ARTICLE

Inclusion Complex of β-cyclodextrin with CTAB in Aqueous Solution

Xiao-ming Chen[a,b*]

a. School of Materials & Chemical Engineering, Anhui University of Architecture, Hefei 230601, China
b. Anhui Key Laboratory of Advanced Building Materials, Hefei 230601, China

(Dated: Received on April 6, 2011; Accepted on June 16, 2011)

Cetyltrimethylammonium bromide (CTAB)/potassium bromide (KBr) micellar system has been used as a viscosity probe to study the inclusion complexation between β-cyclodextrin (β-CD) and CTAB. Viscosity measurements show that the inclusion complexation between β-CD and CTAB may cause the breakdown of CTAB/KBr wormlike micelles, resulting in the decrease of the solution viscosity. The viscosity minimum at $C_{\beta\text{-CD}}/C_{\text{CTAB}}$=2 indicate the molecular ratio of host molecule to guest molecule is 2:1 in the β-CD/CTAB inclusion complex.

Key words: Cetyltrimethylammonium bromide, KBr, β-cyclodextrin, Viscosity

I. INTRODUCTION

Cyclodextrins (CDs) are cyclic oligosaccharides of six to eight glucose units linked by α-1,4 linkages, which are called α-, β-, and γ-CD, respectively. They have a toroidal, truncated, and cone shape, with an apolar, hydrophobic interior and two hydrophilic rims, formed by the primary (narrow rim) and secondary (wider rim) OH groups [1]. The molecular structure of β-CD is shown in Fig.1. The commercial utility and scientific interest in CDs arises because of their ability to form stable inclusion complexes with a wide variety of inorganic and organic guest molecules [2].

Surfactants are a kind of suitable guest molecule with many physical and chemical properties which can be changed with the addition of CDs. Compared with α-CD and γ-CD, β-CD is studied more widely because its interior diameter fits many more guest molecules, such as the hydrocarbon chains of surfactants [3].

To assess the basics of the host-guest inclusion complexes formed by CDs and guest molecules, determinations of the molecular ratio of host molecule to guest molecule is essential. A set of experimental techniques have been used to study the inclusion complexation such as surface tention [4, 5], conductivity [6], NMR [7], fluorescence spectroscopy [8], and isothermal titration calorimetry (ITC) [9]. The primary disadvantage of such techniques is that they are time-consuming and need special testing equipments. Comparatively, Ubbelohde viscometer is a type of easily accessible equipment which is commonly used to study the viscosity of either polymer or surfactant solutions. However, the inclusion complexation between CDs and surfactants may not result in a significant change in the solution viscosity and therefore Ubbelohde viscometer cannot be used to directly characterize the host-guest inclusion complexation effectively as presumed, and an indirect approach is needed.

It is well-known that cationic surfactants can self-assemble in aqueous solution into long, flexible cylindrical micelles upon the addition of salts such as potassium bromide (KBr) or sodium salicylate (NaSal) [10]. The salt serves to reduce the electrostatic interactions between the cationic headgroups, thus reducing the effective area per headgroup and thereby promoting the growth of cylindrical micelles. A sharp increase of the viscosity (changing between 0.001 and 100 Pa·s at low values of surfactant volume fraction [11]) can be related to an increase in micellar size (or change in shape) [12]. Viscosity can be used to get an approximation about micellar size in surfactant solutions, and such results are in qualitative agreement with the scattering techniques [13, 14]. For charged surfactants, the length and the rigidity of cylindrical micelles depend on the surfactant concentration and the degree of counterion binding. Cationic cetyltrimethylammonium bromide (CTAB) forms wormlike micelles with Cl^- and Br^- salt ions due to counterion binding and charge screening but rod-like micelles with salicylate ions as a result of charge attraction, counterion binding, and hydrophobic interactions [15]. In dilute solutions, the length of rod-like CTAB/NaSal micelles can exceed 100 nm [16] while that of wormlike CTAB/KBr micelles is around 50 nm [17].

If adding cyclodextrins into the solution containing wormlike micelles, the inclusion complexation between CDs and surfactants in solution will have a great influence on the micellar size in solution. As a result, the viscosity of solution may have a change enough to be detected by Ubbelohde viscometer. On such an occasion, the wormlike micelle acts essentially as a viscosity probe

*Author to whom correspondence should be addressed. E-mail: chenxmyn@hotmail.com, Tel.: +86-551-3828157

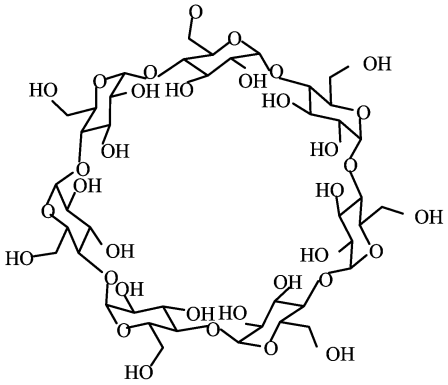

FIG. 1 The molecular structure of β-CD.

by which the inclusion complexation between CDs and surfactants in solution, including the molecular ratio of host molecule to guest molecule, can be identified with the aid of Ubbelohde viscometer.

In this work, the flow time t_0 of pure water was measured and taken as the reference. The flow time t of β-CD in CTAB/KBr mixed solution was measured. The relative viscosity of β-CD in CTAB/KBr mixed solution, used for indicating the inclusion complexation between β-CD and CTAB in solution, was determined by t/t_0, neglecting the kinetic energy correction and fluid density correction as performed in our previous work [18].

II. EXPERIMENTS

Cationic surfactant cetyltrimethylammonium bromide (A.R.) and potassium bromide (A.R.) are purchased from China National Medicines Corporation Ltd. β-cyclodextrin (β-CD, purity>99%) is from Shanghai (China) Yuanju Biology Technique Company. The molecular weight of β-cyclodextrin is 1135. Deionized distilled water was used in all experiments here.

All viscosity measurements were carried out using a conventional Ubbelohde capillary viscometer (inner diameter φ=0.55 mm) at 30±0.1 °C maintained with a thermostatic water bath. Measurements were initiated after approximately 5−10 min equilibrium time. Each flow time was determined by repeating at least three time measurements. The precision of the measurements was 0.01 s and the devition between three data of each flow time was less than 0.2 s. The viscometer was thoroughly cleaned with concentrated chromic acid and deionized distilled water after each experiment.

In order to study the inclusion ratio of β-CD to guest molecule CTAB, two stock solutions, namely solution A and solution B respectively, were prepared. Both solution A and solution B contain the same concentration of CTAB and KBr. The main difference between the two stock solutions is that solution A contains the excess concentration of β-CD whereas solution B contains none of β-CD. By changing the volume ratio of solution A to solution B, the ratio of β-CD to guest molecule CTAB varies accordingly. In our experiments, 10 mL solution B was first put into the viscometer and the flow time was measured. Then solution A with different volumes was added into the viscometer and the flow time of the mixed solution was measured.

^{1}H NMR spectroscopy were performed on a Bruker Avance 400 NMR spectrometer at 30 °C. The NMR spectra of β-CD/CTAB/KBr(0.4 mol/L) were measured in different CD:CTAB ratios: 10:0, 9:1, 8:2, 6.67:3.33, 5:5, 3.33:6.67, 2:8 in D_2O.

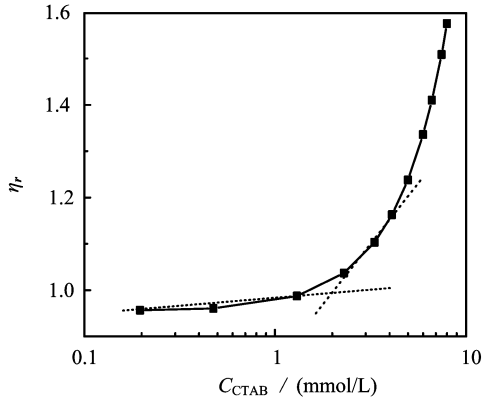

FIG. 2 Relative viscosity η_r of CTAB in 0.4 mol/L KBr aqueous solution at 30 °C.

III. RESULTS AND DISCUSSION

A. Relative viscosity of CTAB in 0.4 mol/L KBr aqueous solution

Figure 2 shows the relative viscosity η_r of CTAB in 0.4 mol/L KBr aqueous solution at 30 °C. Below 2 mmol/L CTAB, the viscosity of the solution increases slightly. But a sharp increase in viscosity occur for C_{CTAB} above 2 mmol/L, which may be closely related

DOI:10.1088/1674-0068/24/04/484-488

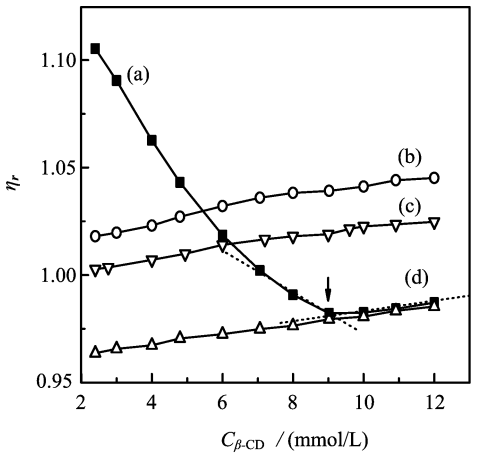

FIG. 3 Relative viscosity η_r of β-CD in (a) CTAB (4.5 mmol/L)/KBr (0.4 mol/L) solution, (b) 4.5 mmol/L CTAB solution, (c) 0.4 mol/L KBr solution and (d) pure water respectively at 30 °C.

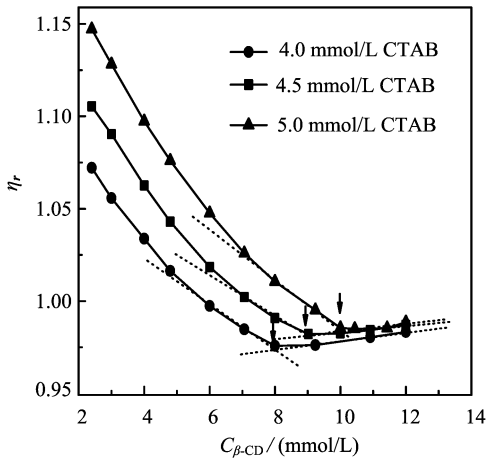

FIG. 4 Relative viscosity η_r of β-CD in CTAB/0.4 mol/L KBr solution with different CTAB concentration at 30 °C.

to the increase of micellar size after the transition. As documented by Ud-Din [12, 14] and Forland [13] *et al*, a pronounced enhancement of the solution viscosity is one of the consequences of the transition from spherical micelles to wormlike micelles of surfactants.

B. Effect of β-CD upon the viscosity of CTAB/KBr wormlike micelle system

The CTAB/KBr wormlike micelles were selected here to determine the inclusion complexation between β-CD and CTAB in order to ensure the change of solution viscosity is enough to be detected by Ubbelohde viscometer during the process of β-CD/CTAB inclusion complexation. Figure 3 shows the relative viscosity η_r of β-CD in different CTAB/KBr solution. From Fig.3 it can be seen that η_r of β-CD in pure water increases slightly due to the increase of the β-CD fraction in the solution. The relative viscosity corresponding to β-CD in 4.5 mmol/L CTAB solution or 0.4 mol/L KBr solution is almost negligible in the whole concentration range and almost parallel to the one in pure water. That means the slight increase of the relative viscosity is also due to the the increase of the β-CD fraction in the solution.

But the relative viscosity of β-CD in CTAB (4.5 mmol/L)/KBr (0.4 mol/L) solution decreases sharply with the β-CD concentration and reaches the minimum approximately at $C_{\beta\text{-CD}}$=9 mmol/L. This result indicates clearly that the inclusion complexation of β-CD and CTAB has a great influence on the size of CTAB/KBr wormlike micelles in solution.

To gain a better understanding of the origin of relative viscosity minimum at $C_{\beta\text{-CD}}$=9 mmol/L, we have to interpret why η_r of β-CD in CTAB/KBr solution decreases sharply with the increase of $C_{\beta\text{-CD}}$ as shown in Fig.3. The increase of micellar size of CTAB/KBr micelles introduces a sharp increase of the viscosity as indicated in Fig.2. With the addition of β-CD to CTAB/KBr solutions the inclusion complexation between β-CD and CTAB occurs. The hydrophobic association between the hydrophobic tails of surfactants are screened by β-CD. As a result the associated CTAB molecules is continually stripped off the wormlike micelles, therefore the CTAB/KBr micellar size decreases as indicated in the decrease of the viscosity shown in Fig.3. Finally the wormlike micelles breakdown completely as can be indicated by the viscosity minimum in the plot. The viscosity minimum at $C_{\beta\text{-CD}}/C_{\text{CTAB}}$=9/4.5=2 indicate that the molecular ratio of host molecule (β-CD) to guest molecule (CTAB) is 2:1 in the β-CD/CTAB inclusion complex.

It should be considered that whether the concentration of CTAB or KBr in the viscosity probe (the CTAB/KBr wormlike micelles) would influence the determination of the inclusion complexation between β-CD and CTAB or not. Figures 4 and 5 show the relative viscosity η_r of β-CD in CTAB/KBr solution with different CTAB concentration and KBr concentration respectively. It can be seen that with different CTAB concentration (4.0, 4.5, and 5.0 mmol/L) the addition of β-CD produces the viscosity minimum at about $C_{\beta\text{-CD}}$=8, 9, and 10 mmol/L, respectively, which is equal to 2 times of C_{CTAB} accurately. Furthermore, Fig.5 show that the inclusion complexation of β-CD and CTAB would not be influenced by KBr concentration. In each experiment the viscosity minimum at $C_{\beta\text{-CD}}/C_{\text{CTAB}}$=2 indicate the molecular ratio of host molecule (β-CD) to guest molecule (CTAB) is 2:1 in the β-CD/CTAB inclusion complex.

The stoichiometric ratio of the inclusion complexation was experimentally verified by Job's method [19, 20] which is generally known as the continuous variation method, using the ^{1}H NMR chemical shift changes

DOI:10.1088/1674-0068/24/04/484-488

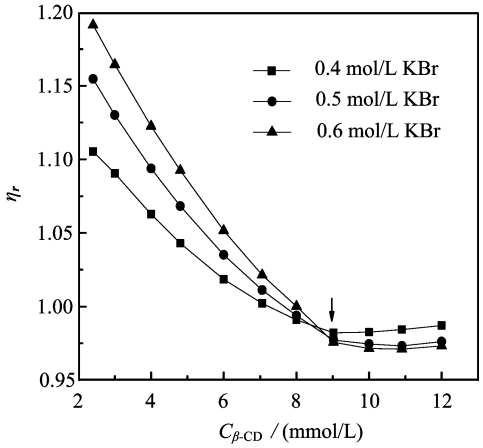

FIG. 5 Relative viscosity η_r of β-CD in 4.5 mmol/L CTAB/KBr solution with different KBr concentration at 30 °C.

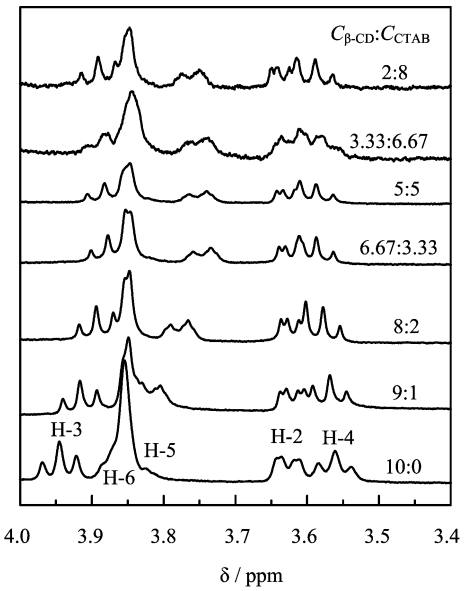

FIG. 6 ^{1}H NMR spectras of β-CD/CTAB/KBr(0.4 mol/L) in different ratios of $C_{\beta\text{-CD}}$:C_{CTAB} at 30 °C.

of the H-3 proton positioned in the interior of β-CD as an indicator [21, 22]. H-3 signal shifts upfield when the inclusion complexation occurs [23]. The NMR spectra were measured in different CD:CTAB ratios: 10:0, 9:1, 8:2, 6.67:3.33, 5:5, 3.33:6.67, 2:8. It can be seen in Fig.6 and Fig.7 that the 2:1 stoichiometry was confirmed since $r\Delta\delta$ values (r=$C_{\beta\text{-CD}}$/($C_{\beta\text{-CD}}$+C_{CTAB}), $\Delta\delta$: the variation of H-3 chemical shift) reached a maximum at r=0.67.

IV. CONCLUSION

In this work, results indicate convincingly that the molecular ratio of host molecule to guest molecule in the host-guest inclusion complexes formed by β-

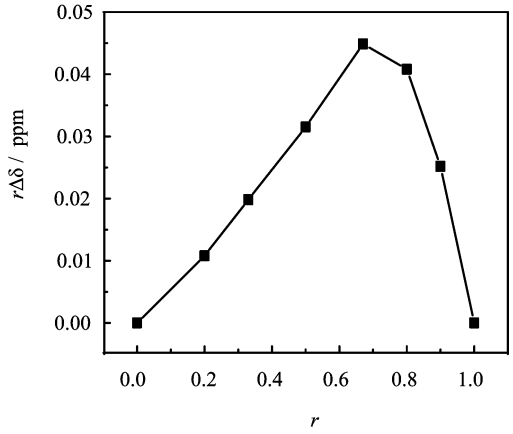

FIG. 7 Job's plot for β-CD/CTAB/KBr(0.4 mol/L) at 30 °C. Chemical shift variations refer to H-3 protons of β-CD.

cyclodextrin and surfactants can be determined by viscosity measurement. CTAB/KBr wormlike micelle has been used as a viscosity probe to study the inclusion complexation between β-CD and CTAB. Viscosity measurements show that the inclusion complexation between β-CD and CTAB may cause the CTAB molecules be stripped off the wormlike micelles, therefore the CTAB/KBr micellar size decreases as indicated in the decrease of the viscosity. The viscosity minimum at $C_{\beta\text{-CD}}/C_{\text{CTAB}}$=2 indicate the molecular ratio of host molecule to guest molecule is 2:1 in the β-CD/CTAB inclusion complex.

V. ACKNOWLEDGMENTS

This work was supported by the Doctor Research Foundation of Anhui University of Architecture (No.20101201) and the Postdoctoral Science Foundation of Anhui University of Architecture (No.20110101).

[1] A. A. Rafatia, A. Bagheria, H. Iloukhania, and M. Zarinehzad, J. Mol. Liquids **116**, 37 (2005).
[2] M. E. Brewster and T. Loftsson, J. Pharm. Sci. **85**, 1017 (1996).
[3] R. Guo, X. J. Zhu, and X. Guo, Colloid Polym. Sci. **281**, 876 (2003).
[4] U. R. Dharmawardana, S. D. Christian, E. E. Tucker, R. W. Taylor, and J. F. Scamehorn, Langmuir **9**, 2258 (1993).
[5] R. Lu, J. Hao, H. Wang, and L. Tong, J. Colloid Interface Sci. **192**, 37 (1997).
[6] R. Palepu, J. E. Richardson, and V. C. Reinsborough, Langmuir **5**, 218 (1989).
[7] N. Funasaki, H. Yamaguchi, S. Ishikawa, and S. Neya, J. Phys. Chem. B **105**, 760 (2001).
[8] J. W. Park and H. J. Song, J. Phys. Chem. **93**, 6454 (1989).

DOI:10.1088/1674-0068/24/04/484-488

[9] W. Eli, W. Chen, and Q. Xue, J. Chem. Thermodynamics **31**, 1283 (1999).
[10] G. C. Kular and S. R. Raghavan, J. Phys. Chem. B **109**, 8599 (2005).
[11] W. C. Zhang, G. Z. Li, Q. Shen, and J. H. Mu, Colloid. Surf. A **170**, 59 (2000).
[12] S. L. David, S. Kumar, and K. Ud-Din, J. Chem. Eng. Data **42**, 198 (1997).
[13] G. M. Forland, J. Samseth, H. Hoiland, and K. Mortensen, J. Colloid Interface Sci. **164**, 163 (1994).
[14] K. Ud-Din, S. Kumar, and P. S. Goyal, Langmuir **12**, 1490 (1996).
[15] S. Panmai, R. K. Prudhomme, and D. G. Peiffer, Colloid. Surf. A **147**, 3 (1999).
[16] M. Y. Lin, H. J. M. Hanley, S. K. Sinha, G. C. Straty, D. G. Peiffer, and M. W. Kim, Phys. Rev. E **53**, 4302 (1996).
[17] M. E. Cates and S. J. Candau, J. Phys. Condens. Matter **2**, 6889 (1990).
[18] X. Chen, H. Yang, X. You, P. Zhu, and P. He, Chin. J. Polym. Sci. **24**, 437 (2006).
[19] P. Job, Ann. Chim. **9**, 113 (1928).
[20] N. Funasaki, S. Ishikawa, and S. Neya, J. Phys. Chem. B **107**, 10094 (2003).
[21] S. Rozou and E. A. Vyza, J. Pharm. Biomed. Anal. **18**, 899 (1998).
[22] S. Lima, C. A. Dias, A. M. A. Dias, I. M. Marrucho, J. A. P. Coutinho, and J. J. C. T. Dias, J. Incl. Phenom. Macrocycl. Chem. **57**, 157 (2007).
[23] L. M. A. Pinto, L. F. Fraceto, M. H. A. Santana, T. A. Pertinhez, S. O. Junior, and E. D. Paula, J. Pharm. Biomed. Anal. **39**, 956 (2005).

DOI:10.1088/1674-0068/24/04/484-488