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Effect of gravity center position on amine absorber with structured packing under offshore operation: Computational fluid dynamics approach

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ABSTRACT

The effect of the center of gravity (CoG) position on the CO_2 removal efficiency was investigated for a pilot-scale amine absorber with Mellapak 250.X (M250X) structured packing subject to the pitching motion (i.e., 12 s period and 1.57° amplitude). A porous medium Eulerian computational fluid dynamics (CFD) model with porous resistance, drag force between gas and liquid, and dispersion force was used to represent the hydrodynamic properties of M250X. Three CoG positions, namely, bottom of the column (Case 1), vertically under the column (Case 2), and diagonally under the column (Case 3), were considered for two different diameters of the absorber. Case 3 showed the biggest liquid maldistribution because of a long distance between the amine absorber and CoG position. The CO_2 removal efficiency was lowest in Case 3 for the absorber having the larger column diameter. However, the difference between the CO_2 removal efficiencies of Cases 2 and 3 was not substantial.

1. Introduction

Liquefied natural gas-floating production, storage, and offloading (LNG-FPSO) is a new conceptual unit, and an effective and realistic way to exploit and utilize marginal gas fields and offshore associated gases (Gu and Ju, 2008). LNG-FPSO includes the pre-processing of natural gas such as de-acidification and dehydration for removing impurities (Gu and Ju, 2008). In the de-acidification process, CO_2 is separated from raw gas (Kim et al., 2014). The CO_2 removal process often uses an amine absorption column containing structured packing, which has less pressure drop, less severe foaming, and higher mass transfer efficiency than a tray column (Aroonwilas et al., 2003; Owens et al., 2013; Pham et al., 2015b; Tsai et al., 2011). Thus, structured packing for the direct contact of gas and liquid is commonly adopted in offshore operations (Gu and Ju, 2008; Weiland et al., 2013).

Offshore columns can be subject to six motions, i.e., angular (roll, pitch, and yaw) and translational (surge, sway, and heave) motions (Spiegel and Duss, 2014). Predominately, the liquid flow path is influenced by dynamic and static deviations of the column axis away from the vertical axis as well as acceleration forces exerted on the liquid phase (Spiegel and Duss, 2014). Angular motions induce an offset of the column axis from the vertical line, which is referred to as the dynamic tilt. Since the liquid is driven by gravity, the dynamic tilt causes liquid maldistribution close to the column wall (Spiegel and Duss, 2014). This maldistribution can result in a substantial reduction in the CO_2 removal efficiency (Moorkanikkara et al., 2014).

An experimental setup combining a column packed with glass bead particles and a robot with six-degree-of-freedom motions was built to investigate two-phase flow hydrodynamics under gas–liquid cocurrent descending flows (Dashliborun and Larachi, 2015). This setup was used for a liquid drainage study wherein dynamic tilting caused a periodic gas–liquid segregation as a result of gravitational and acceleration forces. Using the same equipment as the porous packed-bed, the liquid drainage dynamics in vertical, inclined (or tilting), and symmetric oscillating (or motion) conditions were numerically analyzed via an unsteady-state three-dimensional (3D) two-fluid computational fluid dynamics (CFD) model (Iliuta and Larachi, 2016).

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Nomenclature

A	Cross-sectional area of column (m^2)
a	Modification factor of Ergun equation
a_e	Effective interfacial area (m^2/m^3)
a_s	Specific surface area of structured-packing (m^2/m^3)
b	Modification factor of Ergun equation
c	Modification factor of Ergun equation
C_k	Molar concentration of species k in liquid phase ($kmol/m^3$)
d	Modification factor of Ergun equation
D	Diffusivity coefficient (m^2/s)
D_c	Diameter of column (m)
E_1, E_2	Ergun coefficients
E_a	Activation energy (cal/mol)
F	F-factor ($Pa^{0.5}$)
$\vec{F}_{disp}$	Liquid dispersion force (N/m^3)
f_e	Fraction of wetting area
$\vec{F}_{exch,GL}$	Momentum exchange force (N/m^3)
$\vec{F}_{porous}$	Porous resistance force (N/m^3)
f_{spread}	Liquid spreading factor (m)
g	Gravitational acceleration (m/s^2)
h	Packing height (m)
h_L	Liquid holdup (m^3/m^3)
H	Henry's constant ($Pa\,m^3/mol$)
H_c	Column height (m)
$\vec{i}$	Unit vector of x-direction
$\vec{j}$	Unit vector of y-direction
$\vec{k}$	Unit vector of z-direction
k_0	Pre-exponential factor ($m^3/kmol/s$)
k_c	Chemical reaction rate coefficient ($m^3/kmol/s$)
K_{GS}	Gas–solid drag coefficient ($kg/m^3/s$)
K_{IG}	Momentum exchange coefficient at the gas–liquid interface ($kg/m^3/s$)
K_{LS}	Liquid–solid drag coefficient ($kg/m^3/s$)
k_x	Lumped mass transfer coefficient in liquid phase (m/s)
L_p	Wetted perimeter (m)
l_r	Arc length (cm)
m	Mass flow rate (kg/h)
M_w	Molecular weight (kg/kmol)
P	Pressure (atm)
ΔP_{wet}	Wet pressure drop (Pa/m)
Q	Liquid flow rate (m^3/s)
q_L	Liquid load ($m^3/m^2/h$)
r	Radius from center of gravity (CoG) to top of column
$\vec{r}$	Position vector (m)
R	Gas constant (kJ/kmol/K)
R^2	Correlation coefficient
r_{GL}	Mass transfer rate between gas and liquid ($kg/m^3/s$)
R_i	Chemical reaction rate of species i ($kg/m^3/s$)
$\vec{S}$	Momentum source term (N/m^3)
t	Time (s)
T	Period of ship motion (s)
T_{in}	Inlet temperature (K)
$\vec{u}$	Interstitial volume-averaged velocity (m/s)
$\vec{u}_{d,pitch}$	Unit direction vector under the pitching motion (m/s)
u_{GS}	Superficial gas velocity (m/s)
UI_h	Uniformity index of liquid holdup
UI_v	Uniformity index of liquid velocity
$\vec{v}_{mesh}$	Mesh velocity (m/s)
x_i	Gas mass fraction of species i
y_i	Gas mole fraction of species i

Greek letters

α	Volume fraction
ε	Packing void fraction (porosity)
η	CO_2 removal efficiency (%)
θ	Angle under pitching motion (radian)
θ_{max}	Maximum angle of angular motion (°)
σ	Surface tension of MEA solution (N/m)
μ	Viscosity (Pa s)
ρ	Mass concentration or density (kg/m^3)
$\vec{\omega}$	Angular velocity (°/S)

Subscripts

D	Drift
G	Gas
L	Liquid

Pham et al. (2015a) conducted a CFD simulation for the amine absorber with Mellapak 500.X in order to investigate the effect of ship tilting and motion on CO_2 removal efficiency. In that report, the momentum equation included the porous resistance, gas–liquid momentum exchange, and liquid dispersion in the gas–liquid porous media Eulerian CFD model (Pham et al., 2015a,b). Kim et al. (2016) described how to determine the hydrodynamic parameters of structured packings in this porous media Eulerian CFD model. However, few researchers have addressed the effect of the center of gravity (CoG) position subject to the motion of a ship on the CO_2 removal efficiency of the amine absorber. Since the topside facilities on the deck of offshore floating platforms are located at a distance from the CoG of the ship and may be subject to asymmetric oscillation or motion, the layout of chemical processes can affect the process performance (Mitra, 2009).

In this study, the porous media Eulerian CFD model is applied to an amine absorber packed with M250X for capturing CO_2. The layout of the amine absorber is taken from the location of a real topside plant. The CFD model is first validated with experimental data obtained from a conventional vertically-standing amine absorber. Three CoG positions, i.e., at the bottom of the column, vertically under the column, and diagonally under the column, are applied along with two different amine absorber diameters. The effect of the CoG positions is then examined in terms of pressure drop, liquid holdup, effective interfacial area, gas and liquid velocities, and the CO_2 mole fraction.

2. Geometry and meshing of amine absorber

The performance of an offshore process depends not only on the ship motion but also on the position of the equipment relative to the CoG. For the layout of topside facilities on FPSO, an important consideration is to locate the process equipment as close as possible to the CoG of the vessel, where the vessel motions are the least severe (Mitra, 2009). However, even when the process equipment is mounted on the platform located at a longitudinal position close to the CoG of the barge, the position of the equipment still deviates vertically, longitudinally, and transversally from the CoG.