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Three-Dimensional Investigation of Gas Holdup Changes as a Very Effective Hydrodynamic Parameter in Airlift Reactors

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Abstract

In this study, hydrodynamics, liquid velocity distribution, flow regime, and gas holdup were modeled and simulated in air-stirred reactors such as bubble column, airlift, and net draft tube airlift reactors according to the computational fluid dynamics, while the inner space of the reactors was filled with water or diesel by injecting air through the air distributor from the bottom of the reactor. The present study investigates the three-dimensional changes in gas holdup as a very effective hydrodynamic parameter in airlift reactors. The results and data of this study, which includes thirty-six simulations for the water-air system and the diesel-air system, showed good consistency and agreement with the laboratory data, so the mean error in all these simulations was about 14%. Reactors containing diesel liquid fluid showed different behavior in different superficial gas velocities and different geometries in comparison with reactors containing water. In addition, airlift reactors with a net draft tube were simulated with very high precision in design. They showed that the gas holdup is higher than the simple airlift reactor despite the more complex structure. They also provide better mixing and more optimal fluid distribution than the bubble column reactor throughout the process execution environment.

Keywords: hydrodynamics, gas holdup, simulation, computational fluid dynamics, airlift reactors

Introduction

Air-stirred reactors are extensively applied in industry and are of great interest thanks to their unique specifications. The reactors mentioned in this study include bubble column reactors, airlift reactors, and airlift reactors with a net draft tube. Such reactors are extensively applied due to less energy consumption and less shear stress in the environment during the process. The hydrodynamic complexity of the fluids in the mentioned reactors is vital in the processes related to oil, gas, petrochemical, pharmaceutical, and biotechnology given the production rate, the transition between phases, and the structure and mixing process. Gas holdup (εG), liquid rotation velocity, and superficial gas velocity are among the most important parameters affecting the hydrodynamic behavior of these reactors. Airlift reactors are a significant group of reactors appropriate for various biological processes. Although they do not have a relatively high construction cost compared to other parts of the process, they significantly affect various downstream processes, including separation, purification, wastewater treatment operations, and finally the performance of the process. These reactors are similar to bubble column reactors, except that they include a net draft tube. The gas phase is responsible for aeration and mixing [1],[2],[3].

Pawar (2017) performed computational fluid dynamics simulation and analysis of the airlift photobioreactor to investigate the effect of the net draft tube configuration on hydrodynamics, cell suspension, and shear force. The results revealed that the profile of liquid velocity shows that the effect of the irradiated light can be manipulated and changed in a certain interval based on the superficial gas velocity [4]. Bagheripour et al. (2017) simulated liquid dispersion in two bubble column reactors with different diameters. They stated that the gas holdup is directly dependent on the superficial gas velocity and increases linearly with the increase of the superficial gas velocity. However, it was found that the gas holdup decreases with the doubling of the reactor's diameter from 0.15 m to 0.30 m [5]. In a similar manner, Wagh et al. (2014) performed computational fluid dynamics (CFD) simulations to examine the axial and radial gas holdup in bubble column reactors. Their results demonstrated that gas holdup increases with superficial gas velocity but diminishes as the reactor diameter increases, particularly when it surpasses 0.1 m [6].

Xiao et al. (2017) simulated the multiphase flow in a bubble column reactor with stabilized multi-fluid CFD models. This simulation showed that without using connected parameters, the stabilized multi-fluid model is a better predictor than the multi-fluid model in other papers such as the Schiller-Naumann drag model, the Simonnet drag model, the Krishna three-fluid model, and the TFM-PBM model that better response and better prediction were expected of them [7]. Comparable assessments were carried out by Ziegenhein et al. (2015), who conducted a comparative analysis of various drag models and emphasized their influence on the accuracy of simulations in bubble column reactors [8]. In more recent work, Liao et al. (2021) further advanced this research by evaluating drag force models in CFD simulations, reinforcing the critical role of model selection in the precise prediction of hydrodynamic behavior [9]. Amani and Jalilnejad (2017) performed computational fluid dynamics modeling for the biodegradation of formaldehyde in a bioreactor with fixed cells in the presence of circular and disc-shaped volcanic rock beds. The results, which showed good consistency and agreement with the experimental data, indicated that the discontinuous flow works well in removing pollutants while increasing the concentration and input rate of formaldehyde inversely affects formaldehyde removal [10]. Similarly, Habibi et al. (2019) conducted an investigation on continuous formaldehyde biodegradation utilizing Ralstonia eutropha immobilized on polyurethane foam in a semi-pilot-scale plug flow packed-bed bioreactor. Their study revealed complete formaldehyde removal at inlet concentrations up to 425.5 mg/L, with the initial specific biodegradation rate achieving approximately 44.3 mg/g cell·h at this concentration [11]. Nalband and Jalilnejad (2018) simulated the inhibition kinetics of naphthalene aerobic biodegradation in a net draft tube airlift reactor with R. eutropha by computational fluid dynamics. The performance of the mentioned reactor in different concentrations of naphthalene was investigated by free bacterial cells. The results revealed that complete degradation of naphthalene occurs at a concentration of 90 mg/L, but partial degradation of naphthalene at concentrations of 120 and 150 mg/L is visible due to inhibition that reduces the biodegradation rate [12].

Blasej et al. (2004) simulated the behavior of the airlift reactor in two two-phase states for gas holdup and vertical velocity in the range of 0.075-0.01 m/s using computational fluid dynamics method [13]. In a similar vein, Coimbra et al. (2024) employed CFD modeling to investigate multiphase flow in an airlift reactor, focusing on the effects of superficial gas velocity and gas holdup on loop recirculation. Their study analyzed air inlet velocities ranging from 0.27 m/s to 0.54 m/s, offering valuable insights into the local dynamics of multiphase flow, which are critical for optimizing reactor performance [14]. Mouza et al. (2004) investigated the three-dimensional model of the performance of the rectangular bubble column reactor by combining balance equations and survival laws [15]. Buwa and Ranade (2002) performed both experimental investigations and computational fluid dynamics (CFD) simulations to examine gas-liquid flow dynamics in a rectangular bubble column. Their study offered comprehensive data on flow patterns, gas holdup distribution, and liquid velocity fields, thereby contributing to the optimization of reactor design and operation [16]. Montante et al. (2005) presented a suitable solution for simulation with computational fluid dynamics to calculate the mixing time in two types of fluids with Newtonian and non-Newtonian rheological properties. They achieved a good agreement between experimental data and modeling results [17]. Nigam et al. (2006) simulated gas-liquid movement, velocities, and volume components of the phases in the tubes using Fluent Software [18]. In the same manner, Hu et al. (2021) utilized OpenFOAM® to simulate gas-liquid and gas-liquid-solid systems in stirred-tank reactors. Their research investigated the influence of impeller rotation speeds and bubble diameters on flow patterns and gas holdup, highlighting the efficacy of CFD tools in predicting complex multiphase flow behavior [19].

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This study took a step toward improving the accuracy and better understanding of various airlift reactors as widely used tools in industrial and biological processes that have good efficiency, distribution of phases in them, flow rotation, the effect of different aeration velocities in these reactors, reviewing the results and data obtained from the laboratory work and trying to optimize the processes. Accordingly, this study investigates the three-dimensional changes of gas holdup as a very effective hydrodynamic parameter in airlift reactors [20].

Governing methods and equations

To validate the results obtained from computational fluid dynamics simulation using COMSOL Multiphysics software, the obtained values were analyzed and compared with the experimental values of Dezhaloud et al. [21]. In that experiment, six aeration rates were selected and compared. Table 1 presents these aeration values.

Table 1- Aeration rates in reactors

Aeration rate	1	2	3	4	5	6
Q_G (vvm)	0.0952	0.2381	0.381	0.4762	0.7143	1

Table 2 presents the numerical values and physical specifications of the airlift reactor with a net draft tube. Figure 1 also displays the schematic view of this reactor with design details.

Table 2: Specifications and dimensions of the reactor and the net draft tube

<table>
<tr><td colspan="2">values</td><td colspan="2">Reactor's specifications</td></tr>
<tr><td colspan="2">0.025</td><td colspan="2">The diameter of the upward flow part Dr (m)</td></tr>
<tr><td colspan="2">0.08</td><td colspan="2">The diameter of the downward flow part Dd (m)</td></tr>
<tr><td colspan="2">0.43</td><td colspan="2">The height of the net draft tube Hr (m)</td></tr>
<tr><td colspan="2">0.70</td><td colspan="2">Reactor height H(m)</td></tr>
<tr><td colspan="2">0.50</td><td colspan="2">Reactor operating height HL(m)</td></tr>
<tr><td colspan="2">10.24</td><td colspan="2">The ratio of the cross-sectional area of the upward flow to the downward flow Ad/Ar</td></tr>
<tr><td>The mesh size of net draft tube</td><td>Wire nominal diameter (mm)</td><td>Sieve opening
(mm)</td><td>The rate of non-passage of liquid * (%)</td></tr>
<tr><td>12</td><td>0.725</td><td>1.41</td><td>56.4</td></tr>
</table>

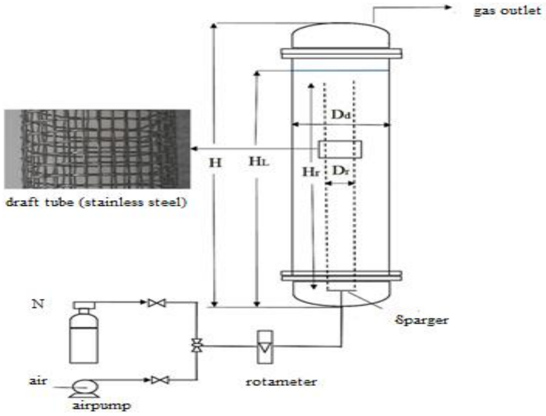

Figure 1: The view of the airlift reactor with the net draft tube used in the laboratory and experimental process

The working volume of the used reactor is 1.2 liters and the air enters through a diffuser with a diameter of 2.5 cm and a pore size of 100-160 µm, which is placed at a height of 0.05 m from the bottom of the reactor. In this study, the pressure drops due to the diffuser glass filter in all aeration values, according to the technical specifications announced by the manufacturer, was not considered. In this study, the aeration rate is reported based on air volume over liquid volume per minute (vvm). A calibrated rotameter is also used to control the aeration rate and the ambient temperature is in the range of 25±2 °C. In this simulation, there were three different geometries of a general reactor template, all of which were designed and modeled in the COMSOL software.

In this simulation, the inner range of the geometry of the bubble column, airlift, and net draft tube airlift reactors was considered computational space. The boundary conditions are such that the upper surface of Sparger, which

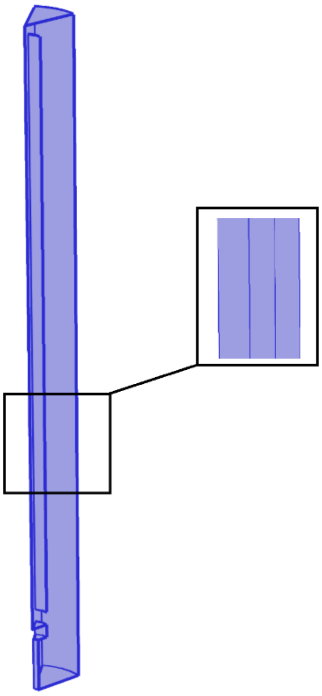

Figure 3- The designed geometry of the airlift reactor

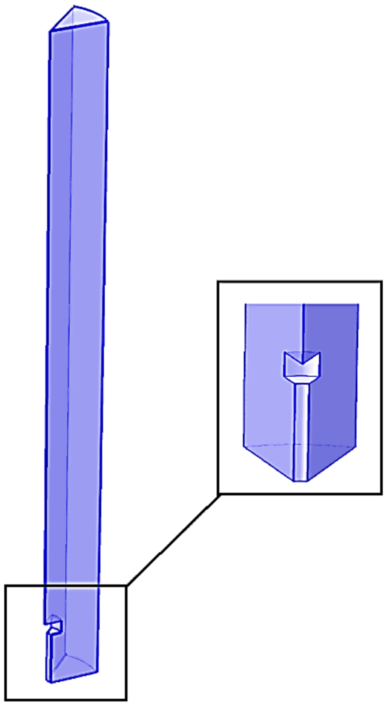

Figure 2- The designed geometry of the bubble column reactor

is the gas-phase distribution factor and the source of superficial gas velocity, is considered as input with the gas flux condition. For the boundary conditions of the inner walls of the reactors, the no-slip or wall function model was used for the liquid phase, while the no-gas flux model was used for the gas phase bubbles. In addition, the gas outlet model for the gas phase and slip for the liquid phase in the upper part of the reactors were considered as the point for the exit of the gas phase, the free surface of the liquid, and the operating height. Since the point that the geometry of the reactors is divided in half in the height, on the surface that is cut due to the symmetry of the shape in different vertical sections, the boundary condition of symmetry was used, which significantly helps to simplify the process and increase the speed of the solution.

Results

Bubble column reactor

In this reactor, we can see the effect of superficial gas velocity on the flow regime, the movement of liquid and gas flow, and the changes in gas holdup over time. The liquid velocity distribution in this reactor for different aeration rates is seen in Figure (4) for water and Figure (5) for diesel.

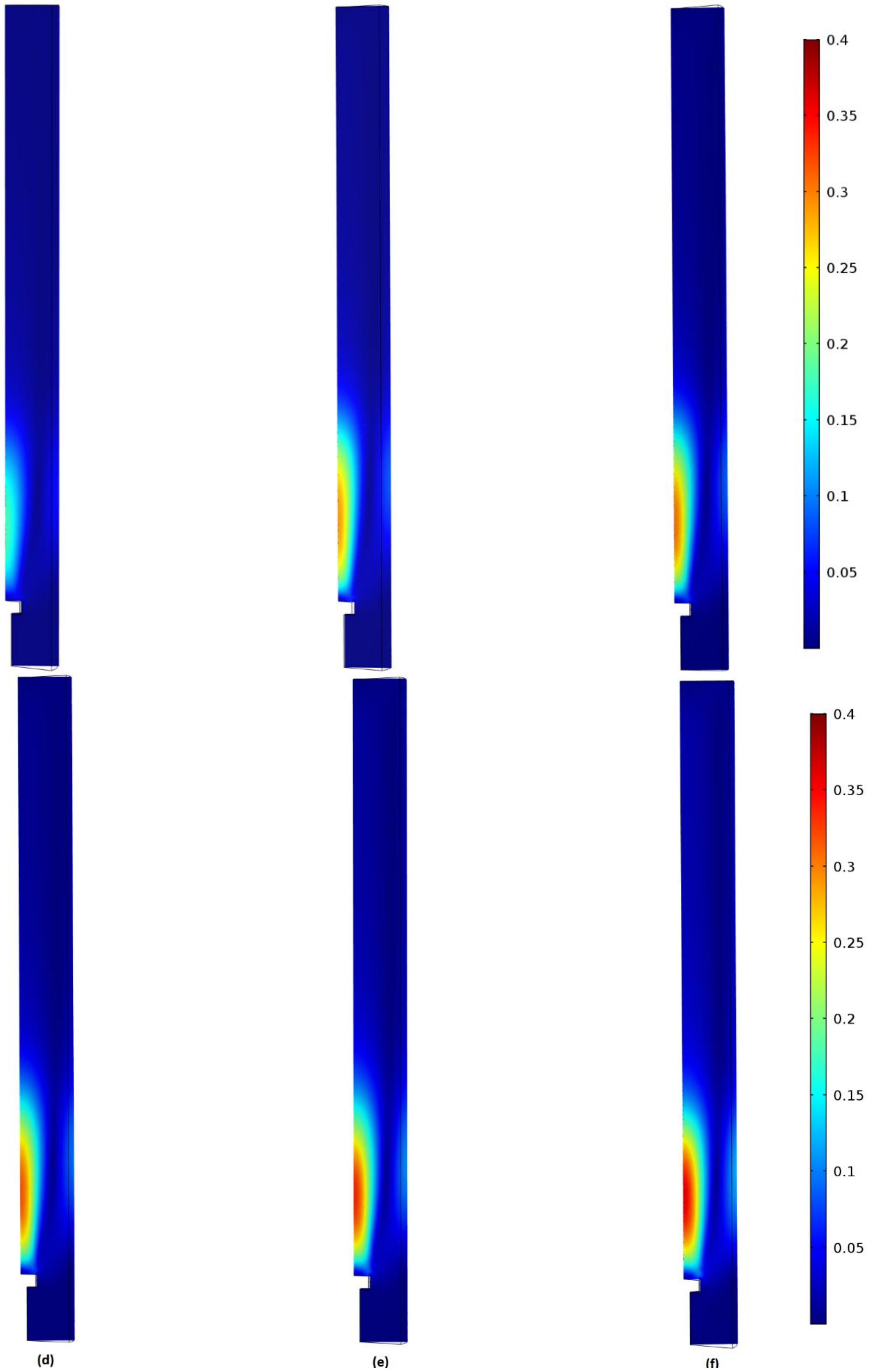

Figure 4: Velocity distribution in aeration rates of 0.0952 (a), 0.2381 (b), 0.381 (c), 0.4762 (d), 0.7143 (e), and 1 (f) in m/s for water-air in a bubble column reactor

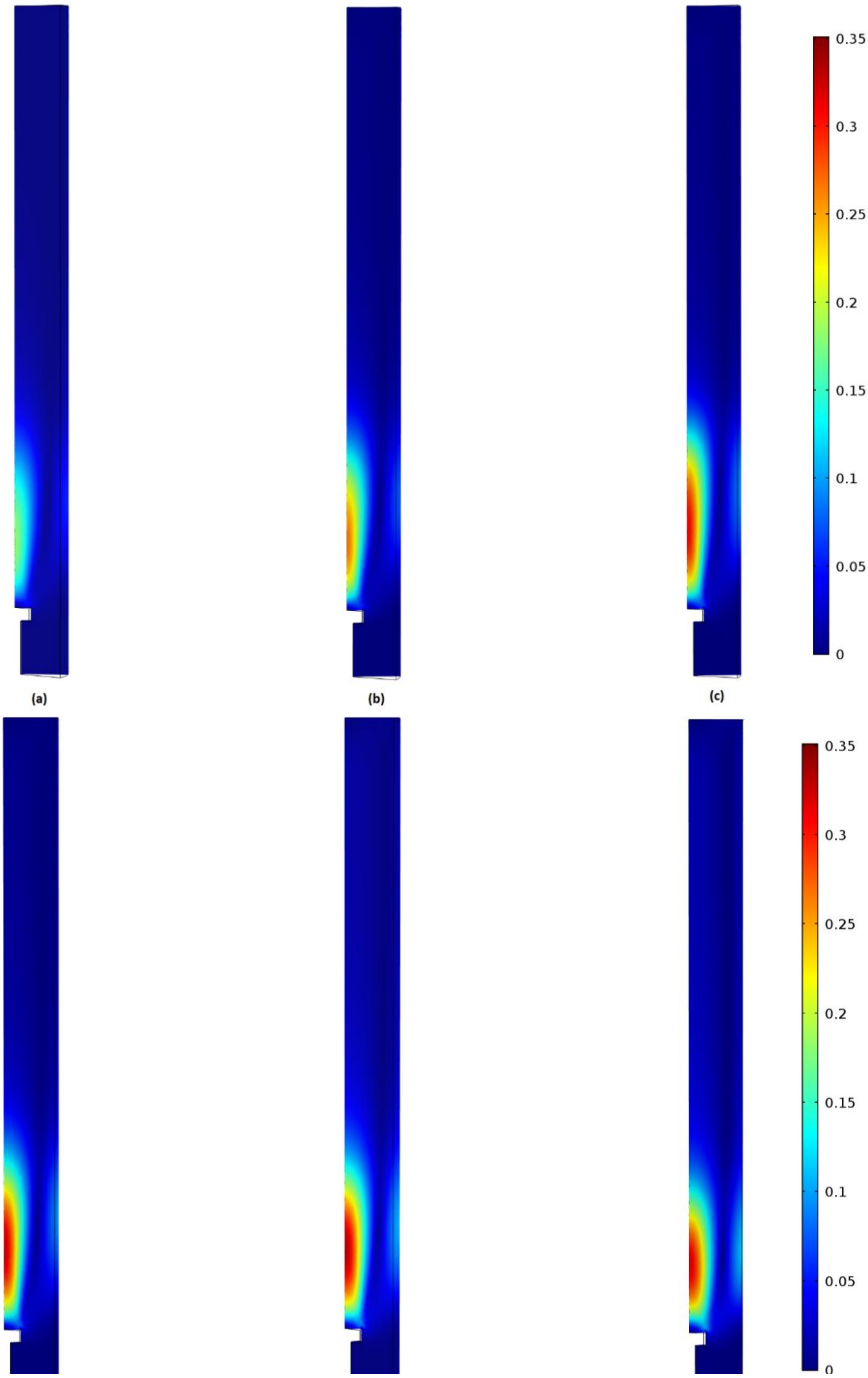

Figure 5: Liquid velocity distribution at aeration rates of 0.0952 (a), 0.2381 (b), 0.381 (c), 0.4762 (d), 0.7143 (e), and 1 (f) in m/s for diesel-air in a bubble column reactor

1. Gas-phase distribution in the air-water system for bubble column reactor

In simulated aeration rates, gas-phase distribution and gas holdup in a bubble column reactor for the air-water system were examined.

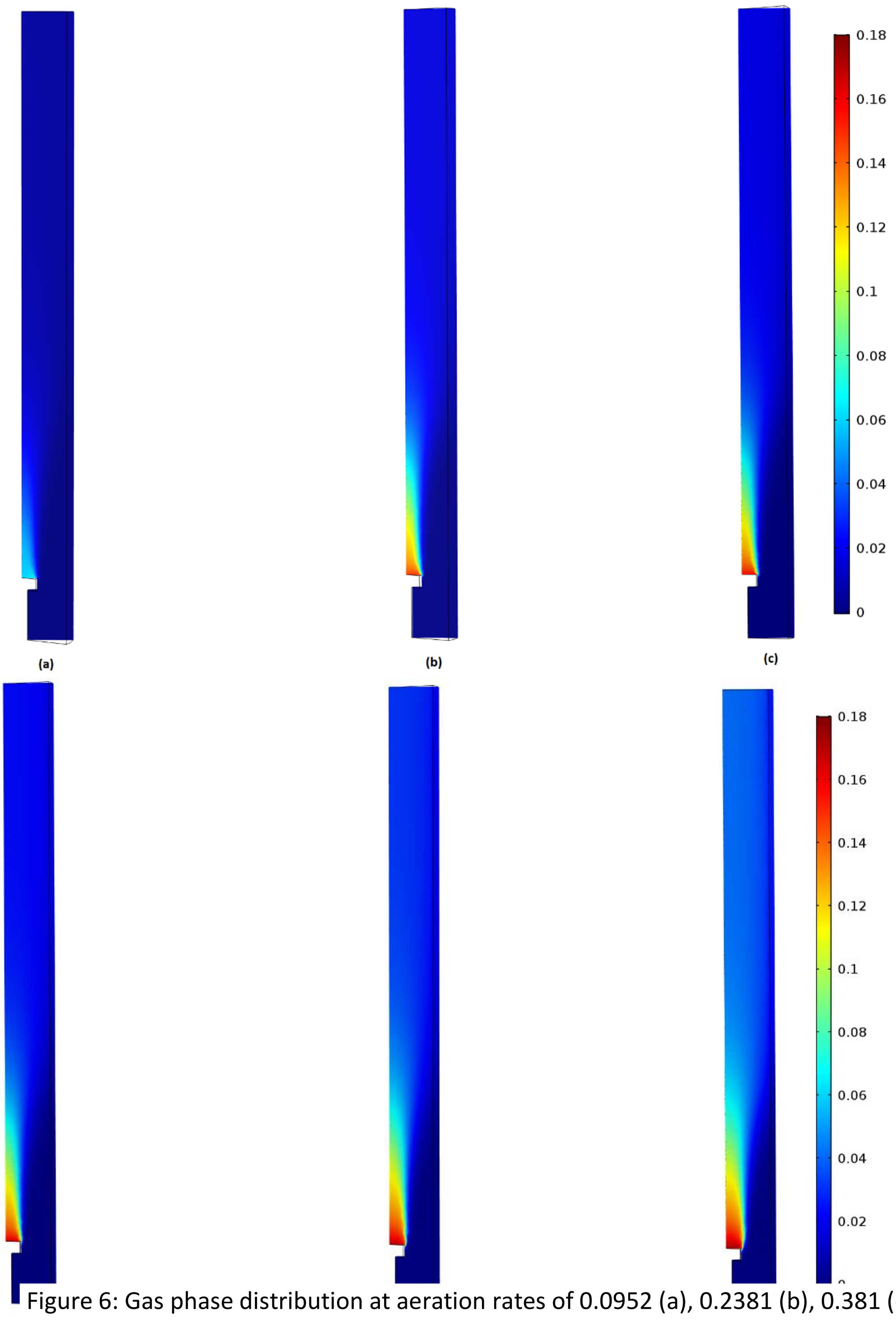

Figure 6: Gas phase distribution at aeration rates of 0.0952 (a), 0.2381 (b), 0.381 (c), 0.4762 (d), 0.7143 (e), and 1 (f) for water- air in the bubble column reactor

As shown in Figure (6), the maximum value of gas-phase distribution in the reactor is about 0.18, which naturally occurred at the highest aeration rate.

At the aeration rate of 0.0952 vvm, the superficial gas velocity is about 0.008 m/s in the bubble column reactor. The gas-phase distribution in the laminar flow regime can be seen in Figure (6) (a) at the completion of the process of calculating the concentration of the gas phase in the liquid for the water-air system. These figures indicate the effect of the fluid type and the effect of its viscosity on the amount of gas-phase distribution and its distribution structure in the reactor environment. This aeration rate is the lowest and the superficial velocity of the incoming gas among all reactors, which gives us the minimum gas holdup in the bubble column reactor, and in the simulation state for water-air, is about 0.005.

Regarding the aeration rate of 0.2381 vvm investigated, the superficial velocity of the incoming gas is about 0.02 m⁄s in this reactor. The flow regime in this reactor with this superficial velocity is of a laminar type. The value of 0.0118 was obtained for gas holdup in the water-air system based on the governing equations of the problem in the simulation state (Figure 6(b)).

The aeration rate of 0.381 vvm, where the superficial velocity of the gas is about 0.032 m⁄s led to a turbulent flow regime and governing different equations and solution mechanism. The holdup gas amount for this aeration rate in the water-air system is 0.014, as shown in Figure 6 (c).

In the aeration rate of 0.4762 vvm, the superficial gas velocity is 0.0406 m⁄s. The turbulent flow regime is seen in this reactor. The holdup gas value for the air-water system is 0.016 in the simulation state (Figure 6(d)).

When the aeration rate is 0.7143 vvm, the superficial gas velocity at the gas phase inlet is about 0.061 m⁄s, which with the turbulent flow regime and the mixing velocity it creates, in the simulation state, it provides the value of 0.0209 for the water-air system for gas holdup in the reactor environment (Figure 6(e)).

In an aeration rate of 1 vvm, the maximum superficial gas velocity at the sparger inlet with a value of about 0.085 m⁄s for this reactor, as shown in Figure 6(f), provides the maximum gas holdup value of about 0.027 for the air-weather system. As stated, the increase in liquid velocity, especially in bubble column reactors, causes the formation of large bubbles and the flow becomes a turbulent regime [22].

2. Gas-phase distribution in diesel-air system for bubble column reactor

In the aeration rates under simulation, gas-phase distribution, and gas holdup in the bubble column reactor for the diesel-air system were also investigated. Figure 7 shows the images of holdup and phase distribution.

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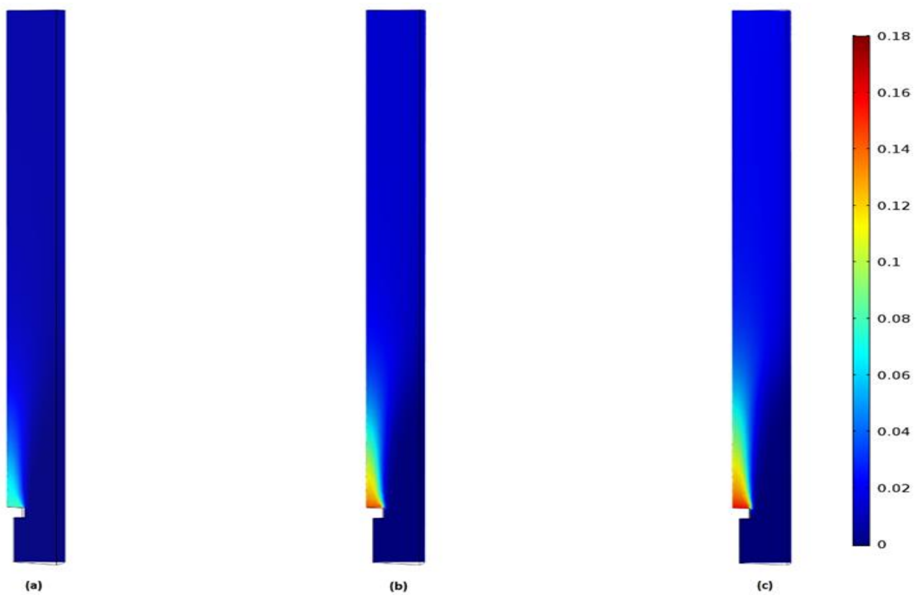

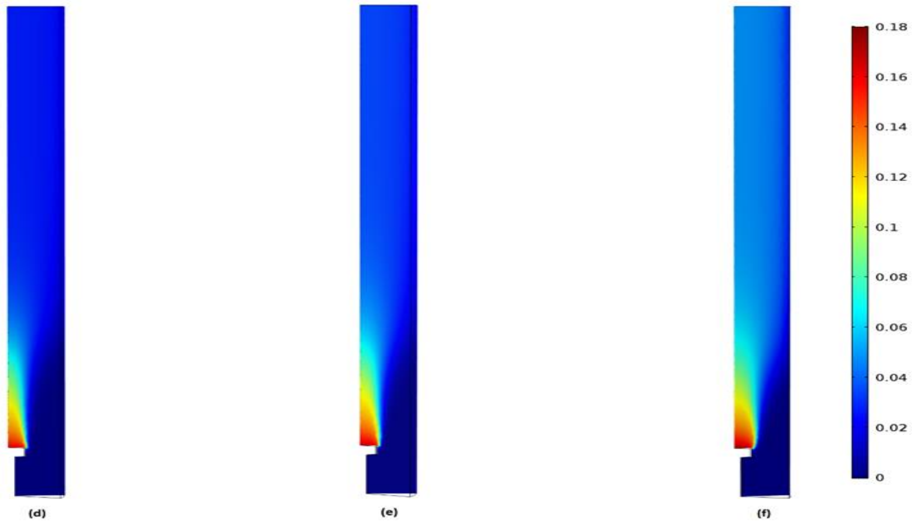

Figure 7-Gas phase distribution in aeration rates of 0.0952 (a), 0.2381 (b), 0.381 (c), 0.4762 (d), 0.7143 (e), and 1 (f) for diesel-air in the bubble column reactor

The mentioned six aeration rates were applied to simulate the air mixing in diesel in the bubble column reactor and to examine the gas holdup value in that reactor in three dimensions. As shown in Figure (7), the maximum value of the gas phase in some points is 0.18, which is the maximum value of the gas phase throughout the reactor environment. Based on the estimates, this maximum value was obtained at the highest aeration rate.

In the aeration rate of 0.0952 vvm for the bubble column reactor filled with liquid diesel fluid inside the reactor and the air phase entering from the bottom of the reactor and causing mixing, the gas phase distribution in these two systems is somewhat different from each other due to the different viscosity of water and diesel (Figure 7(a)). At this rate, the gas holdup value in the simulation state reaches about 0.006, which has a good accuracy with the experimental mode.

For the aeration rate of 0.2381 vvm, which has a laminar flow regime, the gas holdup value in the simulation state was also measured and the distribution structure of its gas phase is also shown in Figure 7(b). The gas holdup was 0.0117 for this aeration rate in the diesel-air system.

Concerning the aeration rate of 0.381 vvm in the diesel-air system for the bubble column reactor, as the gas phase distribution is shown in Figure 7(c), the gas holdup for this aeration rate is also simulated. The turbulent flow regime also governs the fluids inside the reactor. The gas holdup value obtained from the simulation was 0.0166.

In the aeration rate of 0.4762 vvm for the bubble column reactor in the diesel-air system, whose gas phase distribution at the end of the investigation process is shown in Figure 7(d), the gas holdup value is 0.0194. This gas holdup value was obtained while the flow regime governing the fluids inside the reactor environment was turbulent.

In the aeration rate of 0.7143 vvm in the bubble column reactor under turbulent flow conditions, the gas phase distribution is shown in Figure 7(e). This gas phase distribution, which represents the gas holdup in the reactor, is for the diesel-air system. The gas holdup value obtained from this simulation for this aeration rate is 0.024.

The sixth aeration investigated in this study in the bubble column reactor with diesel internal fluid was 1 vvm. Like the previous aeration rate, the governing flow regime in this case is also turbulent. The holdup gas value obtained from the simulation for this aeration rate is 0.034. As shown in Figure 7(f), which displays the gas phase distribution for this aeration rate, the phase has been distributed from a lower point than other aeration rates in the reactor environment. In addition, at points lower than the gas phase inlet, the gas holdup value tends to be almost zero.

2. Airlift and net draft tube airlift reactors

In this airlift reactor, different aeration rates (0.1-0952 vvm) applied in the experimental model were simulated. In these reactors, where the net draft tube improves the mixing rate, the same superficial gas velocity changes the flow regime from homogeneous to heterogeneous. Figure (8) is related to the water-air system and Figure (9) is related to the diesel-air system, which is used to show the velocity distribution of the liquid phase inside the reactor. Figure (10) is related to the water-air system and Figure 11 is related to the diesel-air system to show the velocity distribution of the liquid phase in the net draft tube airlift reactor.

Given the gas phase inlet point, the liquid phase velocity and the gas holdup value are higher in the upward flow and lower in the downward flow (chute). In addition, some air leaves the free surface above the reactor. As a result, a smaller amount of air than the air entering the reactor circulates in the chute point.

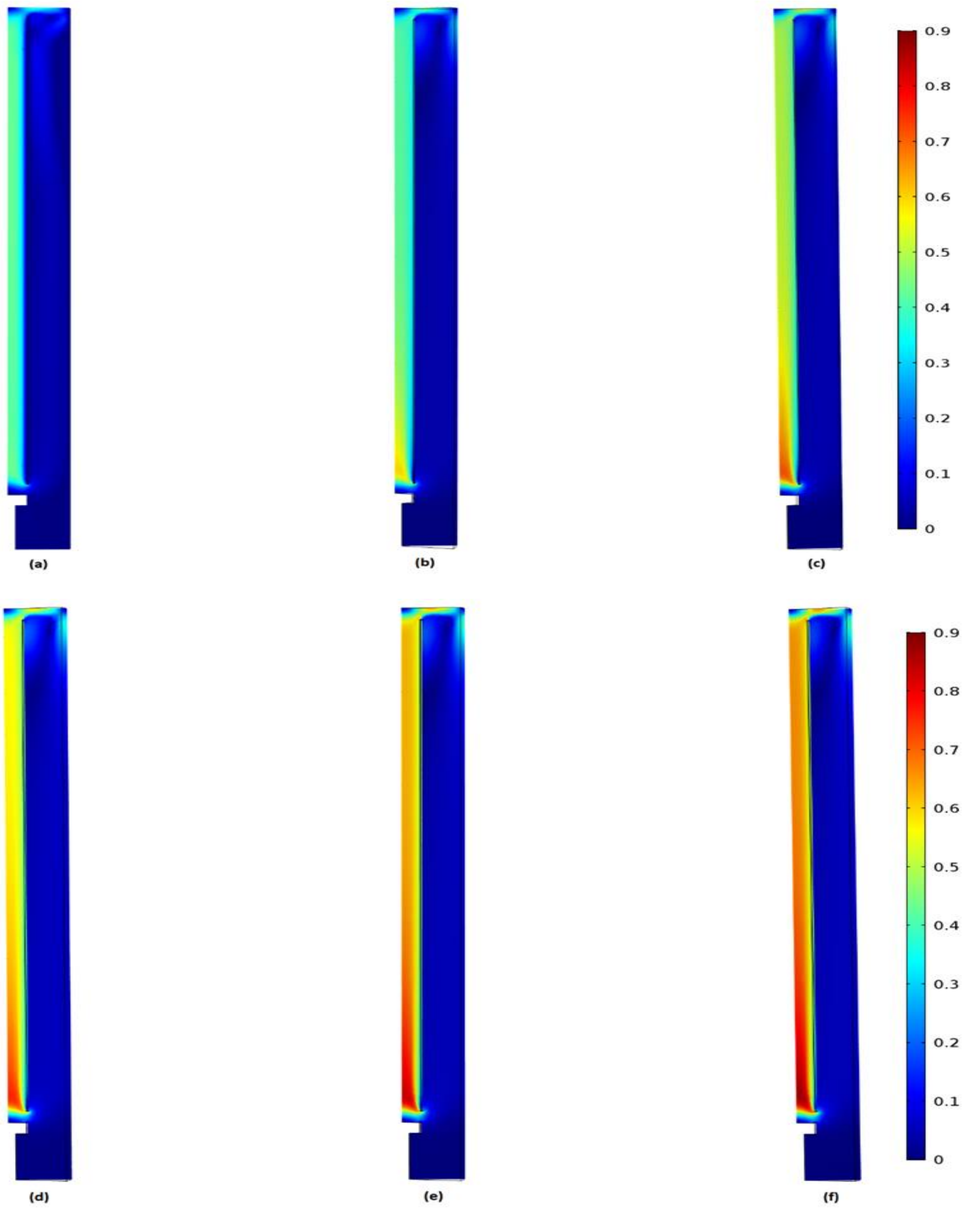

Figure 8: Liquid velocity distribution in aeration rates of 0.0952 (a), 0.2381 (b), 0.381 (c), 0.4762 (d), 0.7143 (e), and 1 (f) in m/s for water-air in the airlift reactor

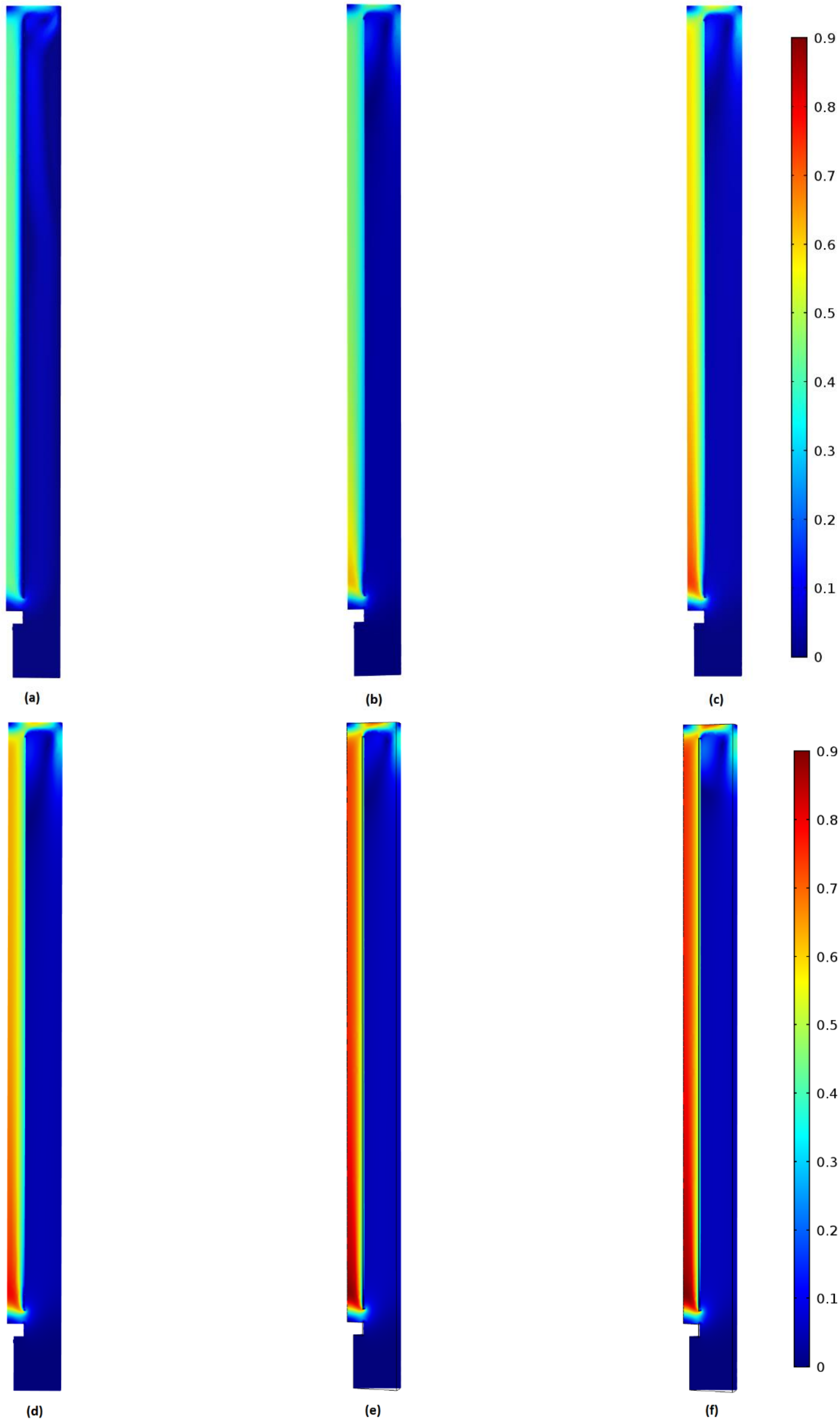

Figure 9: Liquid velocity distribution in aeration rates of 0.0952 (a), 0.2381 (b), 0.381 (c), 0.4762 (d), 0.7143 (e), and 1 (f) in m/s for diesel-air in airlift reactor

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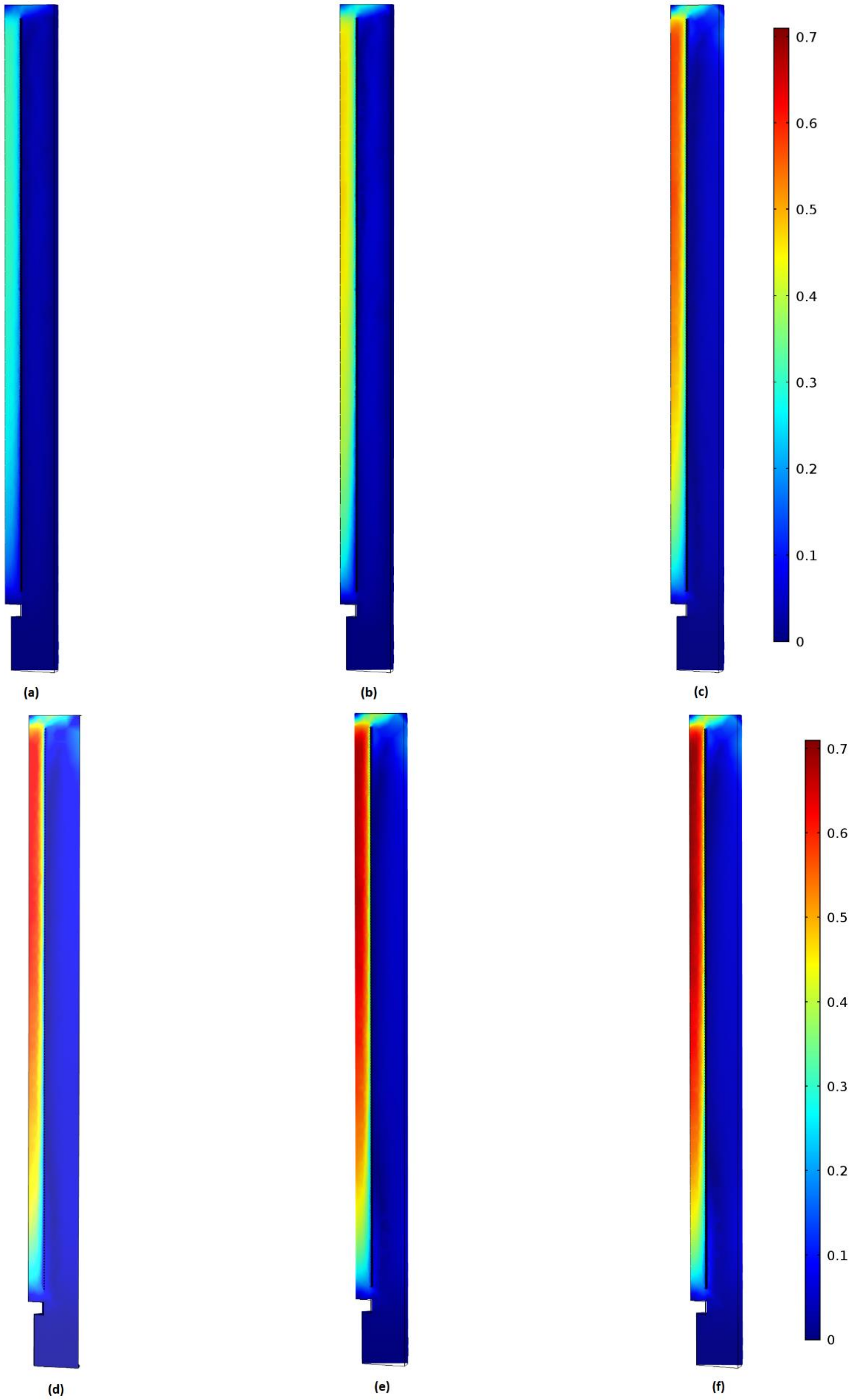


Figure 10: Liquid velocity distribution at aeration rates of 0.0952 (a), 0.2381 (b), 0.381 (c), 0.4762 (d), 0.7143 (e), and 1 (f) in m/s for water-air in a draft tube airlift reactor

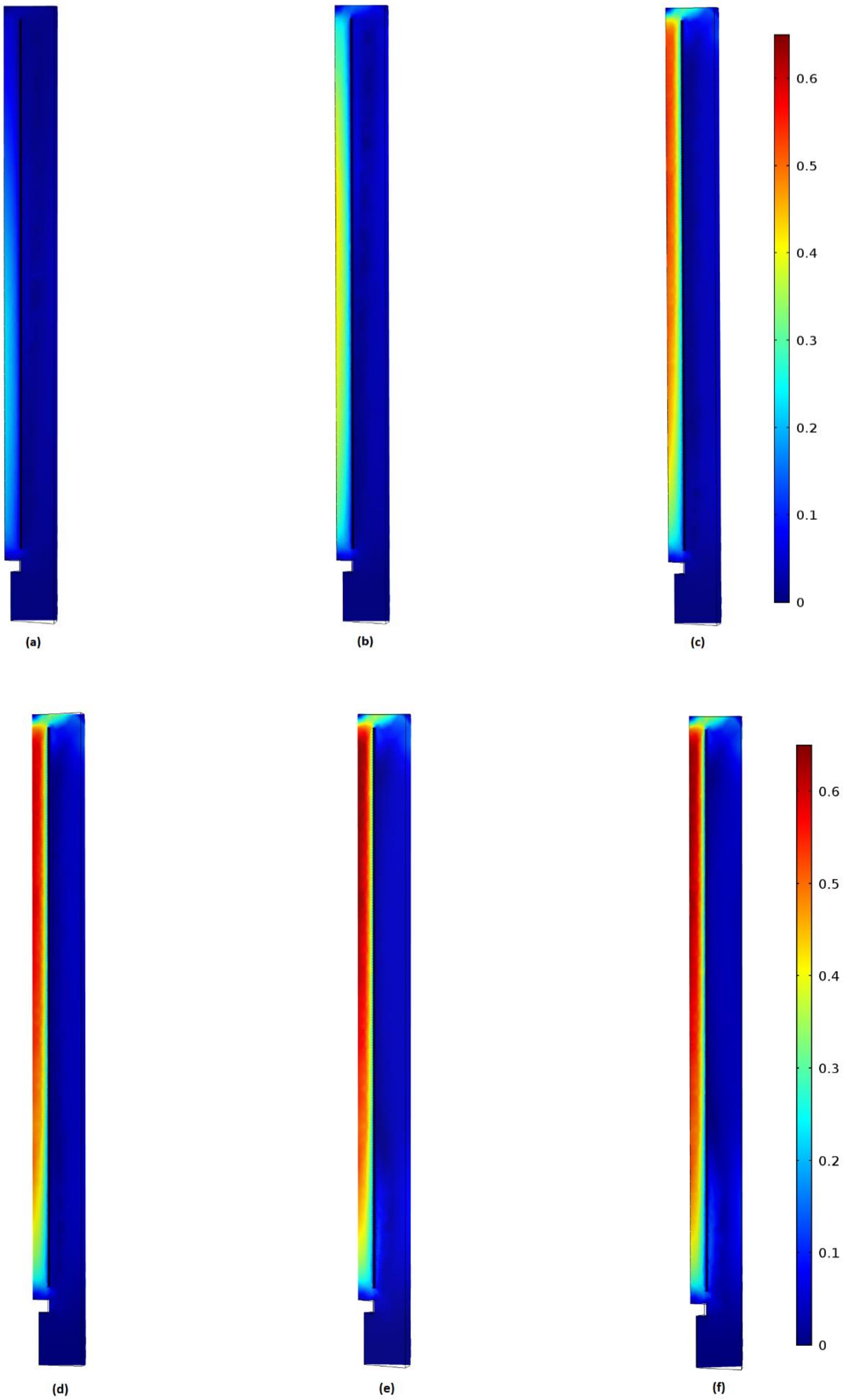


Figure 11: Liquid velocity distribution at aeration rates of 0.0952 (a), 0.2381 (b), 0.381 (c), 0.4762 (d), 0.7143 (e), and 1 (f) in m/s for the diesel-air in a net draft tube airlift reactor

3. Gas-phase distribution in the water-air system for the airlift reactor

In the simulated aeration rates, gas-phase distribution and the gas holdup in the airlift reactor of the water-air system were investigated. Figure 12 displays the images of phase distribution and gas holdup.

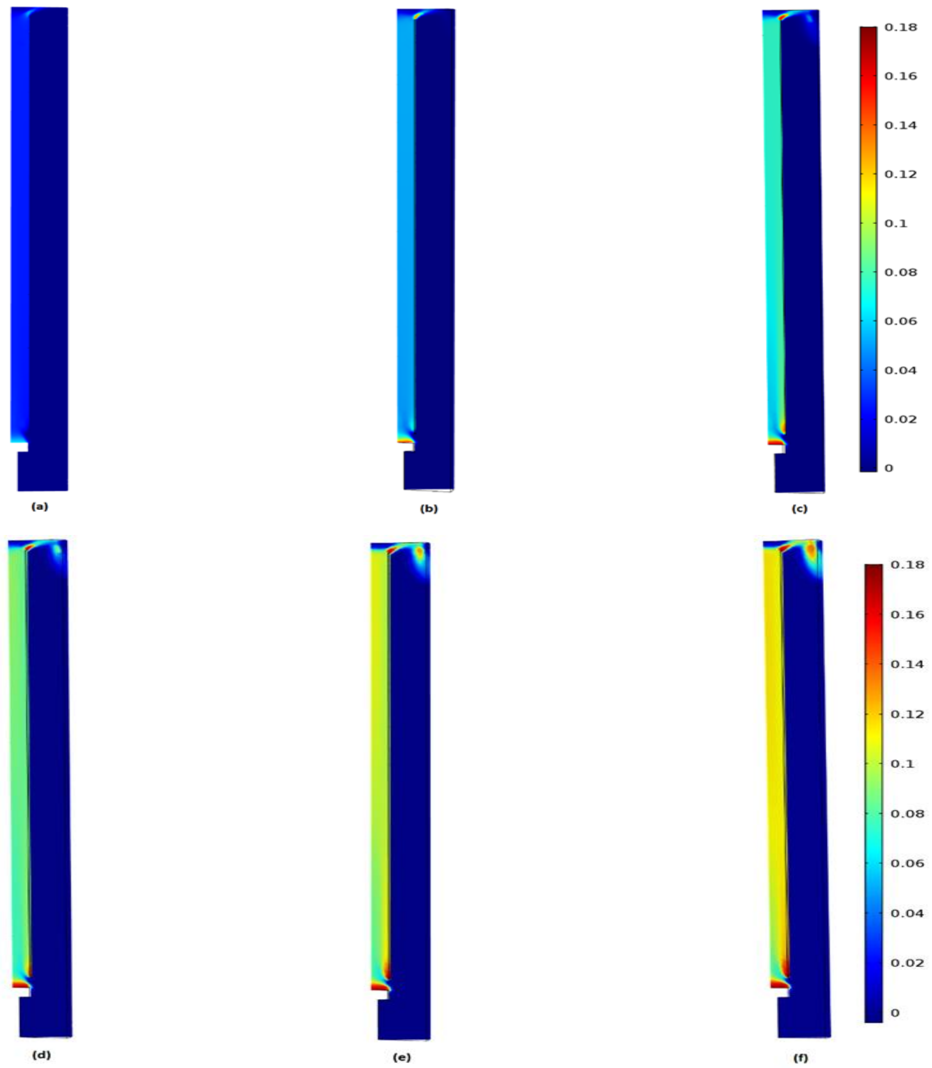


Figure 12: Gas-phase distribution at aeration rates of 0.0952 (a), 0.2381 (b), 0.381 (c), 0.4762 (d), 0.7143 (e), and 1 (f) for water- air in the holder reactor

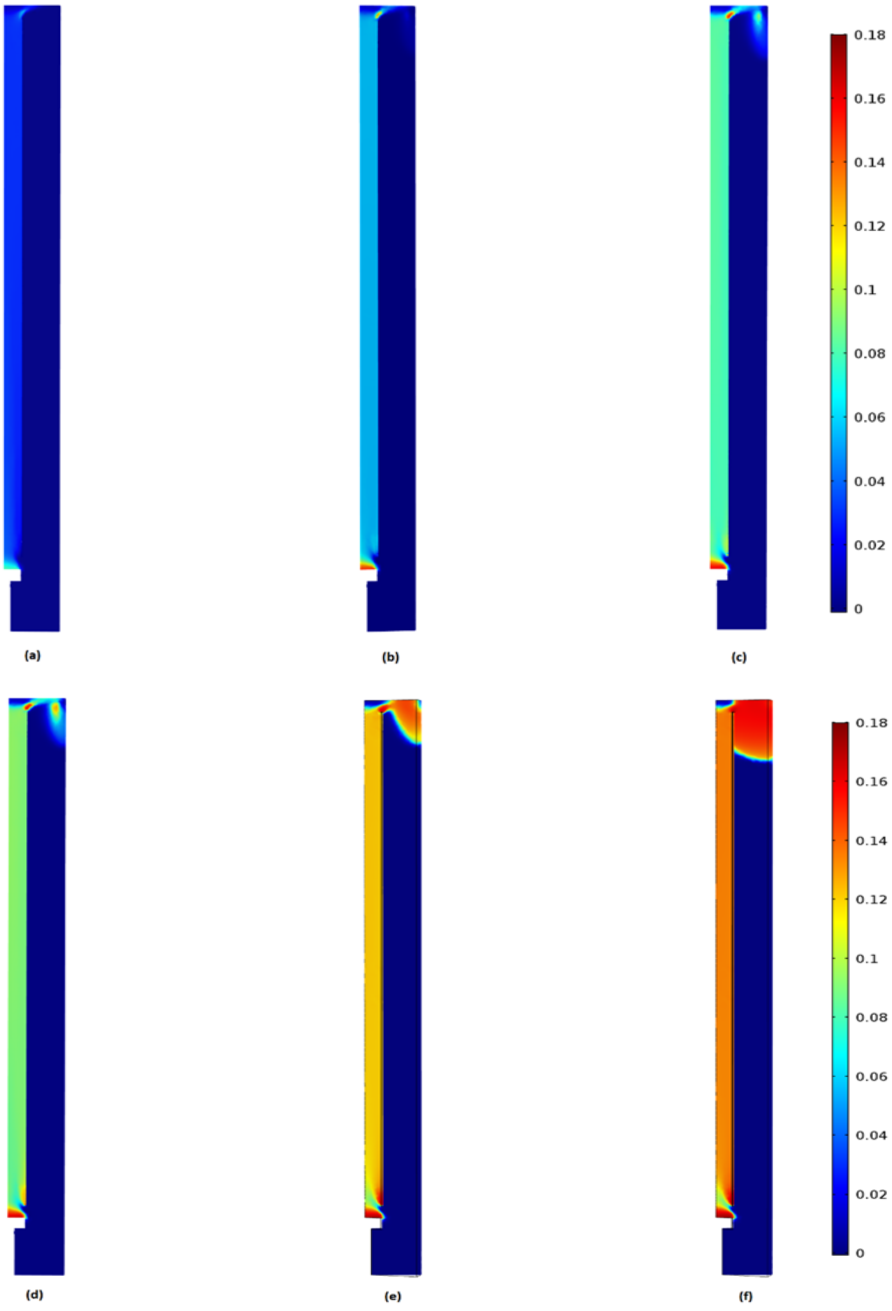
Concerning the aeration rate of 0.0952 vvm, where the superficial gas velocity is about 0.008 m⁄s, the flow regime is laminar. The gas-phase distribution is shown in Figure 12(a) at the completion of the process of calculating the concentration of the gas phase in the liquid for the reactor. In this reactor, the gas holdup value was obtained at 0.0023 for the air-water system in the simulation for the airlift model.

When the aeration rate is 0.2381 vvm, the superficial gas velocity reaches about 0.02 m⁄s. In the airlift reactor with the air-water system, the distribution structure of the gas phase (Figure 12(b)) and the gas holdup value were simulated and investigated. The final holdup gas value was also 0.005 for this system.

The aeration rate of 0.381 vvm in the airlift reactor creates a superficial gas velocity of about 0.03, causing the flow regime to change from a laminar to a turbulent flow regime. In the turbulent state, the governing equations take a different form, especially in the model with a net draft tube, where the flow structure is much more complicated. In this reactor simulated, the holdup gas value obtained in Figure 12(c) for the airlift reactor in the water system is 0.0074.

4- Gas-phase distribution in the diesel-air system for airlift reactor

In the simulated aeration rates, gas-phase distribution, and gas holdup in the airlift reactor of the diesel-air system were investigated. The images of phase distribution and gas holdup can be seen in Figure 13.



Six aeration rates were applied and simulated in the airlift reactor where the internal fluid is diesel. Figure 13

Figure 13: Gas phase distribution at aeration rates of 0.0952 (a), 0.2381 (b) and 0.381 (c), 0.4762 (d), 0.7143 (e), and 1 (f) for diesel- air in the airlift reactor

shows the effect of fluid viscosity on gas-phase distribution in the reactor environment.

When the the aeration rate was 0.0952 vvm, the flow regime was laminar, which provided the minimum gas holdup value in the simulation state, which is 0.0025 (Figure 13(a)).

The aeration rate of 0.2381 vvm applied in the airlift reactor for the diesel-air system caused the laminar flow regime, which created the gas distribution as shown in Figure 13 (b) and the holdup gas value was 0.0053. The difference with the aeration rate of 0.0952 is significant.

Regarding the aeration rate of 0.381 vvm, which is the beginning of the turbulent flow regime in the reactor environment, the holdup gas value is about 0.009. The gas-phase distribution in this aeration rate in Figure 13 (c) indicates that there is a large accumulation of gas phase, especially in higher superficial gas velocities due to the very different viscosity of diesel compared to water in the upper part of the chute in states where the flow regime is turbulent.

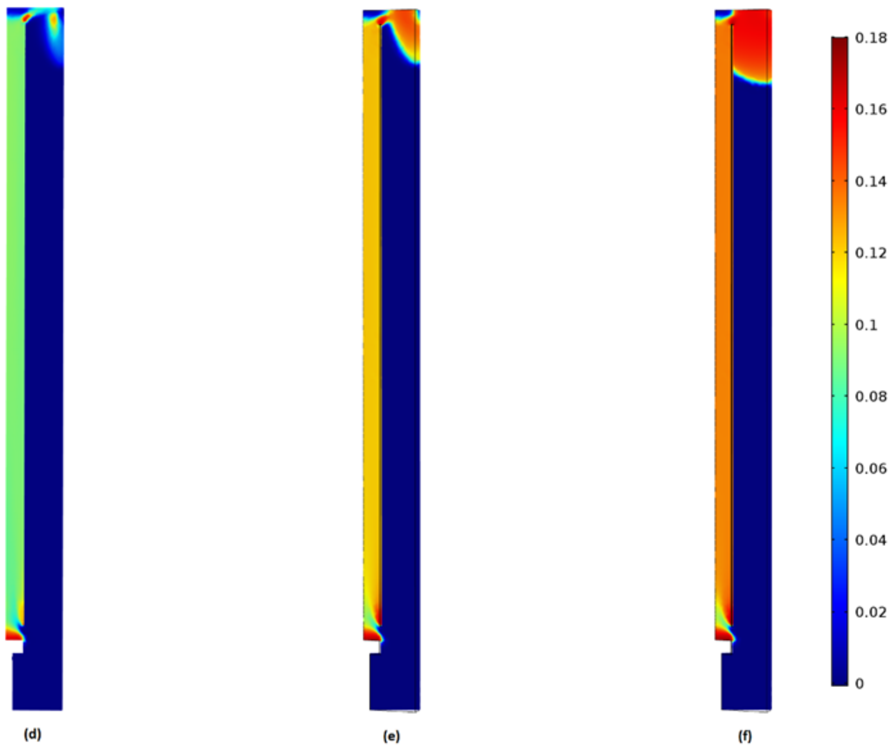
For the aeration rate of 0.4762 vvm in an airlift reactor with the diesel-air system in which the flow regime is turbulent, the gas-phase distribution (Figure 13 (d)) and the gas holdup value were calculated and simulated. The holdup gas value reaches 0.0105 after the completion of the simulation process.

In the aeration rate of 0.7143 vvm, which creates the turbulent flow regime, this aeration rate leads to more mixing and increased holdup gas value, so its value is 0.017. In this aeration rate, a large accumulation of gas phase above the chute area can be seen in Figure 13(e), which is the result of diesel viscosity.

The aeration rate of 1 vvm creates the maximum gas holdup value in the airlift reactor with diesel internal fluid, creating turbulent flow regime. In this aeration rate, the maximum gas distribution, which is 0.18, is obtained (Figure 13 (f)). This aeration rate makes the mean gas holdup throughout the reactor reach 0.025 in the simulation state. Since oily fluids create more resistance against the passage of the gas phase and bubbles inside it and the access of the gas phase to the free surface, larger values of the gas phase fall down the chute, leading to increased rotation of the gas and liquid phase in the system and thus, higher gas holdup.

4 -Gas phase distribution in the water-air system for net draft tube airlift reactor

In the simulated aeration rates, gas phase distribution, and gas holdup in the net draft tube airlift reactor for the water-air system were investigated. Figure 14 displays the images of phase distribution and gas holdup.



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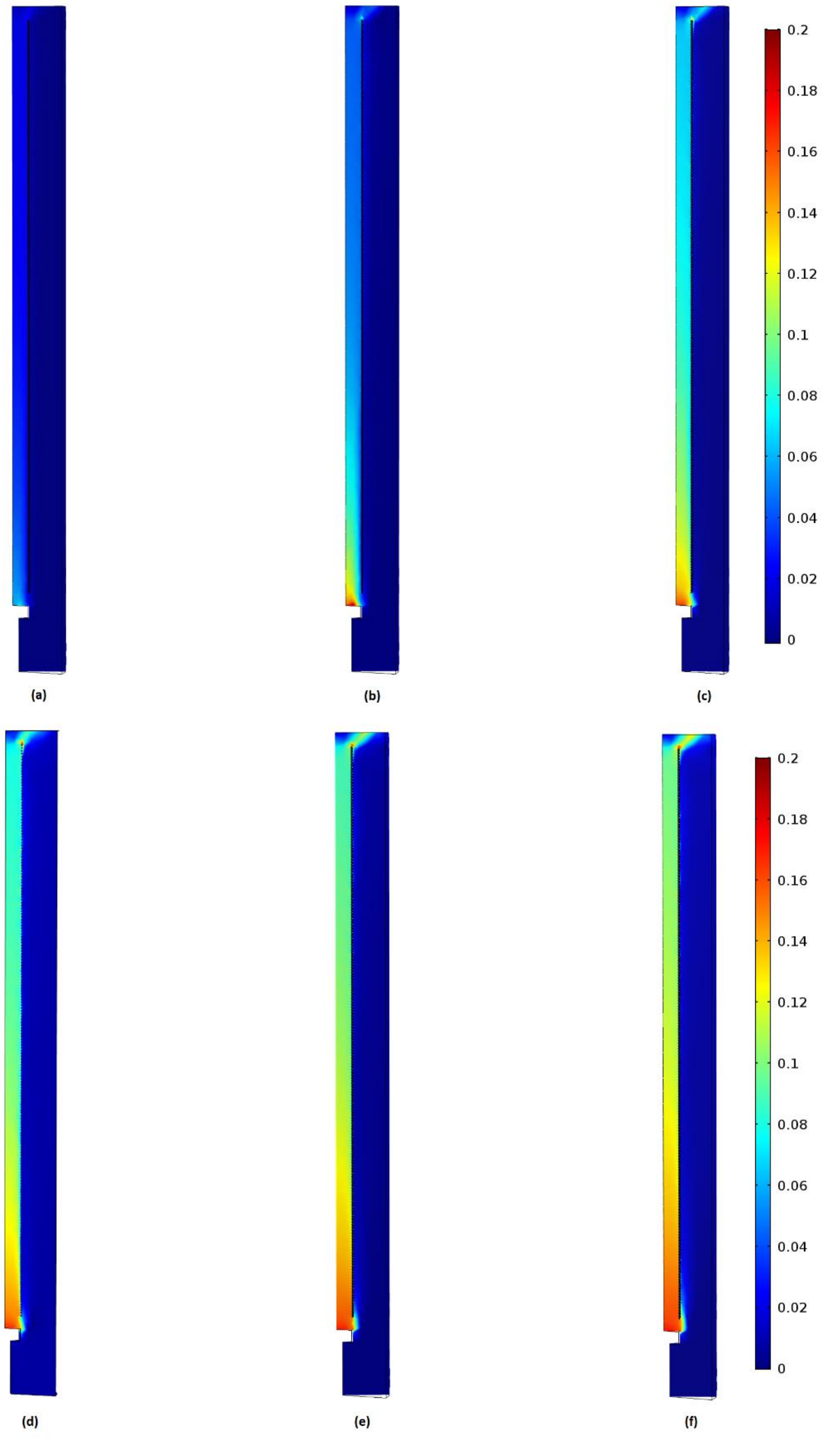

14- Gas-phase distribution in aeration rates of 0.0952 (a), 0.2381 (b) and 0.381 (c), 0.4762 (d), 0.7143 (e), and 1 (f) for water-air in the net draft tube airlift reactor

Due to the presence of holes and voids on the tube in the net draft tube airlift reactor, the moving fluids in the environment pass through them and create proper mixing. The presence of these holes and the increase in mixing causes more air bubbles to come into contact with the liquid inside the reactor (water here) and increase gas holdup. Figure 14 displays the effect of the net draft tube on the gas phase distribution.

The holdup gas value is about 0.0032 for the net draft tube airlift reactor in the aeration rate of 0.0952 vvm, when the flow regime is laminar and the gas phase is distributed in the aqueous environment as shown in Figure 14 (a). It provides good accuracy and precision Due to the flow regime inside the reactors and the complex structures of the geometry of the problem for the reactor with a net draft tube.

5. Gas-phase distribution in the diesel-air system for the net draft tube airlift reactor

In the simulated aeration rates, the gas-phase distribution and gas holdup in the net draft tube airlift reactor for the diesel-air system were also investigated. Figure 15 displays the images of phase distribution and gas holdup.

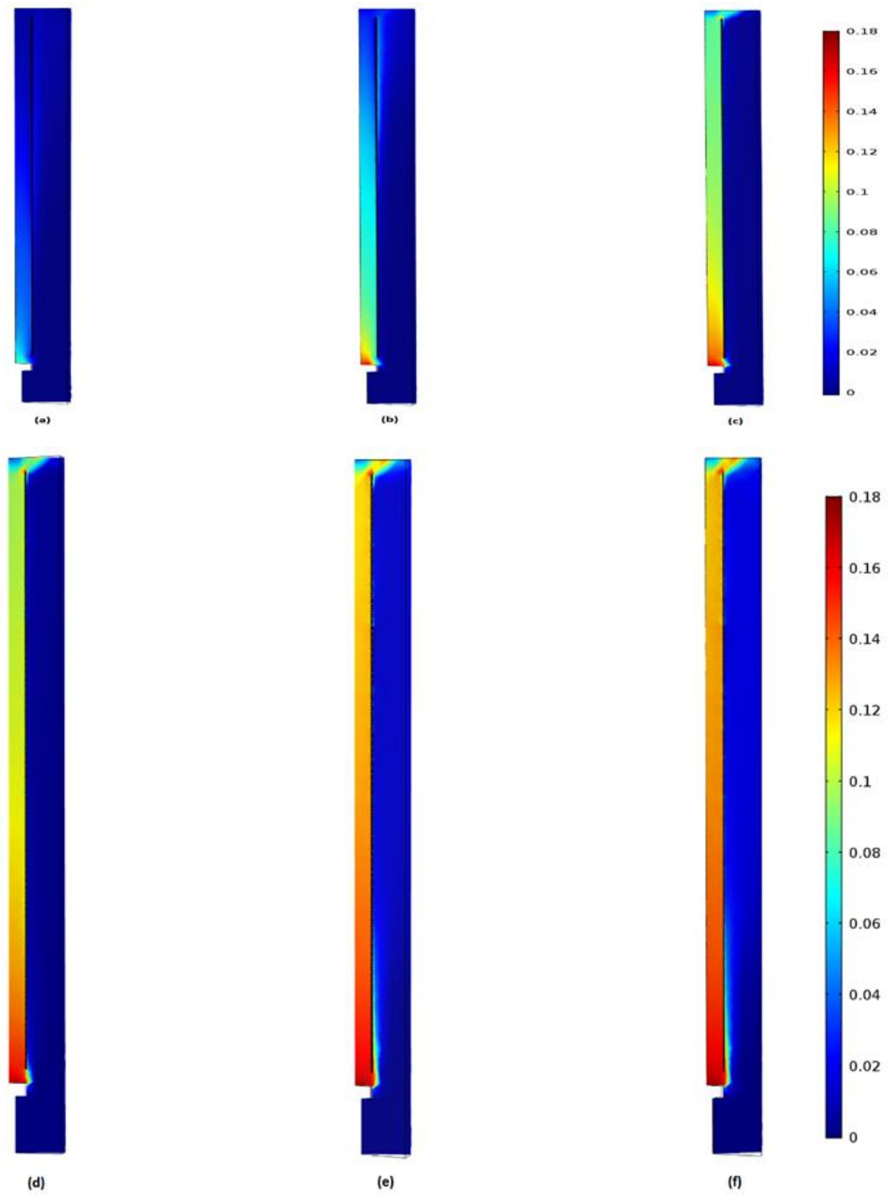

Figure 15- Gas phase distribution at aeration rates of 0.0952 (a), 0.2381 (b) and 0.381 (c), 0.4762 (d), 0.7143 (e), and 1 (f) for diesel-air in the net draft tube airlift reactor

As shown in Figure (15), the gas phase distribution and holdup gas values were calculated and simulated for the net draft tube airlift reactor whose liquid is diesel. This figure shows the high effect of the net draft tube in this reactor. Due to the different viscosity of diesel compared to water and thus, the distribution structure of the gas phase, it has taken a different shape. In this process, the gas phase is restricted from rising and is distributed and spread in the reactor environment since the liquid resists the penetration and failure of its integrity against the gas phase passage. For this reason, the gas phase distribution can be seen at lower points than the water-air system in this reactor.

Conclusion

This study took a step toward improving the accuracy and better understanding of various airlift reactors as widely used tools in industrial and biological processes that have good efficiency, distribution of phases in them, flow rotation, the effect of different aeration velocities in these reactors, reviewing the results and data obtained from the laboratory work and trying to optimize the processes.

In the airlift reactors of this process, more appropriate accuracy can be achieved in the calculations by increasing the input speed for simulation. In the bubble column reactors with this simulation scale, the minimum calculation error for gas holdup with values of 5.8% was obtained for water-air and 5.5% for diesel-air. In the present study, bubble column reactors compared to airlift and net draft tube airlift reactors provide higher gas holdup but a lower internal liquid fluid velocity. It meets the requirements well for biological and industrial operations while requiring less energy resources and limited monitoring. Bubble column reactors are considered a suitable option if the desired system is very sensitive to environmental stress since among all three problem geometries, the minimum stress rate belongs to the bubble column reactor. However, due to the foaming phenomenon, net draft tube airlift reactors, which do not have this problem, are a very appropriate option due to the lower stress compared to the airlift reactor.

In the process of simulating the net draft tube airlift reactor, the geometry of this reactor has been produced with very high accuracy so for the net draft tube with a mesh size of 12, the thickness of the tube, the diameter of the holes on the tube body, the amount of fluid passing through the mesh wall and its height have been simulated and designed with close to 100% accuracy, which plays a vital role in investigating the factors affecting the fluid inside this type of reactors.

Based on the results of the investigation of the effect of increasing or decreasing the temperature of the reactor environment and the input fluid on gas holdup, stress level, liquid fluid distribution inside the reactor and its mass transfer, it is recommended to investigate, compare, and analyze the effect of increasing the mesh number of the net draft tube (from 12 to 18) or reducing it (from 12 to 6) on the gas holdup in the net draft tube airlift reactor and using membrane or fixed substrates to stabilize the enzyme in these reactors to examine and improve the gas holdup and mass transfer values in airlift reactors.

References

1. Merchuk, J. and F. Garcia Camacho, 2009, Bioreactors: airlift reactors. Encyclopedia of industrial biotechnology: bioprocess, bioseparation, and cell technology. p. 887-953.
2. Garcia-Camacho, F., Fernandez, F.G.A., Sanchez Miron, A., Molina Grima, E., and Chisti, Y., 2000, Bubble-column and airlift photobioreactors for algal culture. AIChE Journal. 46(9): p. 1872-1887.
3. Garcia-Camacho, F., 2002, Growth and biochemical characterization of microalgal biomass produced in bubble column and airlift photobioreactors. Enzyme and Microbial Technology. 31(7): p. 1015-1023.
4. Pawar, S.B., 2018, Computational fluid dynamics (CFD) analysis of airlift bioreactor: effect of net draft tube configurations on hydrodynamics, cell suspension, and shear rate. Bioprocess and biosystems engineering. 41(1): p. 31-45.
5. Bagheripour, E., et al., 2017, CFD Simulation of Liquid Dispersion in Bubble Column. International Journal of Petrochem Sci Eng. 02(03): p. 00040.
6. Wagh, S., Deo, M., and Ranade, V.V., 2014, Axial and radial gas holdup in bubble column reactor. Chemical Engineering Journal. 238: p. 301-313.
7. Xiao, Q., et al., 2017, Simulation of the multiphase flow in bubble columns with stability-constrained multi-fluid CFD models. Chemical Engineering Journal. 329: p. 88-99.
8. Ziegenhein, T., Lucas, D., and Krepper, E., 2015, Transient simulation for large scale flow in bubble columns. Physics of Fluids. 27(11): p. 053306.
9. Liao, Y., Lucas, D., and Krepper, E., 2021, Assessment of drag force models in CFD simulation of bubble column reactors. Chemical Engineering Science. 230: p. 116195.

10. Amani, A. and E. Jalilnejad, 2017, CFD modeling of formaldehyde biodegradation in an immobilized cell bioreactor with disc-shaped Kissiris support. Biochemical engineering journal. 122: p. 47-59.
11. Habibi, A., Nalband, M., and Jalilnejad, E., 2019, Experimentation and CFD modeling of continuous degradation of formaldehyde by immobilized *Ralstonia eutropha* in a semi-pilot-scale plug flow bioreactor. Bioprocess and Biosystems Engineering. 42: p. 485-497.
12. Nalband, M. and E. Jalilnejad, 2018, Coupled Transient CFD-Inhibition Kinetics Modeling of Naphthalene Biodegradation in an Airlift Reactor with Net draft tube. Polycyclic Aromatic Compounds. p. 1-17.
13. Blažej, M., et al., 2004, Gas–liquid simulation of an airlift bubble column reactor. Chemical Engineering and Processing: Process Intensification. 43(2): p. 137-144.
14. Coimbra, J.C., Batista, P.H.R., Paz, D.G.S., Oliveira, P.S., and Prata, D.M., 2024, CFD analysis of multiphase flow in an airlift reactor: superficial velocity and gas holdup influence on the loop recirculation. Brazilian Journal of Chemical Engineering. 41(3): p. 789-802.
15. Mouza ,K.A., N.A. Kazakis, and S.V. Paras, 2004. Bubble column reactor design using a CFD code. in 1st International Conference "From Scientific Computing to Computational Engineering", Athens, September.
16. Buwa, V.V., and Ranade, V.V., 2002, Dynamics of gas–liquid flow in a rectangular bubble column: Experiments and single/multi-group CFD simulations. Chemical Engineering Science. 57(24): p. 4715-4736.
17. Montante, G., et al., 2005, CFD simulations and experimental validation of homogenisation curves and mixing time in stirred Newtonian and pseudoplastic liquids. Chemical Engineering Science. 60(8-9): p. 2427-2437.
18. Ghorai, S. and K. Nigam, 2006, CFD modeling of flow profiles and interfacial phenomena in two-phase flow in pipes. Chemical Engineering and Processing: Process Intensification. 45(1): p. 55-65.
19. Hu, X., Ilgun, A.D., Passalacqua, A., Fox, R.O., Bertola, F., Milosevic, M., and Visscher, F., 2021, CFD simulations of stirred-tank reactors for gas-liquid and gas-liquid-solid systems using OpenFOAM®. International Journal of Chemical Reactor Engineering. 19(1): p. 1-20.
20. Faraji, H., Habibi, A., and Jalilnejad, E., 2020, CFD modeling of hydrocarbon-air system hydrodynamics in three types of column reactors. IJCHE. 17: p. 47-64.
21. Dejaloud, A., F. Vahabzadeh, and A. Habibi, 2018, Hydrodynamics and oxygen transfer characterization in a net draft tube airlift reactor with water-in-diesel microemulsion. Fuel Processing Technology. 171: p. 265-276.
22. Chisti, M. and M. Moo-Young, 1987, Airlift reactors: specifications, applications and design considerations. Chemical Engineering Communications. 60(1-6): p. 195-242