DOI 10.1007/s12182-013-0275-4

Formation mechanism of micro-flows in aqueous poly(ethylene oxide) droplets on a substrate at different temperatures

Hu Yin-Chun, Zhou Qiong*, Wang Yu-Feng, Song Yun-Yang and Cui Li-Shan

Department of Material Science and Engineering, College of Science, China University of Petroleum (Beijing), Beijing 102249, China

Abstract: The drying of aqueous poly(ethylene oxide) (PEO) droplet on a substrate at different temperatures was studied. It was found that the contact line receded when the substrate was at a temperature above 60 ºC. Different nucleation behavior and surface profiles of PEO films were found in different droplets drying processes. The rheological properties of aqueous PEO solutions were studied to understand the mechanism of contact line recession and micro-flow in drying aqueous PEO droplets. It was found that at low temperature, the contact line was static because of great viscous stress; while at high temperature, it receded because of great Marangoni force and the decrease of viscous stress. It was indicated that Marangoni convection was inhibited by the outward capillary flow and viscous stress at low temperature, whereas it became dominant at high temperature. Two types of mechanism for surface profiles and nucleation of PEO film from drying droplets are proposed, providing a theoretical guide for polymer solution application in oil and gas foam flooding technology.

Key words: Poly(ethylene oxide), droplet; micro-flow, nucleation, surface profile

1 Introduction

The micro-flow and solute transportation in drying droplets have been extensively studied based on colloidal suspensions or polymer solutions in recent years because of their important application in the fields of high-resolution ink-jet printing, thin films and coating materials (Sirringhaus et al, 2000; Park et al, 2006; Bormashenko et al, 2007; Cawse et al, 2003). Drying droplets of colloidal suspension can form “coffee ring” stains due to the capillary flow caused by contact line pinning (Deegan et al, 1997). The later studies showed that the Marangoni effect must be taken into account to investigate the droplet drying process (Hu and Larson, 2006). Marangoni convection is formed due to the difference of surface tension on the surface of drying droplets, and it plays a major role in the formation of deposition patterns, and can produce solute deposits at the center rather than the edge of the droplets (Hu and Larson, 2002; 2005a; 2005b; 2006).

Viscous force varies with the solute concentration in polymer solutions, and it cannot be ignored in drying droplets of polymer solution. So the deposition pattern formed by micro-flow in drying droplets of polymer solution is complex (Kajiya et al, 2009a; 2009b). Willmer et al (2010) studied drying aqueous PEO droplets with different initial PEO concentrations, c_0, at ambient conditions. They found that a disk-like deposit of solid PEO was left when the drying droplets c_0<3%, and solid conical structures formed during multistage drying of droplets when $c_0 \geq 3\%$. They proposed a drying and deposition process comprising four stages (fixed and drying, receding contact line, “bootstrap” growth, and late drying) to interpret their experimental data. Kim et al (2011) found that the transportation direction of polymer inside the drying droplet varied with substrate temperature, and the resulting deposit patterns were also changed from center-concentrated to edge-concentrated deposit patterns by the flow dynamics. These results clearly show that controlling substrate temperature is an effective way to manipulate the micro-flows inside drying droplets and deposition patterns after the drying process.

Foam flooding oil and gas technology is an important research area in enhanced oil recovery (EOR) in China. A foam flooding system is generally comprised of a foaming agent, foam stabilizer, gas, and water etc. The foaming agent is generally a surfactant, and the foam stabilizer is a water-soluble polymer, such as polyacrylamide or polyvinylpyrrolidone. Foam stability is one key factor affecting foam flooding. Pratt (1991) and Rudin and Wasan (1993) have proposed that the interface turbulence resulting from Marangoni convection could be used in the production of residual oil or gas, and it might be a new method to enhance oil recovery. Polymer solution is widely used

*Corresponding author. email: cuppolymer@163.com
Received August 23, 2012