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Electromagnetic separation of heat stable salt from gas sweetening amine

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ABSTRACT

This paper aims at the development and application of electromagnetic-mechanical salt removal (EMSR) process for the removal of Heat Stable Salt (HSS) from Gas Sweetening Amine. The operation of the EMSR process is investigated numerically to examine its efficiency under different operating conditions. The mathematical approach used for the EMSR modeling is based on solving the Navier–Stokes equations using Eulerian approach, and solving the HSS movement using Lagrangian approach. The important parameters that affect the separation process are examined using the developed model. The study results show that the EMSR process efficiency is enhanced with the increase in MDEA solution temperature. It is found that the decrease in MDEA concentration improves the removal of the HSS. In the study, it is found that around 70% removal of the HSS can be achieved using the EMSR. It is demonstrated that EMSR can be used effectively to separate dissolved HSS from MDEA solution.

1. Introduction

Amine based solvent absorption is the most widely accepted technique for CO_2 and H_2S removal from natural gas. Some of the alkanolamines for this purification process are monoethanol amine (MEA), diethanol amine (DEA), and Nmethyl diethanol amine (MDEA). The main problem of this absorption process is the solvent degradation due to the formation of heat stable salts (HSS) such as sulfates, acetates, formates, and nitrates. This results from the reactions between the amine solvents and other impurities, such as SO_2, NO_2, and O_2, in the feed gas stream. These salts and impurities can cause problems such as an increase in corrosion the operating units and increase in operating cost due to the increase in solvent viscosity.

There is crucial need to purify the alkanolamines in natural gas sweetening units. More clean alkanolamines will increase the overall process efficiency. Thus, it is essential to develop a reliable, and cost effective technology to improve the removal of charged species like HSS and metal ions from lean alkanolamines. Solvents degradation can occur when the solvents are subjected to high temperature (Davis and Rochelle, 2009). Most of the studies postulate that degradation is due to high temperature in the presence of CO_2. There are also some studies that reported solvent degradation due to high temperature without CO_2 (Lepaumier et al., 2009).

Solvent degradation occurs through irreversible chemical reactions between the amine and some components of the gas to be treated, or with contaminants in the solvent itself. The degradation of aqueous amine solvents causes deterioration in performance and increasing costs. Numerous degradation products, formed by exposure of the amine solution to heat, oxygen and strong acids, have been reported over the past few decades. The generated degradation products can cause an increase in foaming which increases the operating costs (Chen et al., 2011; Cummings et al., 2007). The HSS also contribute to system corrosion, which reduces the equipment's lifetime. An increased corrosion rates due to the presence of HSS is reported by (Nainar and Veawab, 2009; Gao et al., 2011; Choi et al., 2010). The presence of only 500 ppm of amine HSS may increase corrosion rates by 50 times (Rooney et al., 1997; Rooney, 1999). Table 1 shows the maximum acceptable concentration of degradation products. Typical salts of heat stable anions include alkali metal sulfates, alkali metal halides, alkali metal acetates, alkali metal thiocyanates, alkali metal thiosulfates, alkali metal nitrates and nitrites, alkaline earth nitrates and nitrites.

There are some methods used to mitigate the effect of these impurities on the operation of the absorption amine systems such as neutralization, purging, filtration and distillation. Filtration is used to remove precipitated salts, but it can cause a loss of amine solution. Alternative techniques such as electrodialysis (ED) and ion exchange are gaining traction; they offer the potential for reduction in both the cost and the amount of waste generated and they can operate at a large pH range. The focus of this study is on the electrical and magnetic separation.

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Nomenclature

B	Magnetic field (Tesla or N s/C m)
C	Salt concentration
C_D	Drag coefficient
d_p	Particle diameter (m)
F_D	Drag force (N)
F_E	Electrical force (N)
F_M	Magnetic force (N)
F_{EM}	Electrical and magnetic force (N)
F_{GB}	Gravitational and buoyant forces (N)
f_D	Drag force per unit particle mass (N/kg)
f_E	Electrical force per unit particle mass (N/kg)
f_M	Magnetic force per unit particle mass (N/kg)
g	Gravitational acceleration (m/s^2)
E	Electrical field (N/C or V/m)
h(y)	Particle distance from the upper wall
H	Height of flow channel (m)
L	Length of flow channel (m)
$\dot{m}$	Fluid flow rate (kg/s)
$\dot{m}_p$	Mass flow rate of ions (kg/s)
n_p	Number of particles
q	Ion charge (C)
R	Ion radius (m)
Re	Reynold number
S	Source term
τ_1	Residence time (s)
τ_2	Capture time (s)
η	Fluid viscosity (cP)
ρ_p	Particle density (kg/m^3)
u_p	Particle velocity in the x-direction (m/s)
v_p	Particle velocity in the y-direction (m/s)
w_p	Particle velocity in the w-direction (m/s)
V_p	Particle volume (m^3)
ν_z	Fluid velocity in the axial z-direction (m/s)
ν_y	Fluid velocity in the y-direction (m/s)

ED is an electrochemical process for separation of ions across charged membranes from one solution to another under the influence of an electrical potential difference used as a driving force. This process has been widely used for desalination of sea or brackish water, treatment of industrial effluents, recovery of useful materials from effluents and salt production. ED was developed in the 1950s for desalting water. The basic principles and applications of ED were reviewed in the literature (Winston Ho and Sirkar, 1992; Mohammadi and Kaviani, 2003; Mohammadi et al., 2004). In order to reduce membrane scaling and fouling, electro dialysis reversal (EDR) process is introduced, where the voltage is reversed at periodic time intervals (typically 15–30 min (Murray, 1995). The current methods for removing charged particles and ions from an electrolytic fluid typically utilize ion selective membranes. Replacing these membranes is costly, time-consuming, and disruptive, as the flow of the fluid being processed may have to be stopped for a period of time. Further, disposal of used membranes items may not be environmentally friendly. In addition, the expected lifespan for anion is 10 years, and for cation-exchange membranes is 15 years (Coberly et al., 1998). Many membranes are designed for a pH range from 2 to 9, and the typical pH range of lean amine solutions is pH 9–11 which may cause membrane failure.

Table 1
Physical properties of MDEA at different concentration and temperature (Abukashabeh et al., 2014).

(a) Density

MDEA density measurement at various concentrations and temperatures

MDEA concentration [wt%]	Density at corresponding temperature, [g/cm^3]		
	20 °C	50 °C	70 °C
40	1.0369	1.0194	1.0045
41	1.0374	1.0195	1.0050
42	1.0386	1.0207	1.0060
43	1.0396	1.0214	1.0074
44	1.0406	1.0222	1.0079
45	1.0412	1.0226	–
46	1.0422	1.0234	1.0084
47	1.0429	1.0240	1.0095
48	1.0433	1.0241	–
49	1.0445	1.0251	1.0104
50	1.0455	1.0259	1.0106

(b) Viscosity

Dynamic viscosity of MDEA solutions at different concentrations and temperatures

Concentration [%]	Viscosity at 20 °C [mPa s]	Viscosity at 50 °C [mPa s]	Viscosity at 70 °C [mPa s]
40	6.3751	2.3609	1.4753
41	6.6945	2.4182	1.5065
42	6.8233	2.4887	1.6226
43	7.4821	2.6161	1.6280
44	7.9937	2.7668	1.6814
45	8.2608	2.8591	1.7518
46	8.9456	2.9931	1.7905
47	9.3160	3.1170	1.8584
48	9.9648	3.3036	1.9537
49	10.5323	3.4021	2.0280
50	11.6181	3.6576	2.1310

The use of ED for amine purification is investigated in numerous studies (Coberly et al., 1998; Gregory and Cohen, 1999; Burns and Gregory, 1995). Electro-dialysis for amine purification is best operated at a low temperature (Smith et al., 2009). Neutralization with a base such as KOH, or NaOH, and microfiltration are usually required upstream of the ED unit (Gregory and Cohen, 1999). Filtration in general can cause loss of amine. The presence of suspended solids, hydrocarbons, or dissolved iron in the amine solution can cause fouling on the membrane surface, thus increasing the stack resistance and reducing the process efficiency (Dumee et al., 2012; Smith et al., 2009). If amine recovery is high, ion removal rates are lowered and ion removal rates is high, amine loss through the membrane is high (Lim et al., 2014). A further disadvantage is that some of the anions and the protonated amine can be transferred and lost in the process.

The main objective of this paper is to develop a simple and scalable continuous apparatus to separate HSS from aqueous amine solutions. The EMSR process does not utilize membranes for the removal of the ions. The object of the study will be approached theoretically and solved mathematically to examine the several important parameters of electrical and magnetic separation of HSS from amine solution. The mathematical approach developed by Alnaimat et al. (Alnaimat et al., 2016) is used in the current study.

2. Process description

The EMSR operation is based on the application of electrical and magnetic forces affecting the HSS particles within the amine solution. This is schematically shown in Fig. 1a and b. The EMSR consists of a rectangular channel with 1-inlet and 2-outlets as shown in Fig. 1b. The amine solution must be moving along the channel to have the magnetic forces deviate the particles in the desired direction. As shown in Fig. 1b, the amine is flowing in the axial z-direction. The electrical force is applied via metallic conductor plates (electrodes) placed on the channel