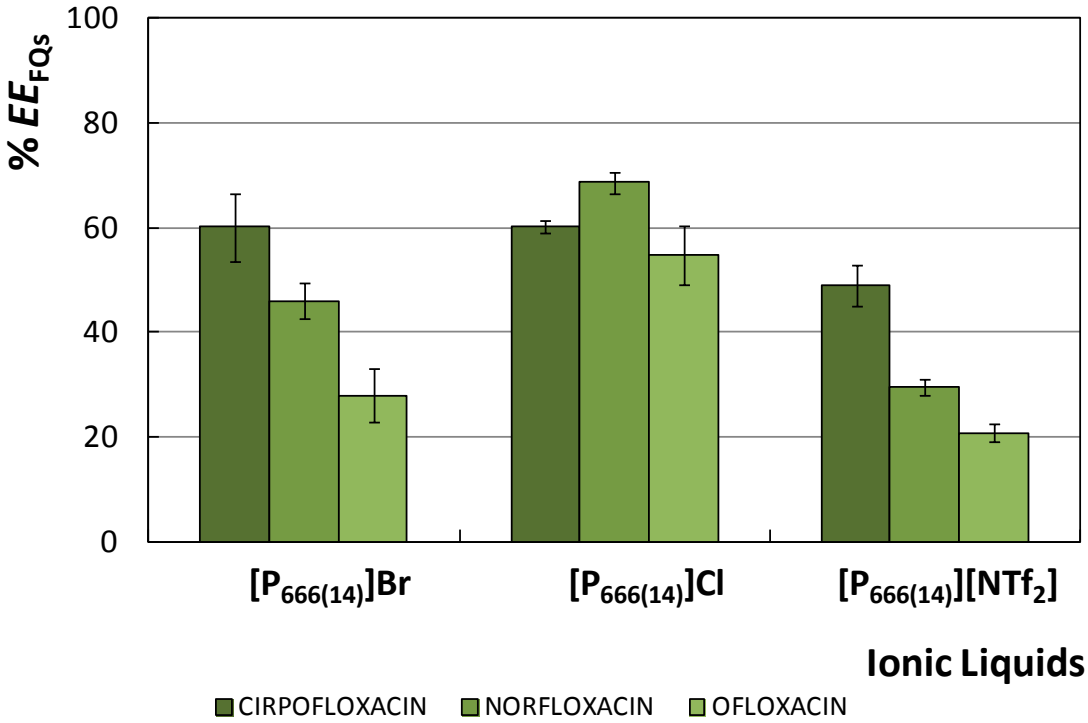

Figure S.I. 5. Extraction efficiencies of FQs (% EE_{FQs}) using hydrophobic phosphonium-based ILs, at 25 ºC..

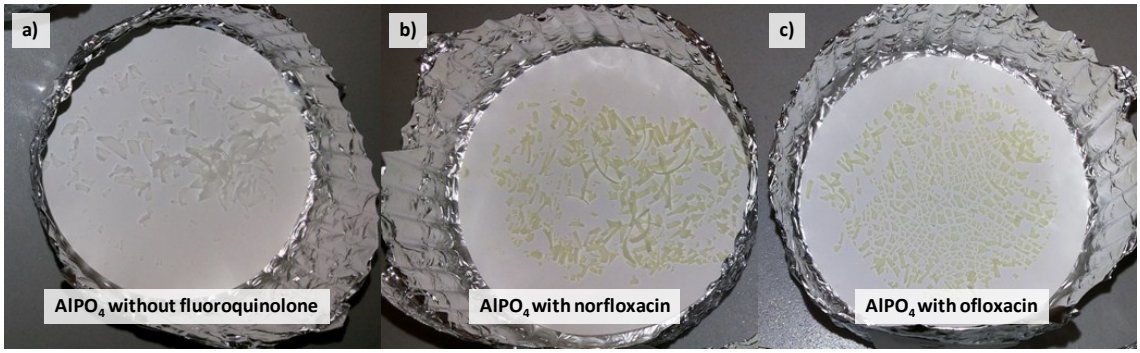

Figure S.I. 6. Precipitates obtained through the addition of K_3PO_4 to: a) an aqueous solution of $Al_2(SO_4)_3$ without fluoroquinolone; b) an aqueous solution of $Al_2(SO_4)_3$ and norfloxacin; and c) an aqueous solution of $Al_2(SO_4)_3$ and ofloxacin.

References

1. J. C. Merchuk, B. A. Andrews and J. A. Asenjo, *Journal of Chromatography B: Biomedical Sciences and Applications* 1998, **711**, 285-293.
2. in *ChemSpider - The free chemical database at www.chemspider.com. (Accessed on October 2015)*, *Vol.*