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The comparison of rheological properties of aqueous welan gum and xanthan gum solutions

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ABSTRACT

Rheological properties of welan gum and xanthan gum solutions have been characterized systematically at various concentrations, temperatures and salinities. It is found that the viscoelasticity of welan gum is higher than that of xanthan gum at the same condition though the molecular weight of welan gum is lower. In view of this, welan gum will make a good performance in enhanced oil recovery, especially in high temperature and high salinity reservoirs. Network structure can be formed in solutions of welan gum and xanthan gum for the dynamic modulus has exponential relationship with the concentration. Moreover, the molecular aggregates of welan gum adopt a different arrangement with that of xanthan gum, adjacent double helices of welan gum arrange in parallel as the zipper model. The structure formed by zipper model is still stable in high temperature and high salinity.

1. Introduction

Water-soluble polymers have been used for polymer flooding in enhanced oil recovery (EOR) (Kjøniksen, Beheshti, Kotlar, Zhu, & Nyström, 2008; Long, Li, Xu, & Masliyah, 2011; Sabhapondit, Borthakur, & Haque, 2003; Taylor & Nasr El Din, 1998; Zhang, Dong, & Zhao, 2010). They can control mobility and reduce the formation permeability in the reservoir by increasing the viscosity of the injected water. The increased viscosity of the polymer solution can increase the residual resistance factor and improve sweep efficiency. So an important feature for a potential polymer to be used for polymer flooding in EOR is that the solution of water-soluble polymer has the favorable rheological behaviors, increasing the swept volume of displacement fluids (Kang & Dong, 1997, chap. 1; Rao et al., 2011).

Xanthan gum is a high molecular extracellular polysaccharide produced by bacterium *Xanthomonas campestris*. At present, xanthan gum is one of the two commonly water-soluble polymers used for polymer flooding, and makes a more excellent performance in salt resistance than that of hydrolyzed polyacrylamide (HPAM) in EOR. But the aqueous solution is deficient in elasticity. At lower temperature xanthan gum molecules exist as a double helix, but get converted into disordered coil at higher temperature (Bejenariu, Popa, Picton, & Le Cerf, 2010). The application of xanthan gum is limited in the high temperature reservoirs for its defect in thermal stability.

Welan gum is a new microbial polysaccharide produced by *Alcaligenes* sp. It has potential industrial applications in food, concrete, petroleum, ink and other industries (Mohammed, 2006; Ogugbue and Shah, 2009; Plank, Lummer, & Dugonjic-Bilic, 2010; Sonebi & Malinov, 2011). Especially in the oil industry, welan gum is expected to become a novel oil recovery agent for its excellent rheological properties (Colby, 2010; Masakuni & Masahiro, 1990). Recently, we have found that when welan gum was injected the oil recovery is markedly higher than that of xanthan gum at the same condition (Xu, 2012, chap. 2).

The rheological properties of macromolecular solutions are important for many industrial fields, and the microstructure or interaction between macromolecule and solvent in solutions may be illustrated via them (Rashidi, Blokhus, & Skauge, 2010; Saadatabadi, Nourani, & Emadi, 2010; Xin, Xu, Gong, Bai, & Tan, 2008; Xin, Xu, Wu, Li, & Cao, 2007; Yu, Zhou, & Zhou, 2010). For example, the rheological behaviors of injected fluids play an important role in modifying oil-displacing efficiency in EOR, which attracts considerable attention in controlling viscoelastic properties of injected fluids (Wang, Xia, Liu, & Yang, 2001). The rheological behavior of welan gum solutions has rarely been reported so far (Masakuni & Masahiro, 1990). In this paper, we have systematically investigated the influence of the concentration, temperature and salinity on the rheological properties of welan gum solutions, comparing with that of xanthan gum at the same time, in order to provide basic data for the application of welan gum in EOR.

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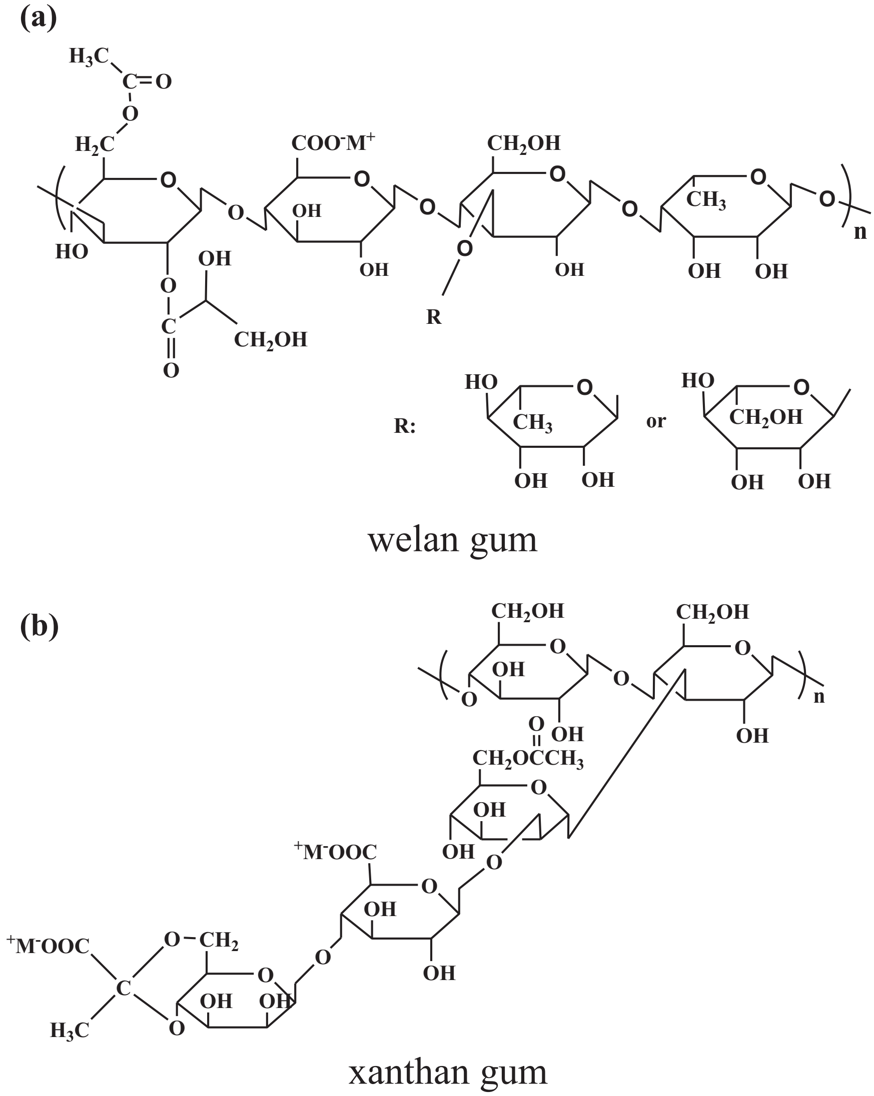

Fig. 1. (a) The structure of welan gum. Welan gum consists of pentasaccharide repeating unit, β-1,3-D-glucopyranosyl, β-1,4-D-glucuronopyranosyl, β-1,4-D-glucopyranosyl and α-1,4-L-rhamnopyranosyl, and a single monosaccharide side-chain at O-3 of the 4-linked glucopyranosyl. The monosaccharide may be either L-rhamnopyranosyl or L-mannopyranosyl in the approximate ratio 2:1, and about half of the repeat units or more have acetyl and glyceryl substituents (Rinaudo, 2004; Tako, Teruya, Tamaki, & Konishi, 2009). (b) The structure of xanthan gum. Xanthan gum has a cellulosic backbone consisting of five monosaccharides to give a pentasaccharide repeating unit. The cellulosic backbone is substituted at C-3 on alternate β-1,4-D-glucopyranosyl residues with a trisaccharide side chains of β-D-rhamnopyranosyl, β-1,4-D-glucuronopyranosyl and α-1,2-D-mannopyranosyl with various amounts of acetyl and pyruvate substituents (De Jong & Van de Velde, 2007; Mukherjee, Sarkar, & Moulik, 2010; Rodd, Dunstan, & Boger, 2000).

2. Experimental

2.1. Materials

Welan gum was supplied by Food Fermentation Industry Research Institute of Shandong Province, China. The molecular weight is about 6.6×10^5 g mol^{-1}, and the intrinsic viscosity is 4479 mL g^{-1}. Xanthan gum (FUFENG 80) was produced by Inner Mongolia Fufeng Biotechnology Co., Ltd. The molecular weight is about 2.0×10^6 g mol^{-1}, and the intrinsic viscosity is 7627 mL g^{-1}. The structures of welan gum and xanthan gum are displayed in Fig. 1a and b. Water used in the experiment was triply distilled by a quartz water purification system. Salinity of three mineralized water used in the experiment is 3908 mg L^{-1}, 6664 mg L^{-1} and 9374 mg L^{-1}, respectively, which is based upon the formation water in three oil fields.

2.2. Rheology

The concentrated solutions of welan gum and xanthan gum were prepared by mechanical stirring at room temperature, and then were diluted to the required concentrations. The rheological measurements were carried out on a Haake RS75 Rheometer (Germany) with a coaxial cylinder sensor system Z41-Ti. The maximum allowable temperature deviation was ±0.1 °C. Samples were kept stationary more than 24 h before measuring to guarantee that no bubbles present in them. Samples were remained 5 min before measuring. Rate control mode, CR, was chosen in the steady-state shearing experiment, the range of shear rates was from 0.01 s^{-1} to 1000 s^{-1}. The stress sweep was carried out with the stress range from 0.01 Pa to 20.00 Pa at the fixed frequency 1.00 Hz. Then the oscillatory frequency sweep measurements were carried out at a frequency of 0.01–10.00 Hz in the oscillation mode, OSC.