



Synthesis of amphiphilic dendrons and their interactions in aqueous solutions with cetyltrimethylammonium *p*-toluenesulfonate (CTAT)

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ABSTRACT

In this work, we report synthesis and rheology of an interesting structured fluid based on the self-assembly of amphiphilic dendrons and wormlike micelles. Two amphiphilic dendrons were synthesized by the combination of aliphatic chains and polar dendritic heads. They showed different degrees of hydrophobicity and formed micelles in aqueous solution at critical micelle concentrations (CMC) of 25 and 125 ppm. The dendrons were soluble in water up to a concentration of approximately 1200 ppm, and produced no measurable increase in the viscosity of the solvent. The rheology of solutions of mixtures of each dendron with cetyltrimethylammonium *p*-toluenesulfonate (CTAT, a cationic surfactant) was characterized in simple shear flow. In the concentration range in which CTAT forms semidilute solutions of wormlike micelles, dendron addition produced a substantial synergy in zero-shear rate viscosity. Parallel-plate oscillatory shear measurements demonstrated that the CTAT/dendron mixtures are significantly more elastic than CTAT solutions. The viscosity synergy occurs at dendron concentrations lower than their CMC, and it is stronger for the more hydrophobic dendron. This suggests that the interactions between dendrons and wormlike micelles are basically hydrophobic, which implies attachment of dendron micelles to wormlike CTAT micelles in a manner similar to micellization of surfactants on polyelectrolytes.

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1. Introduction

The generation of supramolecular structures by self-assembly of molecular building blocks has become a powerful tool in designing new materials. To this aim, a variety of molecular building blocks have already been combined. Recently, dendrimers and their segments, dendrons, have fostered scientific interest as a class of molecular building blocks in the construction of supramolecular systems [1–16].

There are different pathways to combine supramolecular and dendritic chemistry [1]. In order to do that, an attractive option is the generation of dendritic building blocks with accessible synthetic schemes. Investigation in this area has focused on the development of synthetic pathways to obtain materials for specific functions. Dendrons are extensively used as nanoscopic auxiliaries in the development of dendronized polymers [1–6], design of supramolecular structures by self-assembly, use of dendrons as macromonomers [1,2], or in dendronization of materials and surfaces [1–4].

Amphiphilic dendrimers and dendrons are attractive because of the wide variety and high number of functionalities that can be

introduced in one single molecule in a controlled way. They have many potential applications, as nanocarriers, nanoscopic structure directors, catalysts or the possibility of isotropic or anisotropic self-assembly. In addition, they have shown to be compatible with different reactive structures, such as DNA, nanotubes and a wide variety of organic and inorganic compounds.

Certain cationic surfactants based on quaternary ammonium salts form wormlike micelles in aqueous solutions that exhibit rheological properties similar to high-molecular weight polymers, with the added advantage that they cannot be degraded by mechanical means, since their supramolecular structure is established by secondary interactions and not covalent bonds. One of the most studied surfactants that form wormlike micelles is cetyltrimethylammonium *p*-toluenesulfonate (CTAT). Extensive studies have been performed on its rheological properties and on its interactions with polymers and other surfactants [15–21]. As a result of these interactions, formation of structured fluids in which interpenetrated networks (or giant micelles) of wormlike micelles and polymers (or other surfactants) can be established.

The aim of this work is to employ amphiphilic dendrons, specifically synthesized and functionalized, for exploring the behavior and interactions with surfactants like CTAT and therefore develop

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structured fluids that exhibit rheological synergy. For this purpose, we present the synthetic pathway of the amphiphilic dendrons and rheological characterization of solutions containing interacting mixtures of wormlike micelles and amphiphilic dendrons.

2. Experimental

2.1. Materials

Di-tert-butyl 4-amino-4-[2-(tert-butoxycarbonyl)ethyl]-heptanedioate (Behera's amine) was kindly supplied by Newkome Labs. The substrate 5-nitroisophthalic acid was obtained from Sigma; triethylamine, TEA 99% from Anedra; thionyl chloride and silica gel 60 from Merck; stearoyl chloride from Fluka; palladium 10 wt% on activated carbon, potassium bromide 99% FT-IR grade, chloroform-*d* 99.8% D and CTAT 99% from Aldrich. All commercial chemicals were used without purification. Solvents were obtained from Sintorgan, purified by distillation, and dried with 4 Å molecular sieves when necessary.

2.2. Dendrons preparation

The synthesis and characterization of the dendritic structures used as precursor or head in this work (**4** and **5**, respectively) have been previously reported [7]. Their synthetic pathway is shown in Scheme 1.

The novel amphiphilic dendrons (**7** and **8**) were synthesized using a convergent method for the combination of stearoyl chloride with dendritic heads and further hydrolysis of *t*-butyl ester to obtain **9** and **10** (the two amphiphilic dendrons to be used below in conjunction with CTAT). This new synthetic pathway is shown in Scheme 2.

2.2.1. Synthesis of dendrons **7** and **8** (Scheme 2)

In order to obtain dendrons **7** and **8**, an excess of stearoyl chloride (0.3 mL) was stirred for 10 h with **5** (630 mg, 1 mmol) or **3** (420 mg, 1 mmol), respectively. Anhydrous THF was used as solvent (10 mL), TEA (0.5 mL) was added as catalyst and the reaction was carried out in an anhydrous system under N₂. When reaction was complete, the solvent was evaporated under vacuum. The solid was redissolved in hot acetone. Then, after cooling, the remaining stearic acid was precipitated as white solid and the dendritic structures were recuperated from evaporation of mother liquors. Yields 100%.

2.2.2. Characterization of dendron **7**

FT-IR: signals at 1646 and 1535 cm⁻¹ were assigned to Band I (C=O stretching vibration) and Band II (N–H bending vibrations), respectively, corresponding to the amide group. The carbonyl absorption band of ester appeared at 1736 cm⁻¹.

¹³C NMR (CDCl₃): (δ ppm) = 172.1 (C=O amide with stearic acid); 169.6 (C=O aromatic amide); 22.7–45.8 (CH₂ aliphatic chain); 14.1 (CH₃ of stearic acid); 173.1 (C=O ester); 138.9 (C₁ aromatic); 135.9

(C₃ and ₅ aromatic); 120.7 (C₄ aromatic); 120.9 (C₂ and ₆ aromatic); 80.9 (CH₃CO); 58.4 (CNHCH₂); 30.3 (CH₂CH₂CO); 29.9 (CH₂CH₂CO); 27.9 (OC(CH₃)₃).

¹H NMR (CDCl₃): (δ ppm) = 0.9 (t, 3H, CH₃ of stearic acid); 1.3 (broad, CH₂ of stearic acid); 3.1 (t, 2H, CH₂C=O); 3.7 (s, NH amide with stearic acid); 6.7 (s, NH amides with behera amine); 7.9 (s, 1H, CH aromatic); 8.1 (s, 2H, CH aromatic); 2.2 (m, 12H, CCH₂CH₂CO); 2.1 (m, 12H, CCH₂CH₂CO); 1.4 (s, 54H, OC(CH₃)₃).

2.2.3. Characterization of dendron **8**

FT-IR: signals at 1665 and 1537 cm⁻¹ were assigned to Band I (C=O stretching vibration) and Band II (N–H bending vibrations), respectively, corresponding to the amide group. The carbonyl absorption band of ester appeared at 1738 cm⁻¹.

¹³C NMR (CDCl₃): (δ ppm) = 172.3 (C = Oamide with stearic acid); 22.7–45.8 (CH₂ aliphatic chain); 80.9 (CH₃CO); 57.2 (CNHCH₂); 29.3 (CH₂CH₂CO); 29.9 (CH₂CH₂CO); 27.9 (OC(CH₃)₃); 14.1 (CH₃ of stearic acid).

¹H NMR (CDCl₃): (δ ppm) = 0.9 (t, 3H, CH₃ of stearic acid); 1.3 (broad, CH₂ of stearic acid); 2.0 (t, 2H, CH₂C=O of stearic acid); 2.2 (t, 6H, CCH₂CH₂CO); 1.9 (t, 6H, CCH₂CH₂CO); 1.4 (s, 54H, OC(CH₃)₃).

2.2.4. Hydrolysis

A solution of **7** or **8** (600 mg), in 95% formic acid (15 mL) was stirred at 50 °C for 35 h to attain the hydrolysis of *t*-butyl groups. After concentration, toluene (5 mL) was added and the solution was once again evaporated under vacuum to remove residual formic acid azeotropically. Finally, **9** and **10** were obtained as a pale yellowish and a white solid, respectively. Yields were between 85% and 90%.

2.2.5. Characterization of dendrons **9**

¹³C NMR (CDCl₃): (δ ppm) = due to the formation of aggregates, most of the signals shown a shift with respect to **7**; nonetheless the signal occurrence at 178.3 (C=O acid) and the absence of the signals at 80.9 (OCCH₃) and 27.9 (OCCH₃) are significant.

¹H NMR (CDCl₃): (δ ppm) = the *t*-butyl ester signal disappeared at 1.4. Most of the broad signal are observed with respect to **7**, 0.9 (t, 3H, CH₃ of stearic acid); 1.3 (broad, CH₂ of stearic acid); 5.3 (broad, 2H, CH₂C=O); 3.7 (s, NH amide with stearic acid); 3.9 (s, NH amides with behera amine); 8.0 (s, 1H, CH aromatic); 8.1 (s, 2H, CH aromatic); 4.1 (broad multiplet, 12H, CCH₂CH₂CO); 3.6 (broad multiplet, 12H, CCH₂CH₂CO); 1.4 (s, 54H, OC(CH₃)₃).

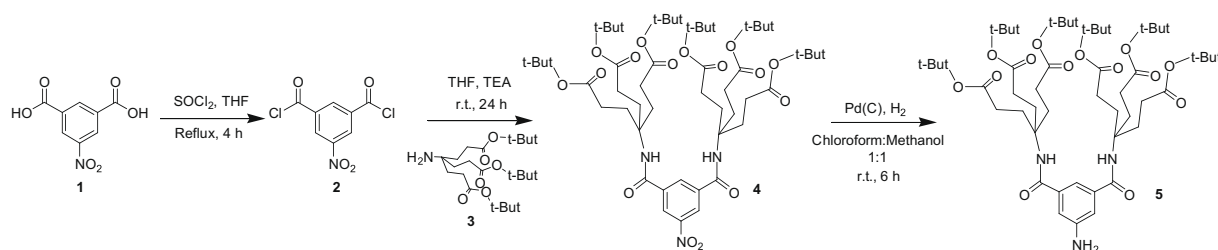
(+)ESI/TOF: calculated for **9**, 536.356; found 536.355 [M + Na]⁺.

2.2.6. Characterization of dendrons **10**

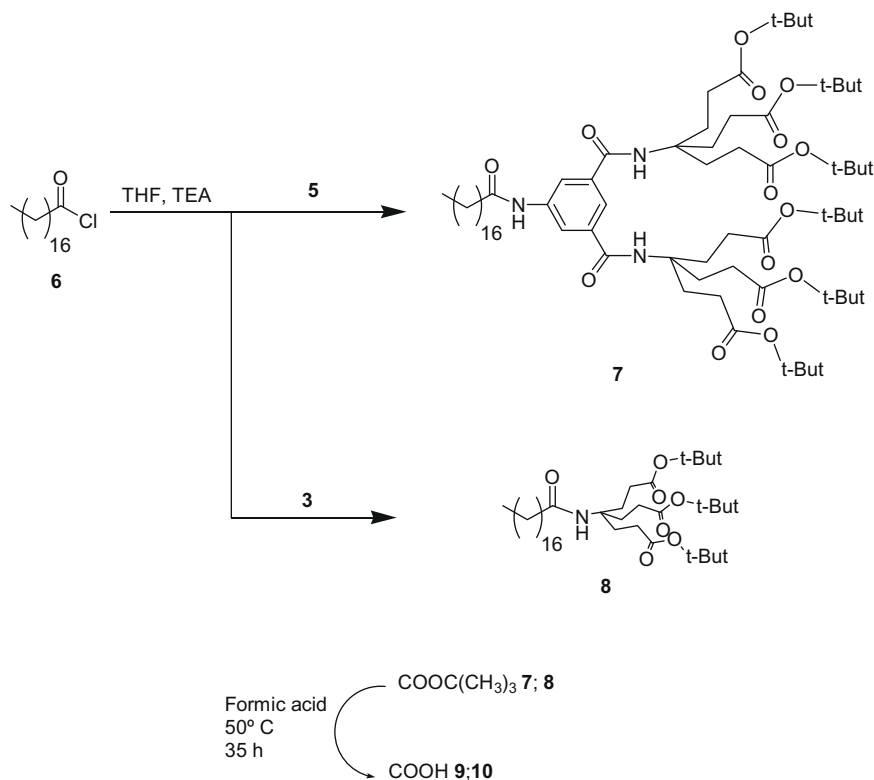
¹³C NMR (CDCl₃): (δ ppm) = 178.3 (C=O acid); the signals at 80.9 (OCCH₃) and 27.9 (OCCH₃) were absent; the rest of the signals remained without change with respect to **8**.

¹H NMR (CDCl₃): (δ ppm) = the *t*-butyl ester signal disappeared at 1.4. Slight broadening of the signals is observed.

(+)ESI/TOF: calculated for **10**, 928.480; found 928.480 [M + Na]⁺.



Scheme 1. Synthetic pathways of dendrons.



Scheme 2. Synthetic pathways of the amphiphilic dendrons.

Fig. 1 shows the chemical structures of the amphiphilic dendrons **9** and **10**.

2.3. Analytical

Fourier Transform-Infrared Spectra (FT-IR) were obtained in a Nicolet 5-SXC FT-IR spectrometer on KBr discs. Nuclear Magnetic Resonance (NMR) was performed in CDCl_3 , D_2O unless otherwise indicated, using a Bruker Avance II 400 MHz NMR spectrometer. FAB spectra were obtained in a $\text{CH}_3\text{DF}/\text{FAB}$ instrument in $\text{CH}_3\text{OH}/\text{mNO}_2\text{-benzyl-OH}$ (matrix). ESI-TOF mass spectra were acquired on an Agilent 6210 system, consisting of an Agilent 1100 HPLC system with a diode array detector and an ESI-MSD TOF by Agilent Technologies.

Steady-state fluorescence measurements were performed in a Perkin-Elmer fluorescence spectrophotometer (LS-550B). The fluorescence probe used was pyrene (Sigma-Aldrich, 99%) at a concen-

tration of 2.0×10^{-7} M. The excitation wavelength was 334 nm, and emission spectra were measured in the range 360–390 nm. The fluorescence intensity ratio between the first (373 nm) and third (383 nm) peaks of the spectrum (I_1/I_3) is sensitive to the micropolarity of the environment surrounding the pyrene in solution and, given the strong partitioning of pyrene into the hydrophobic cores of micelles, this ratio has been extensively used as an indicator of micelle formation [17]. Plots of I_1/I_3 vs. the dendron concentration show a transition around the critical micelle concentration. Measurements were performed at 25 °C.

The dynamic and steady shear rheological experiments were conducted using a Rheometrics ARES shear rheometer equipped with parallel plates (50 mm in diameter and 1 mm gap). All tests were performed at 25 °C, above the Krafft point of CTAT (22.5 °C) and at a wide range of shear rates and oscillation frequencies. Water that was distilled and deionized was employed as the solvent for all rheological measurements. Concentrated stock dendron solutions were prepared by dispersing the solid material in water at 25 °C and stirring continuously for 24 h. In the case of dendrons **9** and **10**, the solutions were originally heated to 50 °C for dissolution, and then the temperature was lowered to 25 °C. For dendron **9** we worked from 20 to 1000 ppm (from 2.24×10^{-2} to 1.12 mM), and for dendron **10** the range used was from 50 to 1000 ppm (from 0.10 to 1.94 mM).

3. Results and discussion

3.1. Synthesis and critical micellar concentration of the dendrons

Scheme 1 shows the synthesis pathway of dendrons **4** and **5**, and Scheme 2 shows the synthesis of amphiphilic dendrons **7** to **10**. Once obtained, the amphiphilic nature of the final product was reached through a covalent bond with stearic acid. These products were soluble in a wide variety of solvents, such as chloro-

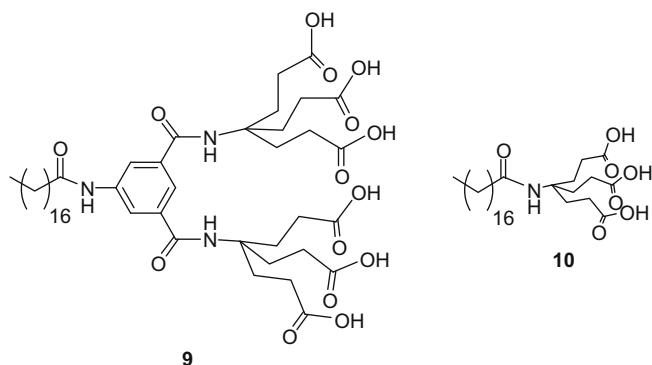


Fig. 1. Chemical structure of the amphiphilic dendrons **9** and **10**.

form, acetone, water and dimethyl sulfoxide. The presence of the *t*-butyl groups in the surface of the dendritic moieties gives the final product a hydrophobic nature; while their hydrolysis converts them into hydrophilic moieties due the presence of carboxylic groups. The results of the analysis of the ^1H NMR and FT-IR spectra of synthesized dendrons were previously presented in the experimental section. Fig. 2 shows examples of the ^1H NMR and FT-IR spectra of dendron **9**.

The hydrolyzed versions of dendrons **7** and **8** (i.e., dendrons **9** and **10**, Fig. 1) were selected for their amphiphilic character as candidates for interaction with CTAT wormlike micelles. Fig. 3 shows the characteristic fluorescence ratios, I_1/I_3 , for these dendrons as a function of their concentration. The shape of the plots clearly indicates that the dendrons form micelles in solution with CMCs of 25 ppm (dendron **9**) and 125 ppm (dendron **10**). The lower CMC value for dendron **9** indicates that it is more hydrophobic than dendron **10**.

3.2. Simple shear behavior

Dendrons **9** and **10** were soluble in water up to a concentration of approximately 1200 ppm. In both cases, the viscosity of aqueous dendron solutions was identical to that of water (results not shown). Therefore, in the concentration range examined, the dendron micelles are in the dilute regime and no significant viscosity effects can be detected.

At its CMC, 0.26 mM at 25 °C, CTAT forms spherical micelles, but at higher concentrations a transition from spherical to rodlike micelles occurs (this is the critical coil to rodlike concentration, CRC, ~ 1.97 mM for CTAT at 25 °C in deionized water [18]). The overlap concentration, ϕ^* , defines the limit between the dilute and the semidilute regime of CTAT wormlike micelles, and has been found to be ~ 11 mM [19]. The predominant rheological shear behavior of aqueous CTAT solutions in a concentration range spanning 2–20 mM is pseudo-Newtonian at low shear rates (constant shear

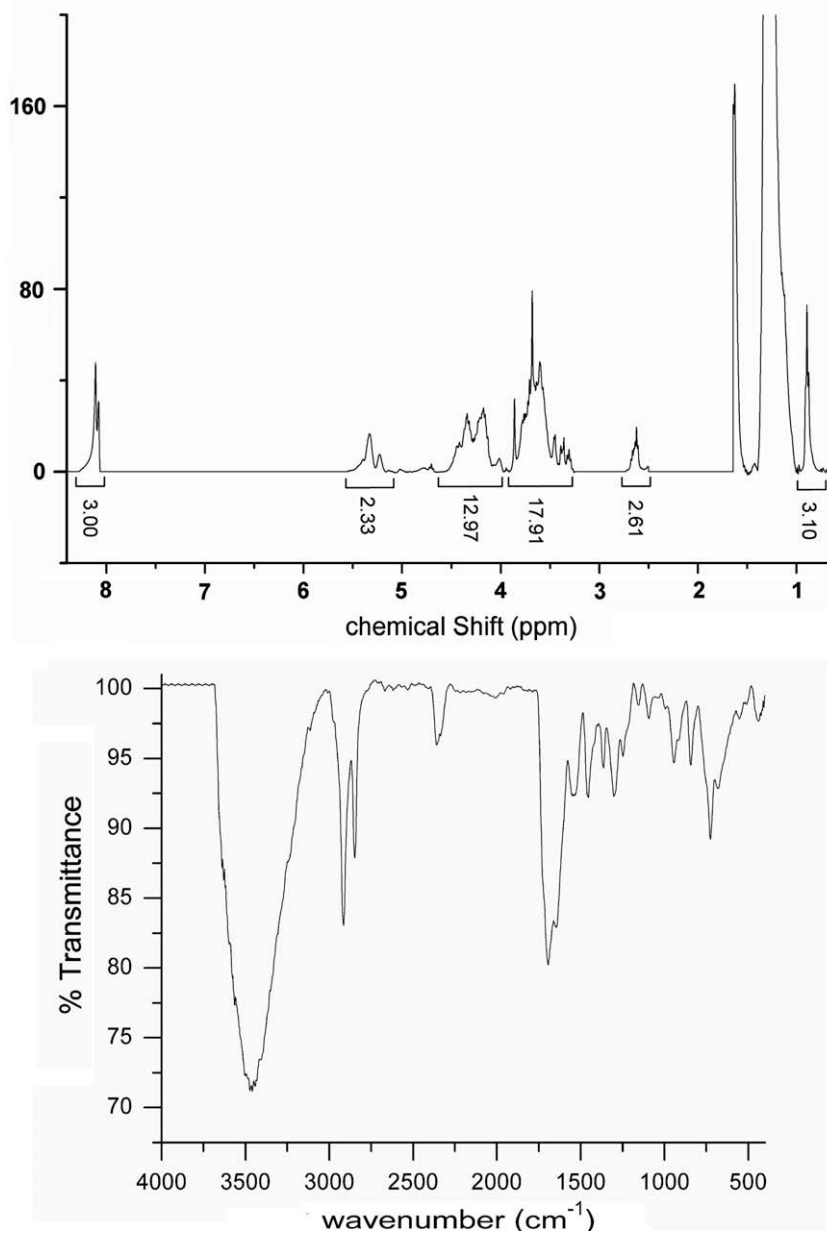


Fig. 2. ^1H NMR and FT-IR spectra of dendron **9**.

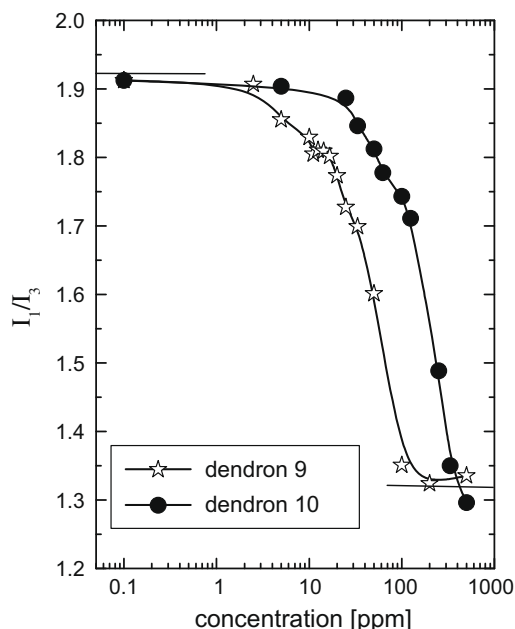


Fig. 3. Fluorescence spectroscopy results for dendrons **9** and **10**. From these results, the CMCs are estimated to be 25 ppm (dendron **9**) and 100 ppm (dendron **10**).

viscosity), followed by a shear-thickening transition caused by the formation of shear induced structures (SIS) [19–21]. These trends are clearly seen in Fig. 4 for a 20 mM CTAT solution. The shear-thickening behavior is typical of concentrations above the CRC, at which the micelles are cylindrical in shape but not long enough to form long-range interactions under static conditions, so that a minimum shear rate is needed to induce the formation of SIS. Since the length of the wormlike micelles increases with concentration [21], the value of the critical shear rate decreases as CTAT concentration increases. Above the semidilute threshold, ϕ^* (11 mM), the micelles are fully entangled under static conditions and therefore exhibit relatively high zero-shear rate viscosities with slight shear thickening. At even higher CTAT concentrations (>20 mM), entangled wormlike micelles exist under static conditions, the shear-thickening transition disappears and the fluid becomes shear thin-

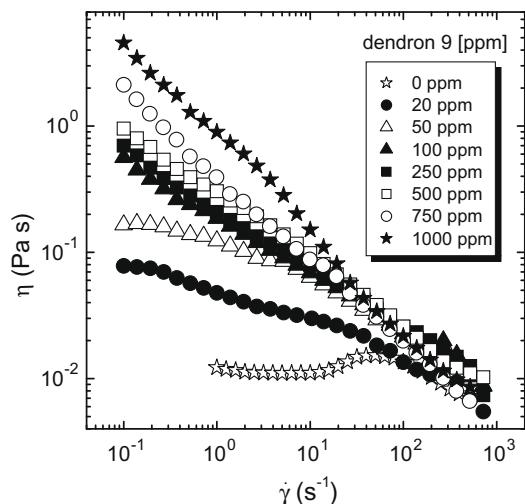


Fig. 4. Shear viscosity as a function of shear rate for CTAT/dendron **9** solutions. [CTAT] = 20 mM ($T = 25^\circ\text{C}$).

ning. Examples are provided in Figs. 5 and 6 for CTAT solutions of concentrations 30 and 40 mM, respectively.

Figs. 4–6 show the rheological behavior of the mixtures of dendron **9** and CTAT for various CTAT and dendron **9** concentrations. Fig. 4 shows that there is a definite synergistic viscosity increase in the mixtures at low shear rates, even at concentrations below the CMC of dendron **9** (25 ppm). Furthermore, addition of dendron **9** to the CTAT solution eliminates the shear thickening at high shear rates since the solutions become strongly shear thinning in the whole range of shear rates explored.

A similar synergy can be seen in Fig. 5, except that the viscosity of the 30 mM CTAT solution is already relatively high, so that the viscosity increase provided by the addition of dendron **9** is not as substantial as for the 20 mM CTAT solution. However, the 1000 ppm dendron **9** solution exhibits a viscosity at low shear rates that is more than an order of magnitude higher than in the absence of the dendron. For 40 mM CTAT solutions, Fig. 5, the viscosity of the mixture seems to be dominated by the rheological behavior of CTAT.

A summary of the synergistic behavior can be found in Fig. 7, where the shear viscosity at the lowest shear rate employed ($\dot{\gamma} = 0.1 \text{ s}^{-1}$) is plotted as a function of dendron **9** concentration

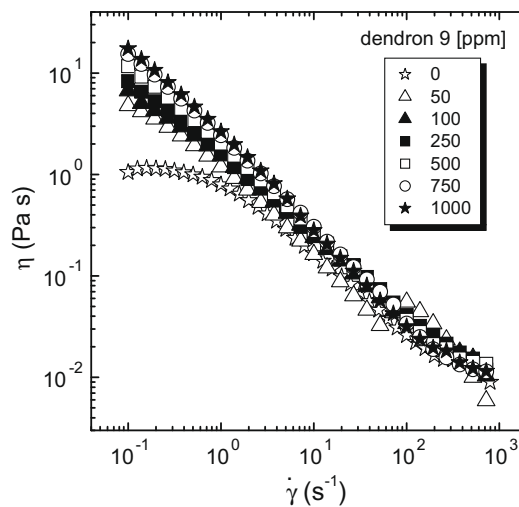


Fig. 5. Shear viscosity as a function of shear rate for CTAT/dendron **9** solutions. [CTAT] = 30 mM ($T = 25^\circ\text{C}$).

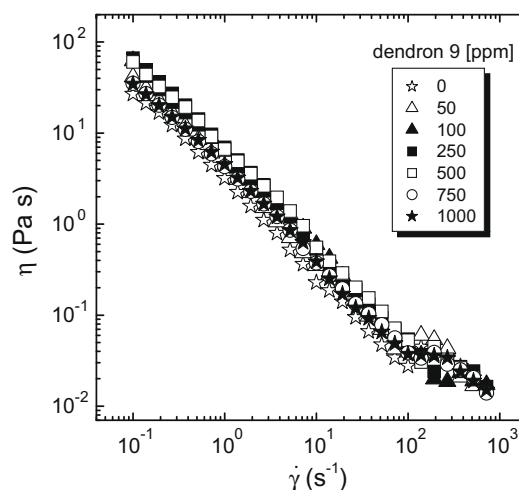


Fig. 6. Shear viscosity as a function of shear rate for CTAT/dendron **9** solutions. [CTAT] = 40 mM ($T = 25^\circ\text{C}$).

for all three CTAT concentrations employed. It should be noted that for most of the dendron **9** solutions employed, the viscosity did not become independent of shear rate at low shear rates, rather, the viscosity increased as the shear rate decreased. In these cases, the zero-shear rate viscosity values could be difficult to establish. In fact, the results may indicate that the solutions exhibit a yield stress, a behavior that is absent in CTAT solutions. The viscosity increases caused by dendron **9** addition can amount up to two and half orders of magnitude. At 40 mM of CTAT, the viscosity seems to exhibit a slight maximum with dendron concentration.

Fig. 8 presents low shear rate viscosity data at fixed dendron **9** concentrations of 100 and 1000 ppm, varying the concentration of CTAT. The synergy of the mixtures extends over the whole range of concentrations shown, but it becomes particularly important beyond the CTAT wormlike micelles overlap concentration (11 mM). For CTAT solutions, increases of viscosity of more than one order of magnitude with respect to water only occur beyond 20 mM. However, for CTAT/dendron **9** solutions, such large increases in viscosity occur already at lower CTAT concentrations.

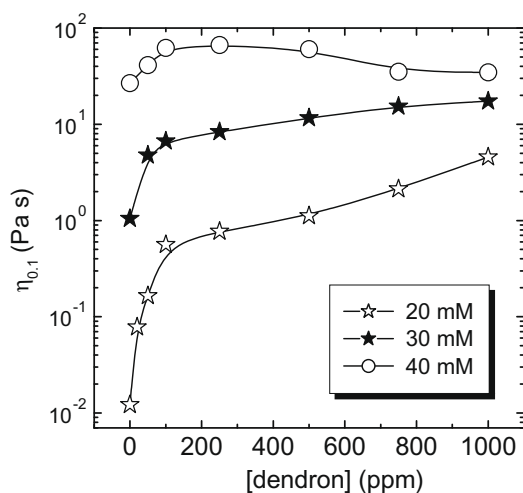


Fig. 7. Low shear rate viscosity ($\dot{\gamma} = 0.1 \text{ s}^{-1}$) as a function of the dendron concentration for CTAT/dendron **9** solutions at various CTAT concentrations (legend) ($T = 25 \text{ }^\circ\text{C}$).

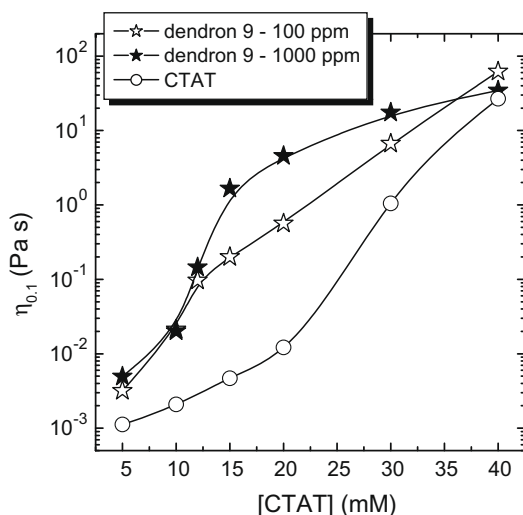


Fig. 8. Low shear rate viscosity ($\dot{\gamma} = 0.1 \text{ s}^{-1}$) as a function of CTAT concentration for CTAT/dendron **9** solutions at different dendron concentrations ($T = 25 \text{ }^\circ\text{C}$).

The synergistic viscosity increases produced by the addition of relatively small dendron **9** quantities to entangled wormlike micelle solutions are a consequence of specific interactions between the dendron and the CTAT wormlike micelles. The fact that substantial viscosity increases start at dendron **9** concentrations below its CMC might be a consequence of two types of interactions. First, it is possible that dendron **9** unimers bind to CTAT wormlike micelles. Due to the amphiphilic nature of the dendron, its hydrophobic tail would penetrate into the CTAT micelle, while the polar head would be located close to the micelle surface. The co-micellization would alter the micelle structure significantly. It would be possible, in this case, that the micelle structure is changed in such a way that it constrains the motion of wormlike micelles in entangled networks. However, given that the dendron molar concentrations (from 0.022 to 1.1 mM) are appreciably lower than those of CTAT, it is difficult to justify changes in CTAT micellar structure that explain the synergy observed. Second, the presence of CTAT may promote the formation of dendron **9** micellar aggregates that attach to the CTAT worm-like micelles, forming “sticky points” that would induce intermicelle physical binding and thus a strengthening of wormlike micelle entanglements. We believe that this is the cause for the synergy. In this scenario, the dendrons/wormlike micelle system behaves similar to other surfactant/polymer systems [22] (Fig. 8).

Mixtures of dendron **10** and CTAT lead to similar rheological behavior, as shown in Fig. 9. However, the values of the zero-shear viscosities were lower than for dendron **9** (Fig. 10). This fact supports the hypothesis that hydrophobic interactions might be the origin of the binding between CTAT and the amphiphilic dendrons **9** and **10**. Since dendron **10** is less hydrophobic, the number of dendrons attached to the micelles would be lower, decreasing the level of interactions. As in the case for dendron **9**, the synergistic viscosity increases are observed at dendron **10** concentrations that are appreciably lower than its CMC (125 ppm).

3.3. Oscillatory shear behavior

Oscillatory shear measurements were performed at a constant strain of 30%. In all cases, independent tests (results not shown) yielded no changes in both viscous and elastic moduli when the strain was varied between 0% and 100%.

The variation of the viscous (G'') and elastic (G') moduli with frequency for dendron/CTAT mixtures at different concentrations were evaluated for dendrons **9** and **10** (Figs. 11 and 12). At low fre-

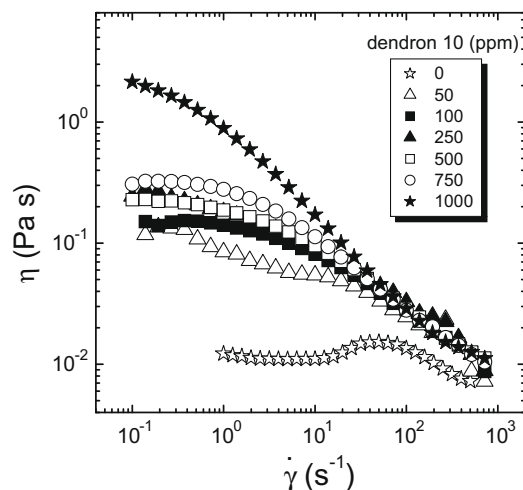


Fig. 9. Shear viscosity as a function of shear rate for CTAT/dendron **10** solutions. [CTAT] = 20 mM ($T = 25 \text{ }^\circ\text{C}$).

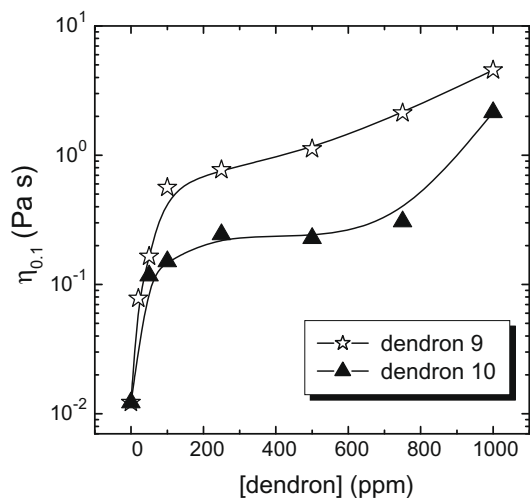


Fig. 10. Comparison of both dendrons: Low shear rate viscosity ($\dot{\gamma} = 0.1 \text{ s}^{-1}$) as a function of dendron concentration for CTAT/dendron **9** and CTAT/dendron **10** solutions. [CTAT] = 20 mM ($T = 25 \text{ }^\circ\text{C}$).

quencies within the range explored, the 20 mM CTAT solution behaves closely to a Maxwell fluid: data on the figures tend to behave as $G' \sim \omega$, $G'' \sim \omega^2$, and $G'' > G'$ as $\omega \rightarrow 0$. Addition of 100 ppm dendron **9** to the 20 mM CTAT solution leads to higher values for both moduli and a lower crossover frequency (Fig. 11), which is consistent with the strengthening of wormlike micelle entanglements (discussed above) due to dendron/micelle interactions. When the dendron **9** concentration is increased to 1000 ppm, the elastic modulus of the mixture becomes higher than the viscous modulus in the range of frequencies explored, which indicates a predominantly elastic character for the solution. This is also consistent with the simple shear flow results for this mixture (Fig. 3), and points to the existence of yield stresses at relatively high dendron **9** concentrations.

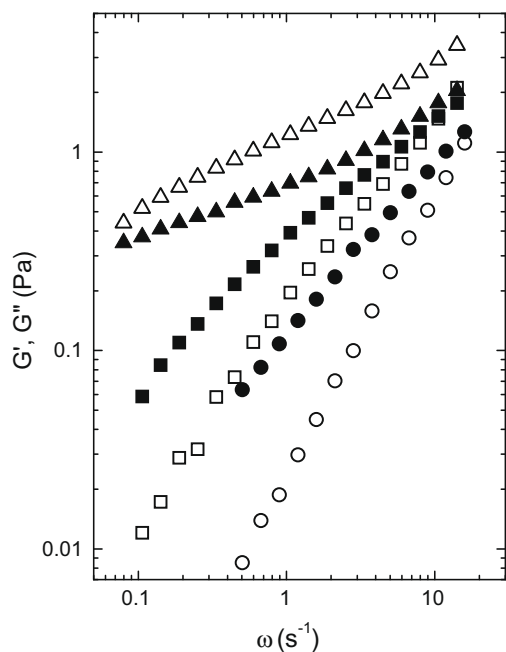


Fig. 11. Oscillatory shear results for a CTAT solution and two dendron **9**/CTAT solutions ($T = 25 \text{ }^\circ\text{C}$). Open symbols: G' , solid symbols: G'' . CTAT 20 mM (\circ, \bullet), dendron **9** 100 ppm/CTAT 20 mM (\square, \blacksquare), dendron **9** 1000 ppm/CTAT 20 mM (Δ, \blacktriangle).

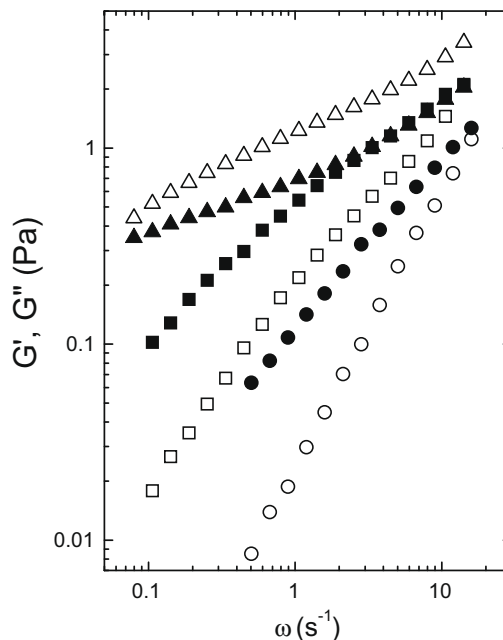


Fig. 12. Oscillatory shear results for a CTAT solution and two dendron solutions ($T = 25 \text{ }^\circ\text{C}$). Open symbols: G' , solid symbols: G'' . CTAT 20 mM (\circ, \bullet), dendron **9** 1000 ppm/CTAT 20 mM (Δ, \blacktriangle), dendron **10** 1000 ppm/CTAT 20 mM (\square, \blacksquare).

Oscillatory flow results for a 1000 ppm dendron **10**/20 mM CTAT solution are shown in Fig. 12. The fact that dendron **10** exhibits weaker interactions than dendron **9** with the CTAT wormlike micelles, as evidenced by the simple shear flow results discussed above and explained by its lower hydrophobicity, is also seen in these results. At 1000 ppm, the dendron **10** mixture does not show the strong elastic character of the dendron **9** mixture.

4. Conclusions

Two novel amphiphilic dendrons were obtained through a rapid and accessible synthetic pathway and with high yields. The results obtained in this work demonstrate that amphiphilic dendrons induce a significant rheological synergy in solutions of cationic wormlike micelles. These mixtures constitute interesting structured fluids based on highly functional molecules such as dendrons. The presence of dendrons intensifies physical entanglements among wormlike micelles, which leads to solutions with appreciably higher low shear viscosities, stronger shear thinning behavior and comparatively higher elastic character at high frequencies. Even though a precise characterization of the microstructural effects of the dendrons on wormlike micelle interactions does not exist at this point, the rheological results point to a behavior that is similar to mixtures of micellar aggregates of surfactants and high-molecular weight polymers. The results suggest that dendron micellar aggregates form on the CTAT wormlike micelles at concentrations that are below the CMC of the dendrons, and they become points of interaction between wormlike micelles, thus strengthening physical entanglements between the micelles.

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