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Fluodynamics of a Column Filled with Glass Rings Using the Air-Water System

João C. F. Lima[*1], **Silvana Mattedi**[2], **Luiz M.N.Góis**[3]
[*1] PPEQ/Federal University of Bahia, Salvador, Bahia, Brazil
[2] PPEQ/Federal University of Bahia, Salvador, Bahia, Brazil
[3]EAETI/UNIFACS, Salvador, Bahia, Brazil

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ABSTRACT

In the current study, we present the fluid dynamics of an absorption tower equipped with glass rings as fillings. The research involved investigating the variations in pressure drop concerning liquid (water) and gas (atmospheric air) flow rates. We thoroughly examined the impacts of these two flows, identifying specific ranges where flooding and liquid entrainment take place. Additionally, we pinpoint a critical threshold that signifies the maximum allowable combination of the two flows, denoted as Q_{water}/Q_{air}, for effective tower operation.

Keywords: Fluodynamics, Packed Columns, Absorption

I. INTRODUCTION

Absorption is an operation wherein a gas mixture comes into contact with a liquid to selectively separate one or more components. This process involves the transfer of the solute from the gas stream to the liquid stream. Conversely, when this transfer occurs in the opposite direction, from the liquid phase to the gas phase, it is referred to as desorption or "stripping" {Treybal, [10]}. These operations are typically carried out in columns known as packing columns.

The use of packing serves to enhance the mass transfer between the gas and liquid phases by facilitating extensive contact between the two phases over a large surface area. This is achieved as both phases must traverse the voids created by the column packing material. Several factors influence the rate of mass transfer between the two phases in this operation, including the type of filling material employed, geometric parameters such as diameter and length, and operational variables like flow rates, temperature, and concentration.

In absorption processes, there are invariably two phases involved: the continuous phase and the dispersed phase. The solute, typically in the form of droplets, is transferred from the continuous phase to the dispersed phase through a counter-current contact mechanism. Consequently, parameters such as interfacial contact area, mass transfer coefficient, holdup fraction, droplet diameter, and others assume critical significance in absorber operations. These parameters are intricately connected to the mass transport occurring within the absorption towers

The hydrodynamic behavior, or hydrodynamics of absorbers, involves the examination of how operating parameters influence the efficiency of towers. Specifically, determining the flooding ranges is of significant importance in countercurrent separation processes, as it indicates the point at which one of the phases encounters flow impedance. In absorbers, flooding typically results from a restriction in the flow of the liquid phase through the gaseous phase, leading to liquid carryover at the top of the tower. This phenomenon can be prevented by understanding the optimal flow ranges for both phases during column operation.

Hence, the current study focuses on investigating the fluid dynamics of an absorber, specifically in the context of determining flooding and column drag. As per the findings of Guilherm et al. [5], these points are established by analyzing the pressure drop curve concerning the continuous phase flow. Guilherm et al. [5] conducted similar research involving three types of fillings (rashing rings) in the absorption of toluene, with pressure drops of 288Pa. In our study, glass rings are employed in a packed column using water, and the pressure drops range from 300 to 1200Pa.

II. LITERATURE ANALYSIS

Numerous studies in the literature have focused on examining the operation of absorbers. These works typically involve the assessment of various aspects such as packing characteristics, mass transfer, design parameters, and the impact of operational variables on tower performance. Notable examples of such studies include those conducted by Caldas et al. [4], Azevedo et al. [1], Liu et al. [8], Murrieta et al. [9], and Guilherm et al. [5].

Among the operational parameters, according to Heyouni et al. [7], pressure drop stands out as the most critical parameter in packed towers. This is because it quantifies the phase dispersion and is influenced by three key factors: the velocity of the liquid and gas phases, the properties of the fluids involved, and the type of packing material used. Heyouni at al [7] also argue that the pressure at the top of the column must always be lower than at the bottom, due to the gravitational force acting in a downward direction. Consequently, as the flow of the liquid occupies the same channels as the upward flow of gas, the pressure drop is always dependent on both flow rates.

According to Caldas et al. [4], the literature offers various models for evaluating pressure drop ($\Delta P.z^{-1}$) in packed columns, with the construction of pressure drop curves. These curves establish the relationship between pressure drop and gas phase flow under dry bed conditions. Caldas et al. [4] also highlight two primary methods for conducting pressure drop tests in packed towers: the dry bed test, where pressure drop is measured when the tower operates solely with the gas stream, and the wet bed test, where the measurement is conducted under conditions of two-phase flow, involving both liquid and gas phases.

In the dry bed test, the pressure drop is measured when the tower operates solely with the gas stream, without any liquid flow. In contrast, in the wet bed test, the measurement is carried out under conditions of two-phase flow, involving both liquid and gas phases.

According to Bianchini [3], the absorption process consistently involves two phases, one identified as the dispersed phase and the other as the continuous phase. These two phases commonly interact with each other in a counter-current manner, and various parameters, such as holdup, and the points of loading and flooding, play a pivotal role in influencing the operation of the towers.

Holdup, as explained by Bianchini [3], characterizes the fraction of the dispersed phase that is retained by the continuous phase during their contact. Conversely, flooding and loading denote the impediment that one of the phases faces while moving through the entire length of the column. Dragging, which occurs after reaching the flood point, leads to the escape of liquid from the top of the column.

According to Heibel et al. [6], flooding refers to the flow condition where the downward flow of liquid reverses its course and starts moving upwards due to the interaction between the two phases. In line with Balogun [2], this phenomenon occurs when the flow of either gas or liquid exceeds the capacity of the column, thereby establishing an upper limit on the flow rates for both streams.

According to Guillerm et al. [5], the assessment of flooding and loading ranges can be achieved through logarithmic graphs where the pressure loss ($\Delta P.Z^{-1}$) is correlated with the molar gas flow (U). These graphs involve the construction of operating lines under two conditions: one with a dry bed (absence of liquid) and the other with a wet bed (presence of both liquid and gas simultaneously). As noted by these authors, variations in the behavior of the lines obtained on the graphs signify the loading points and the flooding point.

However, this study reveals that the method employed can introduce uncertainties and errors in determining these points. This is primarily due to the difficulties in accurately reading the graphical points where the behavior of the lines changes, especially when these changes are subtle or discrete.

In this current study, flooding and entrainment boundaries are established in a packed column containing glass rings and operating at room temperature. These flooding and entrainment bands and points are derived from observed alterations in behavior, such as pressure peaks, detected in the pressure drop curves generated from experimental data. The system employed in the experiments consisted of water and atmospheric air, with the column being filled with glass rings. The study presents more reliable data regarding flooding and entrainment and also includes a curve depicting the relationship between pressure drop and the ratio of the two flows

III. METHODS AND MATERIAL

The experimental tests were conducted using an acrylic column with a diameter of 0.07m and a length of 1.0m, filled with glass rings having a total packing height of 0.79m. In these tests, the column feeds were introduced from both the base (for the gas phase) and the top (for the liquid phase), with both flows being regulated by rotameters. The pressure drop across the column was measured using a U-tube manometer installed at both ends of the tower. Fig. 1 illustrates a schematic of the experimental setup employed in the testsAn easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it.

A total of forty experimental runs were conducted utilizing two feed streams, one introduced at the top and the other at the bottom of the column. The gas phase consisted of atmospheric air and was fed from the bottom, while the liquid phase involved water and was introduced from the top. In all the tests, the flow rates for both phases were carefully measured using the two rotameters, and pressure drops were recorded using the U-tube manometer after reaching a steady state. The air flow rates varied within the range of 1.2 to 15.0 liters/min, while water flows ranged from 0.72 to 1.41 liters/min. Fig. 2 provides a photograph of the experimental apparatus used in the study.

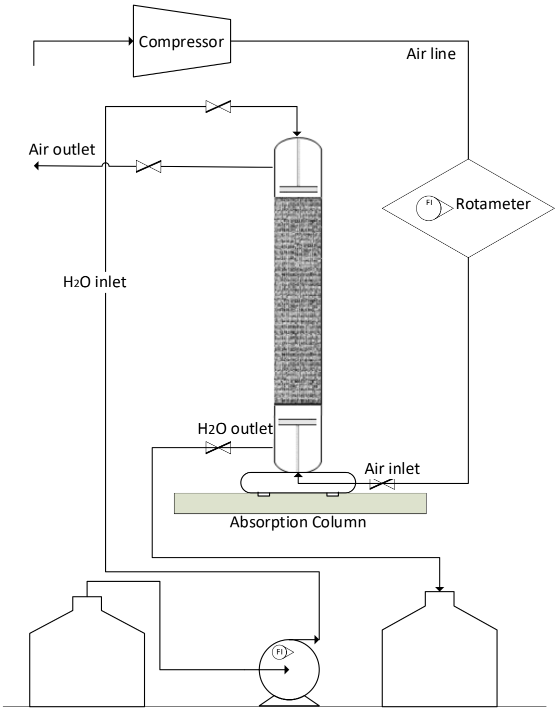

Figure 1 - The experimental installation

Figure 2 - Photograph of the experimental apparatus

IV. RESULTS AND DISCUSSION

The results from the dry and wet tests are depicted in Fig. 3 and Fig. 4, illustrating the variation of pressure drop ($\Delta P/Z$) in relation to air (G_{air}) and water (G_{water}) flows. The air flow rates ranged from 1.2 to 4.0 liters/min, and water flows ranged from 0.72 to 1.41 liters/min.

In Fig. 3, a consistent increase in pressure drop with increasing air flow is evident in all curves.

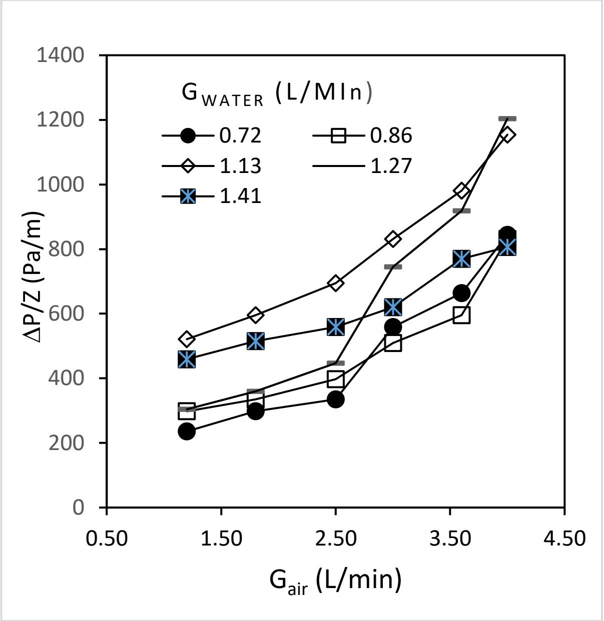

Figure 3 –Pressure drop variation with the air flow

This phenomenon occurs due to the rising gas inlet velocity. The observed behavior is consistent across all curves, indicating that higher inlet gas flow rates result in an increase in the pressure drop within the column. This is a consequence of the elevated air inlet pressure (Po) within the tower associated with higher flow rates.

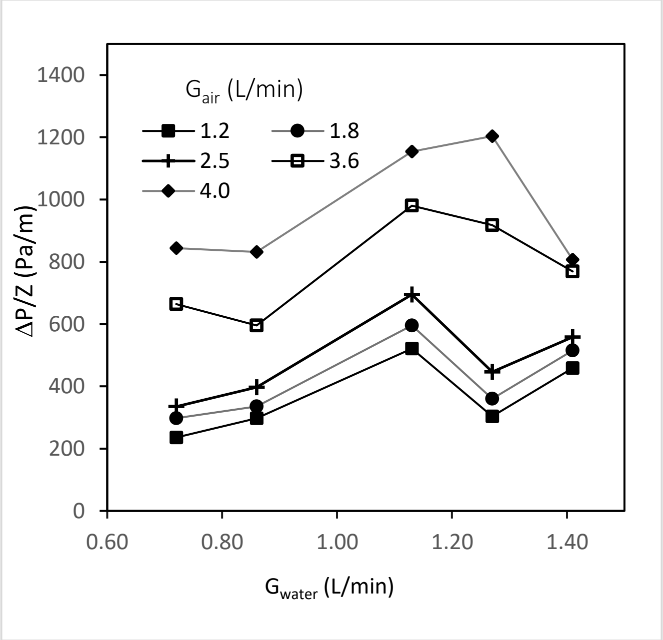

Figure 4 - Pressure drop variation with the water flow

Fig. 4 illustrates the relationship between pressure drop ($\Delta P/Z$) and liquid flow (G_{water}) for different air flow rates (G_{air}). In all the curves, there is a consistent pattern of an initial increase in $\Delta P/Z$ followed by a subsequent decrease after reaching a maximum point. Notably, the curves with the highest air flow rates are positioned at the top of the graph. This observation aligns with the phenomenon previously confirmed in Fig. 3, indicating that higher air flow rates have a significant impact on the pressure drop behavior.

The observed pressure drop peaks in each curve are indicative of the flooding phenomenon being reached. During flooding, the forces exerted by the two phases become balanced, resulting in a reduction in pressure drop within the column. In Fig. 4, it's evident that flood points are almost universally reached at a water flow rate of 1.13 liters/min. However, in the curve with the highest air flow rate (4.0 liters/min), the flood peak was reached only at a water flow rate of 1.27 liters/min. This discrepancy can be attributed to the fact that both the air flow and water flow were higher in that specific curve.

Another notable observation from Fig. 4 is the occurrence of a secondary increase in $\Delta P/Z$ after the flooding point is reached in the curves with lower air flows. In these curves, it is apparent that after flooding, the process of entrainment, also known as dragging, takes place, resulting in a subsequent rise in pressure drop. Entrainment is a phenomenon that usually follows flooding and leads to the accumulation of liquid at the top of the column. It is a process that should be avoided because it hinders the efficient mass transfer between phases, ultimately reducing the column's operational efficiency.

To ensure optimal tower operation, it is crucial to prevent both flooding and entrainment phenomena. This can be achieved by carefully balancing and controlling the combination of the two feed flows. Fig. 5 shows the behavior of the pressure drop ($\Delta P/Z$) with the relative flow between the two streams, G_{air} and G_{water}.

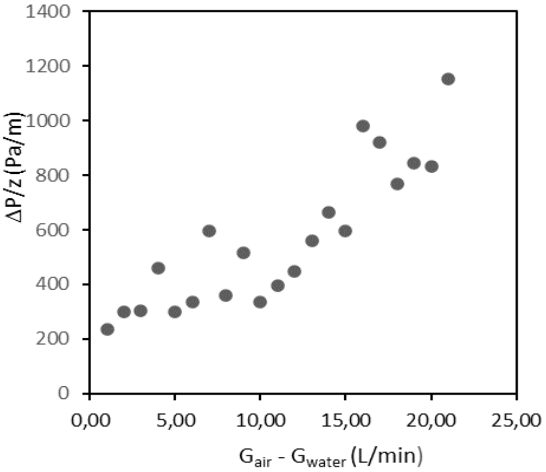

Figure 5 – Pressure drop variation with the relative flow ($G_{air} - G_{water}$)

Fig. 5 clearly demonstrates a discernible trend of pressure drop increasing in correlation with the difference between the values of air and water flows, denoted as $G_{air} - G_{water}$. In other words, when there is a larger disparity between the two flow values, the pressure drop within the column becomes more significant. Additionally, another analysis can be conducted by examining the behavior of pressure drop concerning the ratio between the two flows, G_{water}/G_{air}. This information is visualized in Fig. 6.

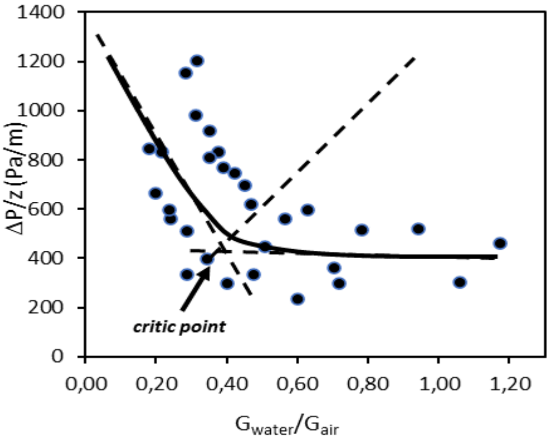

Figure 6 - Pressure drop variation against G_{water}/G_{air} and the critic point.

Fig. 6 depicts a curve that can be interpreted as having two distinct segments, each of which appears to converge at a single point. This point can be aptly termed a "critical point" and signifies the juncture at which the pressure drop tends to stabilize, primarily due to the occurrence of column flooding. Consequently, the critical point serves as a valuable reference, indicating the maximum permissible limit of the G_{water}/G_{air} ratio at which the column should operate without encountering flooding and liquid entrainment over the top of the column.

V. CONCLUSION

Based on the data presented in this study, several significant findings have been established to enhance the fluid dynamics of the column and improve the efficiency of absorbers' operation.Firstly, it was observed that there is an increase in pressure drop with higher flow rates of both gas and liquid, as evident from the graphs in Figs. 3 and 4. This relationship was further explored and confirmed in Fig. 4, where the increase in pressure drop with water flow was also evident. Fig. 4 also allowed the identification of flood points and the onset of entrainment in certain curves. Flooding is marked by the occurrence of pressure peaks, while entrainment is indicated by the resumption of ΔP growth in the curves.

This comprehensive analysis provides valuable insights into the factors that influence the performance of absorption columns and serves as a foundation for improving their efficiency and operation. The graph presented in Fig. 5, illustrating the variation in pressure drop with the ratio between the two flows (G_{water}/G_{air}), is instrumental in determining the critical point. This critical point is identified as the location where the pressure drop stabilizes within the column. The determination of this critical point holds great significance as it not only marks the region where flooding and entrainment phenomena occur but also highlights the boundary that needs to be avoided. Flooding and entrainment are undesirable phenomena that must be prevented, as they directly impact the contact area and mass transfer between the phases, ultimately affecting the overall efficiency of the process.

The results obtained in this study provide valuable insights that can serve as a foundation for further research involving towers packed with glass rings and potentially other geometries. Among the noteworthy findings, the variation of pressure drop with air and water flows, as depicted in Figs 3 and 4, is a key aspect. Additionally, the identification of operating conditions where flooding and entrainment, which are detrimental to column performance, occur is a crucial observation. The presence of a critical point, as shown in Fig. 6, where the ratio between the two flows (G_{water}/G_{air}) stabilizes, is another significant aspect. This information is essential for determining the most efficient strategies for utilizing such towers, especially on an industrial scale.

Certainly, it's crucial to recognize that the findings from this laboratory-scale study may not be directly applicable to larger-scale tower operations due to potential variations in behavior. Nonetheless, the insights gained from this work can serve as a valuable starting point for further research and optimization in various industrial applications involving packed towers. The principles and trends identified in this study can guide future investigations, helping researchers and engineers refine their understanding and approaches in designing and operating absorption towers with glass ring packing or similar geometries on a larger scale.

VI. NOMENCLATURE

G_{water} - Flow of water (L/min)
G_{air} - Flow of air (L/min)
DP - Drop pressure (Pa)
Z - Lenght of column (m)

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