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Potential applications of cyclodextrins in enhanced oil recovery

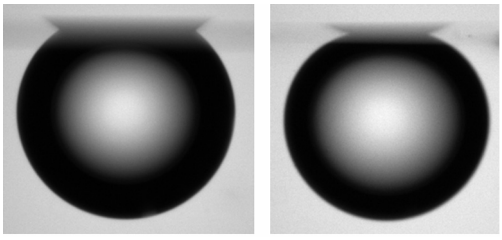
Lucas Stori de Lara [1], Thiago Voltatoni, Manuella Caramelo Rodrigues, Caetano Rodrigues Miranda *, Sergio Brochsztain *

Nanopetro Research Group – Universidade Federal do ABC (UFABC), Avenida dos Estados, 5001, 09210-580, Santo André, SP, Brazil

HIGHLIGHTS

- We tested the use of cyclodextrins (CD) as additives for enhanced oil recovery.
- The CD decreased the oil-water contact angle for a dodecane drop immersed in brine in contact with a quartz surface.
- Molecular dynamics calculations indicated that the observed effects are due to the formation of inclusion complexes at the brine/dodecane interface.

GRAPHICAL ABSTRACT



only brine | brine + HP-α-cyclodextrin

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ABSTRACT

In the present work, cyclodextrins (CD) were tested as potential agents for enhanced petroleum recovery. For this purpose, wettability was evaluated through a combination of experimental measurements of the contact angle of a hydrocarbon drop (dodecane) on a quartz surface and molecular dynamics (MD) simulations. The whole system was immersed in a 0.6 M NaCl aqueous solution containing the CD. Here, the dodecane, the quartz and the NaCl solution represent the oil, the rock surface and the reservoir brine, respectively, thus mimicking the situation occurring in actual oil reservoirs. It was found that the presence of the CD in the aqueous phase consistently decreased the oil–water contact angle for the dodecane drop on quartz, indicating that the CD have an effect in displacing the hydrocarbon from the rock surface. The results show that cyclodextrins are potential candidates as additives in enhanced oil recovery. Complementary, MD calculations were performed to clarify the molecular mechanisms involved in the wettability modification due to the presence of the CD. Two different strategies were employed to determine the contact angles through MD, the first of them employing the Young–Laplace equation and the second using direct geometric measurements. The calculated contact angles were in good agreement with the experimental data. The MD results suggest that the decreased contact angles are mainly due to two effects: (i) formation of inclusion complexes between the CD and dodecane at the oil:water interface; and (ii) formation of CD monolayer on the quartz surface, resulting in a decreased surface wettability for the dodecane drop.

1. Introduction

About two thirds of the crude oil existing underground cannot be produced by the existing technologies, even after primary and secondary recovery methods have been employed [1]. Tertiary methods, also known as enhanced oil recovery (EOR), employ additives with the aim of further increasing petroleum recovery.

* Corresponding authors. Tel.: +55 11 49967943; fax: +55 11 49967943.
E-mail addresses: caetano.miranda@ufabc.edu.br (C.R. Miranda), sergio.brochsztain@ufabc.edu.br (S. Brochsztain).
[1] Current address: Universidade Estadual de Ponta Grossa (UEPG), Ponta Grossa, PR, Brazil.

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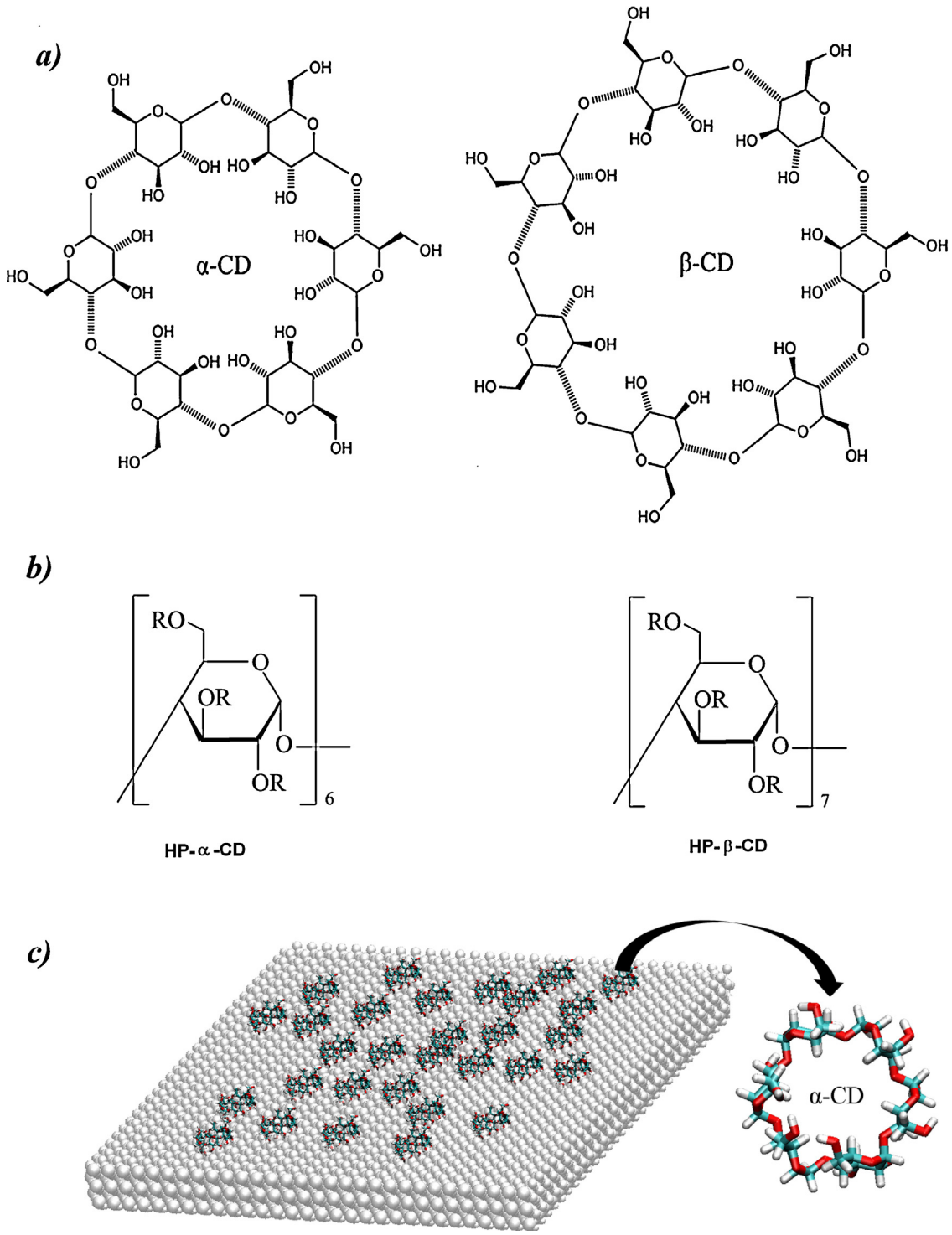

Fig. 1. (a) Structures of the pristine cyclodextrins α-CD and β-CD. (b) Structures of the 2-hydroxypropyl-cyclodextrins HP-α-CD and HP-β-CD; R = –H or $-CH_2CH(OH)CH_3$. (c) Schematic representation of a CD monolayer on a quartz surface, exposing the hydroxyl groups.

Among the different classes of additives used for EOR are those that modify the wettability of rock surfaces. Wettability has been known as an important factor in oil recovery [2,3]. These compounds are designed to make the rock surfaces more water-wet, or to decrease the oil/water interfacial tension, thus facilitating the displacement of oil by water-flood processes [4].

Among the classes of compounds that have been explored as additives for EOR are the polysaccharides, particularly modified cellulose derivatives [5] and natural gums [6], such as xanthan and guar. These polysaccharides, however, are intended to alter fluid mobility (through viscosity increase), but not for wettability changes [7]. In the present work, we studied the potential use of cyclodextrins (CD) as additives for EOR. The CD are cyclic oligosaccharides constituted by glucose units linked to each other by α-1→4 bonds [8], resulting in truncated cone structures with a central cavity (Fig. 1). Although the CD have been extensively employed as additives for food and drugs, there are only scarce reports of studies involving CD for the petroleum industry [9,10].