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Study on foaming of formulated solvent UDS and improving foaming control in acid natural gas sweetening process

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ABSTRACT

The influences of various factors including concentration of solvent, operation temperature, gas flow rate, CO_2 loading on foaming tendency of UDS solvent were experimentally investigated under simulated conditions. Foaming tendency test was combined with physical characterization to enhance the understanding of the foaming behavior. It was indicated that the foam height kept increasing while the foam breaking time first rose and then dropped as gas flow rate increased. Foaming tendency increased and eventually decreased with UDS concentration. Moreover, an increase in CO_2 loading enhanced foaming tendency. Meanwhile, lower solution temperature resulted in larger foam height and longer breaking time. Surface tension, viscosity, and density of solutions played complex roles in determining foaming tendency and foam stability. A semi-empirical model considering gravitational force, viscous force and surface tension force was found to be able to explain the parametric effects on the foaming of UDS solution and predict its foaming behavior very well. Finally, defoaming agent DF-C was observed to improve the foaming control of UDS system to a satisfactory level.

1. Introduction

Foaming has always been one of the most serious problems in high acid natural gas purification process that remove carbon dioxide and various sulfides by using aqueous solutions of various alkanolamines. It has been reported to have a lot of negative impacts on purification performance and operation stability, including premature flooding, solvent carryover to downstream plants, consumption of recycling solvents, reduction in plant production, and unqualified products (Pauley, 1991; Stewart and Lanning, 1994). Foaming is caused by improper operating conditions and contaminants on the basis of available operation experiences from industrial plants (Liebermann, 1980; Keaton and Bourke, 1983; Abdi et al., 2001). Systematic work has been carried out to reveal the influences of different factors and to explain the mechanism of foaming induced by various contaminants (Al-Dhafeeri, 2007; Chen et al., 2011; Thitakamol and Veawab, 2008; Alhseinat and et al., 2014a; Pal et al., 2013; Alhseinat and et al., 2015; Alhseinat and et al., 2014b). These contaminants could be degradation products of alkanolamine, dissolved hydrocarbons, organic acids, suspended solids, additives (for example, corrosion inhibitors and defoaming agents), water-soluble surfactants, and ionogenic substances in mining water. Various measures, such as mechanical filtration, hydrocyclone separation, activated carbon adsorption, and addition of defoaming additives, have been extensively investigated and tested to prevent and control foaming problems (Pauley, 1991; Abdi et al., 2001).

Several semi-empirical equations have also been put forward to explain the foaming mechanism of liquid–vapour systems based on the Buckingham-Pi theory (Ito and Fruehan, 1989; Jiang and Fruehan, 1991; Zhang and Fruehan, 1995). Pilon et al. (Pilon et al., 2001) developed a foaming model to predict the height of isothermal foam produced by blowing gas in a solution by using the governing equation for the transient foam layer. In addition, it is concluded that foaming tendency and foam stability are functions of process parameters and physical properties of solution. Specifically, the viscosity, density, and surface tension of solution all play a fundamentally important role in determining its foaming performance through acceleration or deceleration of thinning process of the foam (Thitakamol and Veawab, 2009).

The desulfurization solvents UDS, a new formulated solvents based on alkanolamine, have been developed in the laboratory (Shen et al., 2014). UDS solvents are composed of UDS formula

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Table 1
Properties of anhydrous UDS solvent.

Properties	Value
Appearance	Light yellow liquid
Content of active components (wt %)	≥97.0
Density (g/ml), 20 °C	1.035–1.065
Viscosity (mPa s), 20 °C	≤90.0
Content of basic nitrogen(g/L)	≥110

component and MDEA solvent. Furthermore, their formulas can be varied according to the compositions of raw natural gases as well as the purification requirements. UDS formula component is mainly composed of morpholine compound with ring structure and sulfolane compound improving physical solubility of organosulfurs. Furthermore, it has been successfully applied in natural gas sweetening processes and shows excellent desulfurization and decarbonization performance (Zhang and et al., 2009; Zhang and et al., 2011; Zhang and et al., 2014). Besides the desulfurization capability of solvent and operation conditions, various factors including concentration of solvent, operation temperature, gas flow rate, CO_2 loading also play important roles in affecting the foaming tendency of solvent and determining the desulfurization performance of industrial processes. The main objective of this paper is, therefore, to reveal the parametric effects and to understand the possible mechanism related to foaming of UDS solvent. The comprehensive relationships among solvent properties, operation parameters and foaming tendency were experimentally investigated under simulated conditions. Such a study leads to find the underlying reasons and to improve the foaming control during natural gas sweetening process.

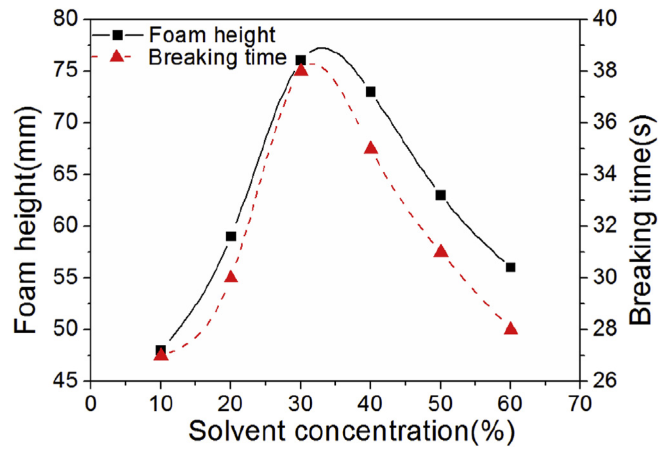


Fig. 2. Effect of concentration of UDS on foam height and breaking time at 313 K.

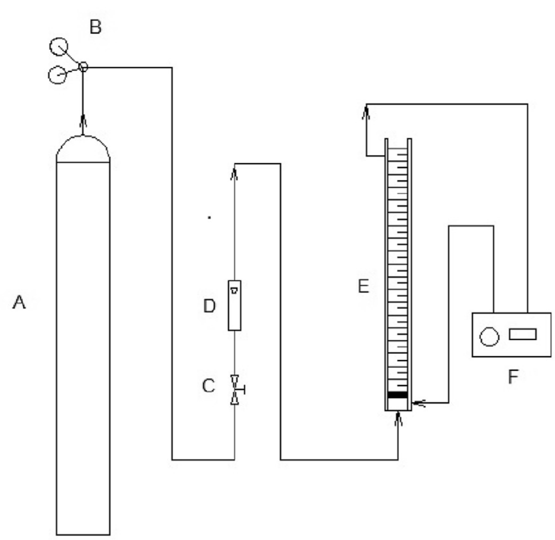
2. Experimental

2.1. Materials and reagents

UDS solvent was prepared in this laboratory with the content of effective components more than 99% and its properties (anhydrous) were shown in Table 1. Deionized water was used for all experiments. N_2 and CO_2 with a purity 99.99% was from Shanghai Wugang Gas Company. Four types of defoaming agents were used for reducing the foaming tendency of UDS. The defoaming agent

Table 2
Manufacturer and composition of different defoaming agents.

Type of antifoaming agents	Manufacturer	Composition
DF-A	Dow corning corporation	Milky-white liquid and silicone emulsion
DF-B	Yantai Hengxin Corporation	Block polymers of poly-oxypropylene and poly-oxyethylene
DF-C	Nanjing Huaxing Corporation	Polysiloxane, silicone resin, white carbon black, dispersant and stabilizer
DF-D	Nanjing Huaxing Corporation	Mineral oil, white carbon black, polyether ester and synergistic agent



A- gas cylinder, B- reducing valve, C- needle valve, D- rotor flow meter, E-foaming pipe,
F- thermostatic waterbath

Fig. 1. Flowchart of foam performance test.