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# A liquid distribution model for a column with structured packing under offshore conditions

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## HIGHLIGHTS

- Liquid distribution model under offshore conditions was firstly proposed.
- The results of proposed model were agreed well with the behaviors of published experimental data.
- The effects of offshore conditions and column dimensions on liquid distribution were studied.

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## ABSTRACT

A liquid distribution model for a packed column with structured packing under offshore conditions is proposed. In this paper, permanent tilt and dynamic roll motion were selected as representative offshore conditions for the proposed model, considered to be the most severe offshore conditions. The proposed model is composed of an intersection network model with a liquid split algorithm. Parameter estimation was performed for the proposed model using published experimental data to adjust the parameters in the liquid split algorithm for the considered offshore conditions. A comparison between the liquid distribution of the proposed model and that of literature data was also presented. Using the adjusted parameters and proposed model, the main characteristics of liquid distribution under offshore conditions were investigated. In addition, the effects of column diameter and packed height on liquid distribution were studied. The results obtained from the proposed model could be the basis for the design of an absorption column installed on a buoyant platform like a floating production storage and offloading (FPSO) unit.



## 1. Introduction

The gas absorption column, typically designed as a packed bed, is one of the traditional unit operations that have been long employed in the chemical industries. Although large amounts of experimental results and operational experience have been accumulated, the hydrodynamic and mass transfer phenomena inside the packed bed are still hard to predict, and the packed bed design inevitably bears a larger uncertainty than do other unit operations. For this reason, studies are still continuously being conducted, especially on the liquid and gas distributions inside the column (Adler et al., 2000), using mechanistic models (Nawrocki et al., 1991; Aroonwilas and Tontiwachwuthikul, 2000; Qiu et al., 2003; Brunazzin and Paglianti, 1997), computational fluid dynamics (CFD) models (Yin et al., 2002; Raynal and Royon-Lebeaud, 2007; Atta et al., 2007), and experimental observations (Marchot et al., 1999; Fourati et al., 2012; Doan and Lohi, 2011; Aferka et al., 2011).

Acid gas removal (AGR) in the liquefied natural gas (LNG) facility and also in the refinery is a representative application of the packed-bed gas absorption column. Due to its long industrial history, there have emerged no outstanding issues in the design of the AGR unit (AGRU) operated under onshore conditions. As the floating production storage offloading (FPSO) plant has become important from the economic recovery of offshore stranded gas, however, the behaviors of the absorption column under offshore conditions need to be newly investigated. Various offshore motions such as tilt and rolling create a mal-distribution of liquid flow, and this causes the degradation of the mass transfer and thereby the absorption performance. Experimental and theoretical studies to investigate the liquid distribution under offshore conditions have been reported (Waldie et al., 2004; White et al., 2010; Tanner et al., 1996; Pham et al., 2015; Duss and Roza., 2014), but

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**Nomenclature**

*Parameters and variables*

| | |
|---|---|
| $B$ | half of corrugation base length (m) |
| $H_{crimp}$ | crimp height (m) |
| $L_i^{exp}$ | experimental liquid flow rate of $i$th row sector ($m^3/s$) |
| $L_{mean}$ | mean liquid flow rate ($m^3/s$) |
| $L_i^{LDM}$ | model liquid flow rate of $i$th row sector ($m^3/s$) |
| $M_f$ | mal-distribution factor |
| $N$ | the number of cells over the column cross-section |
| $Q$ | sum of incoming liquid flow ($m^3/s$) |
| $\widehat{Q}$ | sum of incoming liquid flux ($m^3/m^2/s$) |
| $Q_{mean}$ | average liquid flow rate over the column cross-section ($m^3/s$) |
| $\widehat{Q}_{mean}$ | average liquid flow rate over the column cross-section ($m^3/m^2/s$) |
| $T$ | period of roll motion (s) |
| $X$ | vector of adjustable parameters |
| $X_{\min}$ | lower bound of X |
| $X_{\max}$ | upper bound of X |
| $W_p$ | percentage of wall flow (dimensionless) |
| $f$ | perforation ratio (dimensionless) |
| $f_v$ | vertical flow ratio (dimensionless) |
| $f_w$ | wall flow ratio (dimensionless) |
| $h_i$ | unit length of $i$-axis ($y$-axis) |
| $h_j$ | unit length of $j$-axis ($x$-axis) |
| $h_k$ | unit length of $k$-axis ($z$-axis) |
| $q_1$ | liquid rivulet for packing channel in direction #1 ($m^3/s$) |
| $q_2$ | liquid rivulet for packing channel in direction #2 ($m^3/s$) |
| $q_3$ | liquid rivulet for perforation channel in direction #3 ($m^3/s$) |
| $q_4$ | liquid rivulet for perforation channel in direction #4 ($m^3/s$) |
| $q_5$ | liquid rivulet for perforation channel in direction #5 ($m^3/s$) |
| $q_6$ | liquid rivulet for perforation channel in direction #6 ($m^3/s$) |
| $q_7$ | liquid rivulet for vertical flow ($m^3/s$) |
| $q_w$ | liquid rivulet for wall flow ($m^3/s$) |

*Greek letters*

| | |
|---|---|
| $\alpha$ | split ratio of the flow to a packing channel rivulet |
| $\beta$ | split ratio of the flow to a perforation channel rivulet |
| $\gamma$ | asymmetric fraction for perforation channel rivulet |
| $\lambda$ | asymmetric fraction for packing channel rivulet |
| $\tau$ | tilt angle (°) |
| $\tau_{eff}$ | effective tilt angle (°) |
| $\phi$ | alignment angle (°) |
| $\psi$ | position angle on the wall intersection (°) |
| $\eta_i$ | split ratios for wall flow, $i = up, low, ver$ |
| $\mu$ | weighting factor |

there have been few published papers that propose a liquid distribution model in a packed column under these conditions. Because understanding the liquid mal-distribution is the starting point for the systematic exploration of the performance decline of a packed column subject to offshore conditions, a reliable liquid distribution model (LDM) would significantly help the investigation.

LDMs have been proposed for a vertical packed column. Nawrocki et al. (1991) firstly proposed a systematic liquid distribution model to calculate mass transfer area. Their LDM is based on intersections created by the contact points of corrugated sheets of structured packing. By applying a mechanistic liquid split algorithm at each intersection, the liquid rivulet distribution could be obtained in a three-dimensional region. The simple liquid split algorithm was employed to divide the liquid flow at an intersection point into two paths; one is along the original channel, and the other through the intersection point. Aroonwilas and Tontiwachwuthikul (2000) improved the Nawrocki et al.'s model by introducing more split paths. However, they did not consider the wall and vertical flows. Qiu et al. (2003) incorporated the wall and vertical flows proposed into their LDM, but did not consider the flow division through the perforation holes.

To establish an LDM with improved model accuracy and reliability, liquid rivulets in all possible directions up to the wall flow need to be included on the basis of the geometric configuration of the packing material. Moreover, for the model to be able to appropriately represent the mal-distribution caused by offshore motions, the liquid distribution along the various directions should be flexibly adjusted.

Inspired by previous contributions (Nawrocki et al., 1991; Aroonwilas and Tontiwachwuthikul, 2000; Qiu et al., 2003), an improved mechanistic LDM for an absorption column packed with a structured packing is proposed. The LDM was designed to be able to flexibly represent the liquid mal-distribution by offshore motions. For this, all conceivable flow directions up to the wall, including vertical and perforation flows, were included in the model with the respective flow split ratios as adjustable parameters. The liquid flow distribution becomes radially asymmetric under the offshore conditions, where the asymmetry depends on the tilt direction in relation to the packing orientation. This effect was also taken into account in the model. In this study, the proposed LDM was fit to published experimental data (Fourati et al., 2012) for tilted columns and was found to represent the behaviors of real columns fairly well. Using the LDM with estimated parameters, the major characteristics of the liquid distribution in a packed column with structured packing were derived, including the effects of the column height, diameter and offshore conditions, using the mal-distribution factor and percentage of wall flow.

## 2. Development of an improved liquid distribution model

### 2.1. Configuration of the structured packing

A packed column is composed of various column internals such as the liquid distributor, packing materials, demister, and sump. In the case of structured packing, multiple packing elements are stacked one over another and constitute a single bed. Fig. 1 shows the configuration of employed packing same as Mellapak 500Y by Sulzer, a representative structured packing type. The packing element is fabricated by the side-by-side layering of two mirror-image corrugated sheets. During stacking, a packing element is placed so that the orientation of the corrugated sheets is perpendicular to that of the lower element for a uniform liquid distribution.

In Fig. 1, the black solid lines indicate corrugated sheets of type A, and the gray dashed lines represent sheets of type B, which is the mirror image of type A. Corrugations are designed to be parallel and slanted. For two paired sheets, the slant directions are reversed, and the sheet pairs touch at points called intersections.