Supporting Information

The Perspective of Cooperative Hydrotropy on the Solubility in Aqueous Solutions of Cyrene

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S1. Cyrene Acidity

De bruyn et al.[1] reported the pH of water-Cyrene mixtures in a narrow composition range, from pure water to around 30 wt% of Cyrene. This data, complemented with data measured in this work for the full composition range of the water-Cyrene system, is depicted in Figure S1. Since a pH of 2.5 corresponds to a hydronium ion concentration of around 3 mM, the concentration of dissociated diol is much smaller than the concentration of protonated diol in the system. The pH was measured using a Mettler Toledo U402-M3- S7/200 micro electrode. The instrument was previously calibrated with a standard solution in the pH range of 4.0, 7.0 and 9.0. The readings were performed in triplicate at a temperature of (300.2 ± 0.5) K.
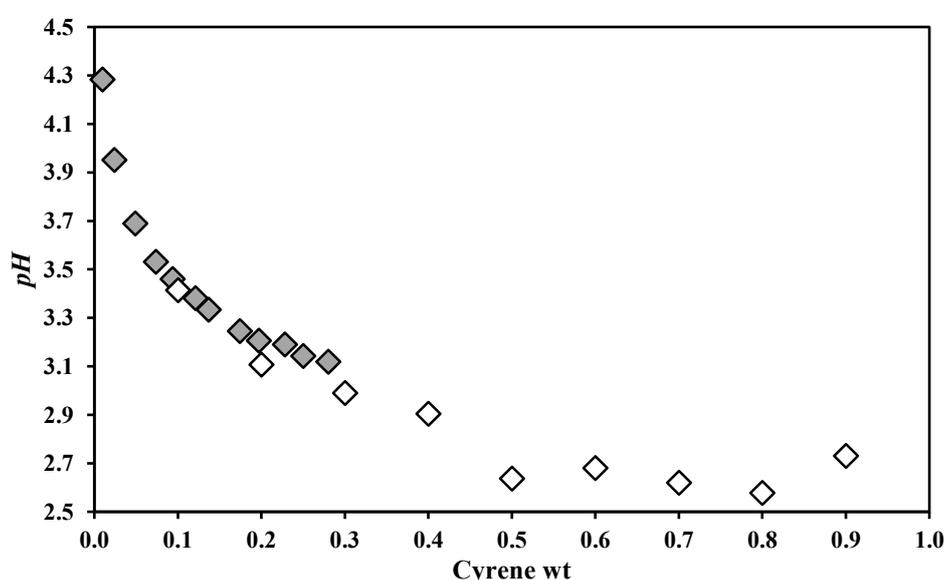

Figure S1. *Acidity of water-Cyrene mixtures in terms of the pH of the mixture as a function of the mass fraction of pure Cyrene added to water (◇ De bruyn et al.[1]; ◇ This work).*

To test if acidifying a water-Cyrene mixture changes its chemical equilibrium (which would be problematic when studying the solubility of acidic solutes), the ultraviolet absorbance spectrum of water-Cyrene mixtures, in the concentration range from 0 to 15 wt% of Cyrene, was measured in this work. All spectra were acquired using 1 mm quartz cells in a SHIMADZU UV-1700, Pharma-Spec spectrometer, in the wavelength range 220-350 nm, with 1 nm step intervals.

The UV spectra data is reported in Figure S2 (left) and reveals the existence of a double peak around a wavelength (λ) of 260 nm. The absorbance of this peak, namely at a wavelength of 261 nm, is proportional to the concentration of Cyrene, as shown if Figure S2 (right). Figure 3 depicts the same Spectra with the additional spectrum of a 10 wt% water-Cyrene mixture buffered at a pH value of one, using HCl.
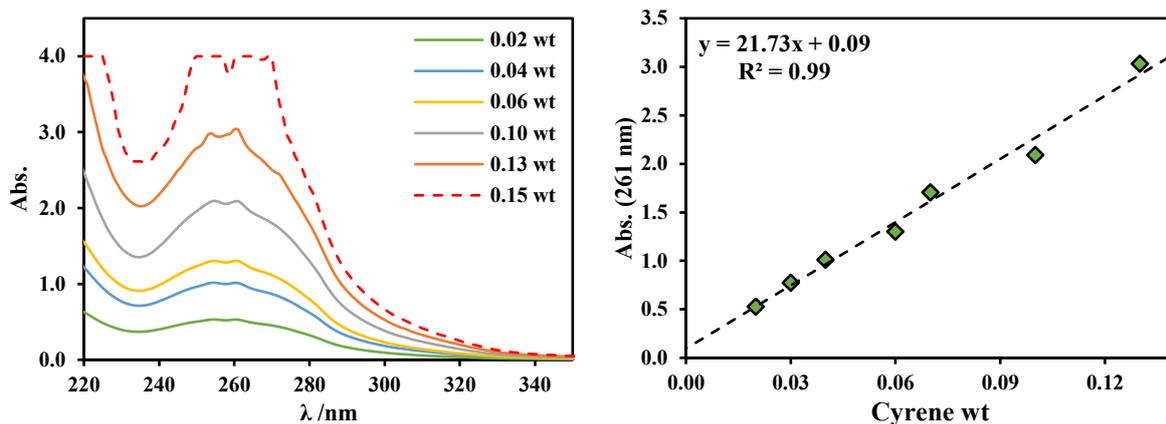
Figure S2. *UV spectra of water-Cyrene mixtures in the Cyrene concentration range 0-15 wt% (left) and absorvance of water-Cyrene mixtures at a wavelength (λ) of 261 nm as a function of Cyrene concentration (right). The dashed line (right) is the line fitted to the data using the least squares method (coefficient of determination is 0.99).*
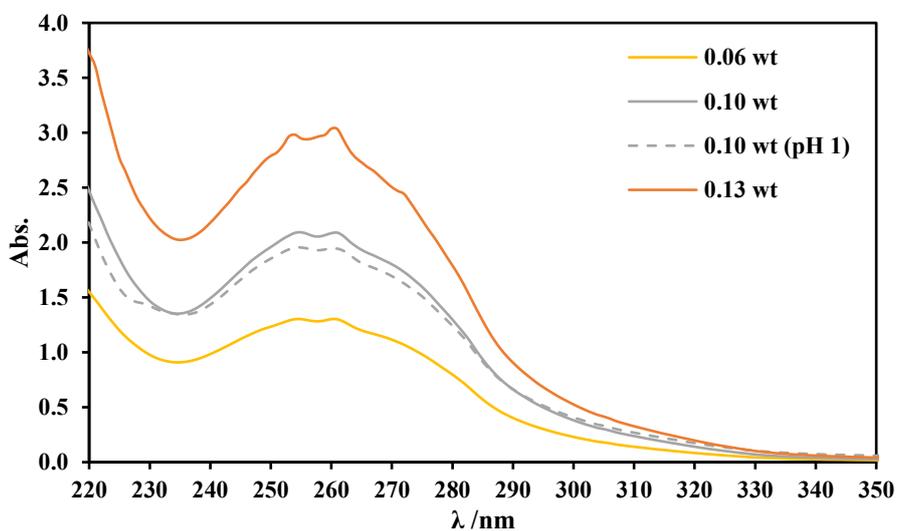

Figure S3. *UV spectra of water-Cyrene mixtures in the Cyrene concentration range 6-13 wt% along with the UV spectrum of a water-Cyrene mixture buffered at a pH of 1 with HCl, showing the negligible influence of pH in the chemical equilibrium of Cyrene in water.*

S2. Water-Cyrene System Composition

De bruyn et al.[2] reported the molar concentration of water (C_w) and of the ketone (C_{C_1}) and diol (C_{C_2}) forms of Cyrene for the entire composition range of the water-Cyrene system. From this data, the mole fractions of the individual components are calculated using:

$$x_i = \frac{C_i}{C_w + C_{C_1} + C_{C_2}} \tag{S1}$$

where x_i is the mole fraction of component i (w, C_1 or C_2) and C_i its molar concentration.

The mole percentage of each form of Cyrene ($Mole_i$ %) is defined as:

$$Mole_i \% = \frac{x_i}{x_{C_1} + x_{C_2}} \tag{S2}$$

The total mole fraction of Cyrene ($x_{Total\ Cyrene}$) is defined as:

$$x_{Total\ Cyrene} = x_{C_1} + x_{C_2} \tag{S3}$$

Similar to Equation S1, mass fractions of the individual components are calculated using:

$$w_i = \frac{C_i \cdot M_i}{C_w \cdot M_w + C_{C_1} \cdot M_{C_1} + C_{C_2} \cdot M_{C_2}} \tag{S4}$$

where w_i is the mole fraction of component i, M_i its molar mass, and M_w, M_{C_1} and M_{C_2} are the molar masses of water, and the ketone and the diol forms of Cyrene, respectively. To avoid ambiguity, the original mass fraction of Cyrene (w_{OC}) is defined as:

$$w_{OC} = \frac{m_{Cyrene}}{m_{Cyrene} + m_w} \tag{S5}$$

where m_{Cyrene} and m_w are the masses of **<u>pure</u>** Cyrene and pure water used to prepare a given water-Cyrene mixture.

Due to the difficulty of assigning an equilibrium constant to the water-Cyrene system, the mass fraction of the individual components in the final system (after equilibrium is achieved) was fitted against the original mass fraction of Cyrene. The resulting fitting is depicted in Figure S4 and the expressions are:

$$w_{C_1} = 1.6228 \cdot w_{OC}^6 - 9.6663 \cdot w_{OC}^5 + 16.4868 \cdot w_{OC}^4 - 9.6440 \cdot w_{OC}^3 + 2.3399 \cdot w_{OC}^2 - 0.1432 \cdot w_{OC} + 0.0017 \tag{S6}$$

$$w_{C_2} = -1.6668 \cdot w_{OC}^6 + 10.4154 \cdot w_{OC}^5 - 18.0321 \cdot w_{OC}^4 + 10.5373 \cdot w_{OC}^3 - 2.5396 \cdot w_{OC}^2 + 1.2902 \cdot w_{OC} - 0.0019 \qquad \text{(S7)}$$

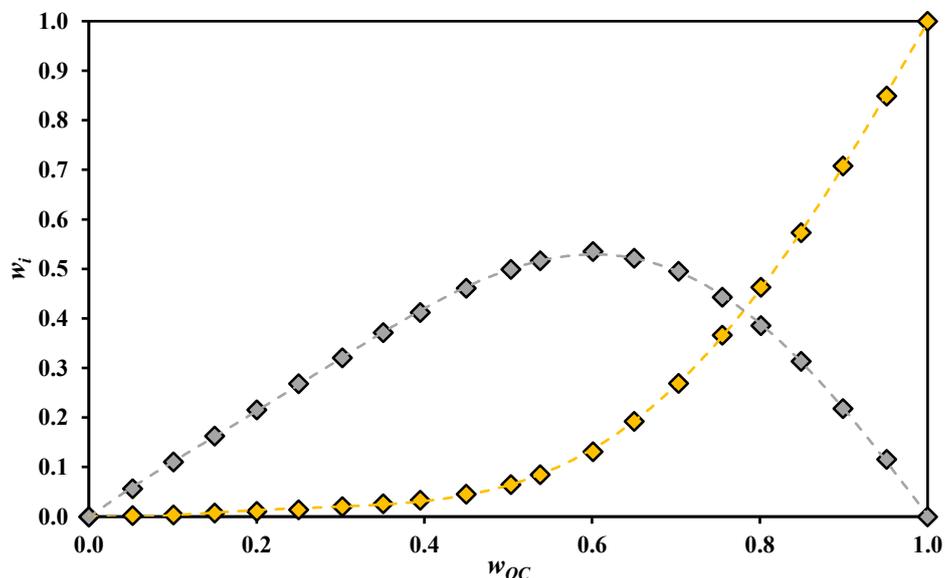where w_{OC} is an abbreviation of $w_{Original\ Cyrene}$.

Figure S4. *Composition of water-Cyrene mixtures: mass fraction of ketone form (◇) and diol form (◇) of Cyrene as a function of its original mass fraction calculated from the data reported by De bruyn et al.[2] and fitted with sixth degree polynomials (- - - for the ketone form and - - - for the diol form).*

The density of water-Cyrene mixtures (ρ), depicted in Figure S5, was calculated from the data reported by De bruyn et al.[2] using the following expression:

$$\rho\left(\frac{g}{mL}\right) = \frac{C_w \cdot M_w + C_{C_1} \cdot M_{C_1} + C_{C_2} \cdot M_{C_2}}{1000} \qquad \text{(S8)}$$

This data was then fitted using a third-degree polynomial:

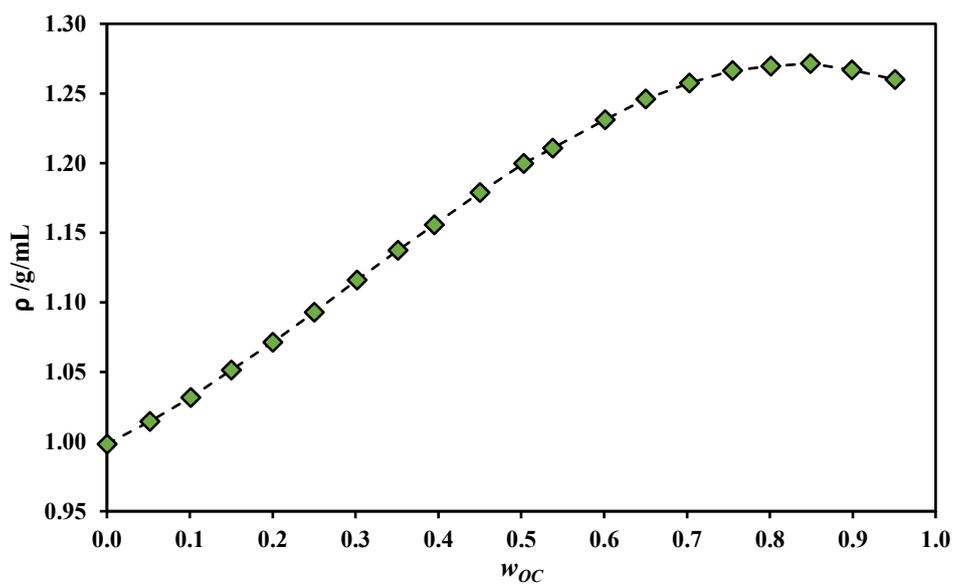$$\rho\left(\frac{g}{mL}\right) = -0.50550 \cdot w_{OC}^3 + 0.45749 \cdot w_{OC}^2 + 0.29735 \cdot w_{OC} + 0.99797 \qquad \text{(S9)}$$

Figure S5. *Density of water-Cyrene mixtures as a function of the original mass fraction of Cyrene. The dashed line is a visual aid.*

S3. Solubility in Water-Cyrene Mixtures

As explained in the main text, the presence of the solute, due to its low concentration, does not affect the equilibrium established between both forms of Cyrene. This is true also for acidic solutes. In the following calculations it is assumed that, due to the low concentration of the solute, the density of the final mixture is equal to that of the solvent. For any given hydrotropic mixture, using 1 L as the basis for calculations, the total mass (m_t) is given by:

$$m_t = 1000 \cdot \rho \tag{S10}$$

Note that ρ is calculated using Equation S9. The mass of each component (m_i) is calculated as follow:

$$m_S = S_S \cdot M_S \tag{S11}$$

$$m_w = (m_t - m_S) \cdot \left(1 - w_{C_1} - w_{C_2}\right) \tag{S12}$$

$$m_{C_1} = (m_t - m_S - m_w) \cdot \left(\frac{w_{C_1}}{w_{C_1} + w_{C_2}}\right) \tag{S13}$$

$$m_{C_2} = (m_t - m_S - m_w) \cdot \left(\frac{w_{C_2}}{w_{C_1} + w_{C_2}}\right) \tag{S14}$$

where m_i is the mass of component i (w for water, C_1 for the ketone form of Cyrene, C_2 for the diol form of Cyrene and S for the solute. Finally, the mole fraction of each component (x_i) is calculated using the following expression:

$$x_i = \frac{\frac{m_i}{M_i}}{\frac{m_w}{M_w} + \frac{m_{C_1}}{M_{C_1}} + \frac{m_{C_2}}{M_{C_2}} + \frac{m_S}{M_S}} \tag{S15}$$

where M_i is the molar mass of component i.

Note that the solubility data discussed in this work was measured at a temperature of either 293 K or 303 K, while De bruyn et al.[2] reported the composition of the water/Cyrene system at 298 K. Owing to the small temperature difference (5 K), the change in composition of the solvent is not significant, as also suggested from the analysis of the influence of temperature on the composition of water/Cyrene mixtures performed by De bruyn et al.[2]
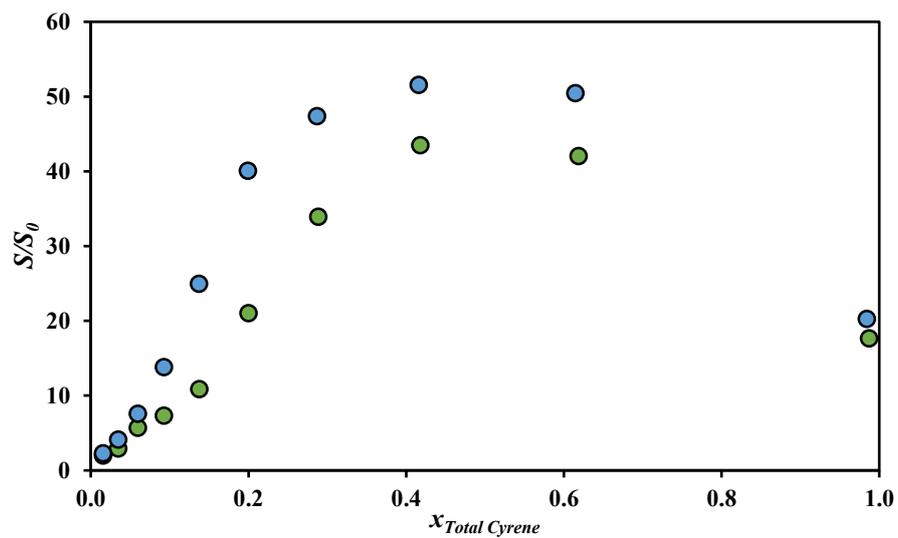
Figure S6. *Solubility of syringic acid in water-Cyrene mixtures at 20 ℃ (○) and at 30 ℃ (○)* herein experimentally measured (see Tables S2 and S3).

S4. Tables

Table S1. *Solubility of gallic acid monohydrate and vanillin in water-Cyrene mixtures at a temperature of (303.2 ± 0.5) K.*

	Gallic Acid			Vanillin	
wt% Cyrene	Solubility /M	s /M[a)]	wt% Cyrene	Solubility /M	s /M[a)]
0	0.074	0.002	0	0.086	0.003
10.02	0.136	0.003	10.02	0.164	0.005
20.04	0.276	0.007	20.04	0.325	0.006
30.02	0.44	0.01	30.02	0.647	0.008
40.02	0.62	0.01	40.02	1.62	0.01
50.01	0.77	0.01	50.01	2.18	0.01
60.04	0.81	0.01	60.04	2.64	0.02
70.03	0.87	0.01	70.03	3.18	0.02
80.02	0.806	0.008	80.02	3.38	0.03
90.01	0.679	0.006	90.01	3.33	0.03
100	0.44	0.02	100	2.68	0.03

a) standard uncertainty calculated from three data points.

Table S2. *Solubility of syringic acid and benzoic acid in water-Cyrene mixtures at a temperature of (293.2 ± 0.5) K.*

	Syringic Acid			Benzoic Acid	
wt% Cyrene	Solubility /M	s /M[a)]	wt% Cyrene	Solubility /M	s /M[a)]
0	0.0069	0.0004	0	0.0197	0.0004
10.02	0.0138	0.0002	10.02	0.050	0.003
20.04	0.0202	0.0009	20.04	0.070	0.001
30.02	0.0393	0.0003	30.02	0.137	0.002
40.02	0.0507	0.0004	40.02	0.19	0.03
50.01	0.075	0.001	50.01	0.312	0.002
60.04	0.145	0.005	60.04	0.526	0.005
70.03	0.234	0.007	70.03	0.891	0.001
80.02	0.30	0.01	80.02	1.21	0.04
90.01	0.29	0.02	90.01	1.34	0.04
100	0.122	0.009	100	0.83	0.04

a) standard uncertainty calculated from three data points.

Table S3. *Solubility of syringic acid in water-Cyrene mixtures at a temperature of (303.2 ± 0.5) K.*

	Syringic Acid	
wt% Cyrene	**Solubility /M**	**s /M[a)]**
0	0.0074	0.0004
10.02	0.0170	0.0004
20.04	0.0308	0.001
30.02	0.057	0.003
40.02	0.1032	0.0002
50.01	0.187	0.002
60.04	0.299	0.004
70.03	0.354	0.007
80.02	0.385	0.008
90.01	0.38	0.01
100	0.151	0.007

a) standard uncertainty calculated from three data points.

S5. References

(1)   De bruyn, M.; Sener, C.; Petrolini, D. D.; McClelland, D. J.; He, J.; Ball, M. R.; Liu, Y.; Martins, L.; Dumesic, J. A.; Huber, G. W.; et al. Catalytic Hydrogenation of Dihydrolevoglucosenone to Levoglucosanol with a Hydrotalcite/mixed Oxide Copper Catalyst. *Green Chem.* **2019**, *21* (18), 5000–5007.

(2)   De bruyn, M.; Budarin, V. L.; Misefari, A.; Shimizu, S.; Fish, H.; Cockett, M.; Hunt, A. J.; Hofstetter, H.; Weckhuysen, B. M.; Clark, J. H.; et al. Geminal Diol of Dihydrolevoglucosenone as a Switchable Hydrotrope: A Continuum of Green Nanostructured Solvents. *ACS Sustain. Chem. Eng.* **2019**, *7* (8), 7878–7883.