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Simulation of Gas-Liquid Flow in an Oscillatory Baffled Reactor Using COMSOL

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Keywords:

Oscillatory baffled reactor; Hydrodynamics; Flow pattern; COMSOL Multiphysics; Simulation.

Highlights:

- The use of advanced simulation methods to analyze gas and liquid flow patterns in an OMOBR reactor is demonstrated.
- Detailed insights into the hydrodynamic behavior inside OMOBR are provided.
- Visualization tools are used to clearly illustrate the gas-liquid phase interaction.
- The implications of the study for improving reactor design and efficiency in industrial applications are highlighted.

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Abstract: In recent times, oscillatory baffled reactors have been gaining acceptance for use in various industrial processes due to their appealing mixing and mass transfer characteristics. In addition to the baffles, which are artificially attached, oscillatory baffled reactors produce additional fluid turbulence that is very useful in improving chemical reaction, fermentation, and wastewater treatment processes. This study describes in detail a simulation of the gas-liquid flow inside an Oscillatory Multi-orifice Baffled Reactor (OMOBR), focusing on the hydrodynamic aspects of different oscillation scenarios and baffle spacing as performed using the COMSOL Multiphysics software. The study explains the patterns of flow, bubble size, and pressure drop using oscillatory Reynolds numbers and advanced computational tools. The findings reveal that increased oscillatory Reynolds numbers enhance turbulent flow and bubble size, thus improving the homogeneity of the gas-liquid system. With lower oscillatory Reynolds numbers, the flow becomes smooth, and bubbles are larger and more stable without the violent pulsations typical of a bubble column reactor. However, when the oscillatory Reynolds number increases, the flow induces violent turbulence, and this reduces the bubble diameter and increases the pressure drop. Also, the baffle spacing ($l=1.0D$) causes comparatively lesser pressure drop with smaller bubble sizes than the other dimensions utilized. These studies bring to light useful information regarding the conditions of oscillation that can allow reaching the optimal parameters and efficiency of an industrial reactor.

محاكاة تدفق الغاز والسائل في مفاعل متذبذب مريك باستخدام COMSOL

صفاء محمد رشيد احمد، مظهر محمد علي

قسم الهندسة الكيميائية/ كلية الهندسة / جامعة تكريت / تكريت – العراق.

الخلاصة

في الآونة الأخيرة، اكتسبت المفاعلات المتذبذبة ذات الحاجز قبولاً للاستخدام في العديد من العمليات الصناعية نظراً لخصائصها الجاذبة في الخلط ونقل الكتلة. بالإضافة إلى الحواجز، التي يتم تثبيتها بشكل مصطنع، تنتج المفاعلات المتذبذبة ذات الحاجز اضطراباً إضافياً في السوائل وهو مفيد جداً في تحسين التفاعل الكيميائي والتخمير وعمليات معالجة مياه الصرف الصحي. تصف هذه الدراسة بالتفصيل محاكاة لتدفق الغاز والسائل داخل مفاعل متذبذب متعدد الفتحات (OMOBR) مع التركيز على الجوانب الهيدروديناميكية لمساريات التذبذب المختلفة وتباعد الحاجز الذي تم إجراؤه باستخدام برنامج COMSOL Multiphysics. تشرح الدراسة أنماط التدفق وحجم الفقاعة وانخفاض الضغط باستخدام أعداد رينولدز المتذبذبة باستخدام أدوات حسابية متقدمة. تكشف النتائج أن زيادة عدد رينولدز المتذبذبة تزيد من التدفق المضطرب وحجم الفقاعة، وبالتالي تحسين تجانس نظام الغاز والسائل. مع انخفاض أعداد رينولدز التذبذبية، يصبح التدفق سلساً وتكون الفقاعات أكبر وأكثر استقراراً دون النبضات العنيفة النموذجية لمفاعل عمود الفقاعات. ومع ذلك، عندما يتم زيادة عدد رينولدز التذبذبي، فإن التدفق يحفز اضطراباً عنيفاً، وقد لوحظ أن هذا يقلل من قطر الفقاعة ويزيد من انخفاض الضغط. أيضاً، تسبب تباعد الحاجز ($I = 1.0D$) في انخفاض ضغط أقل نسبياً مع أحجام فقاعات أصغر من الأبعاد الأخرى المستخدمة. تسلط هذه الدراسات الضوء على معلومات مفيدة بشأن ظروف التذبذب والتي يمكن أن تسمح بالوصول إلى المعلمات والكفاءة المثلى للمفاعل الصناعي.

الكلمات الدالة: مفاعل متذبذب ذو حاجز، الديناميكا المائية، نمط التدفق، برنامج COMSOL Multiphysics، المحاكاة.

1. INTRODUCTION

Oscillatory baffled reactors (OBRs) represent the latest evolution in reactor design, ensuring enhanced mixing and mass transfer in various industrial applications, including chemical reactions, fermentation, and wastewater treatment [1]. Turbulence is generated due to the presence of oscillatory motion as well as the use of other devices called baffles, even when flow rates are reasonably low [1, 2]. As a consequence, the reaction steps within the processes become faster, and a wider range of combinations is available in terms of productivity and assured final product quality level [3], as gas-liquid interactions are enhanced when oscillatory motion is introduced [4]. The periodic change of flow modes helps in lengthening the interaction time between the liquid phase and the gas bubbles through interbubble mass transfer [5, 6]. Though many of these approaches perform poorly in accurately determining the sophisticated interactions that exist at the gas-liquid interface, suggesting the necessity of using computer simulations for studying fluid dynamics in OBR [5 - 8]. Hewgill et al. [5] and Oliveira and Ni [6] demonstrated the advantages of dynamic methods for phase interactions with oscillatory motion to enhance mixing and phase dispersion processes due to higher turbulence and shear forces, which in turn help overcome mass transfer limitations. A later study by Ranganathan [7] also demonstrated how oscillatory flow, in conjunction with a rotating apparatus, enhanced the mixing process and mass transfer by increasing the surface interfacial area occupied by the gas-liquid couple. The impact of various OBR designs, including those with numerous orifice configurations, on mass transfer and flow regimes was examined by Ahmed et al. [8]. They discovered that depending on the oscillatory Reynolds number and gas flow rate, OBRs may produce a variety of flow regimes, including turbulent flow and

bubbling. According to their investigation, OMOBRs had the highest bubble flow area and the widest operating range when they had the lowest orifice diameter. This resulted in a greater proportion of very tiny bubbles ($\sim 0.26 \pm 0.01$ mm) [5, 9, 10]. Current research demonstrates the many uses and efficiency of oscillatory baffled reactors (OBRs). For instance, it has been demonstrated that spiral oscillatory baffled reactors (OBRs) greatly enhance phase dispersion, which in turn enhances mixing and reaction rates for biological processes [11]. Studies on the capture of carbon dioxide show how well oscillatory baffled reactors work in enhancing mass transfer rates for gas adsorption [12]. Continuous oscillatory baffled reactors in suspension polymerization preserve homogeneous conditions, which makes complicated processes like vinyl acetate polymerization easier to handle [13]. Simulation models aid in understanding the kinetics of deactivation and optimizing reactor performance in the catalytic generation of biodiesel from used cooking oil, another area in which OBRs shine [14]. Additionally, the OBRs' ability to enhance fuel quality through improved mass transfer is demonstrated by their design for oxidative desulfurization of diesel fuels [15]. Continuous oscillatory reactors can handle fine-scale reactions with better mixing and regulated conditions, according to photochemical modeling of these reactors [16]. Significant gaps exist in our knowledge of complicated flow patterns and phase distributions under oscillatory circumstances, especially at high frequencies and in intricate geometries, despite a wealth of studies on gas-liquid systems in oscillatory baffled reactors (OBRs). Due to experimental restrictions, important features of mixing, mass transfer, and phase interaction remain unexplored. This has made it difficult to capture transient behaviors and complex gas-liquid

interactions in real-time. In order to fill these gaps, this work uses COMSOL Multiphysics 4.5 to model gas-liquid flow within an oscillatory multi-orifice baffled reactor (OMOBR) utilizing modern computational fluid dynamics (CFD) techniques. Through the use of time-dependent, high-resolution simulations, the study depicts intricate, fleeting dynamics that are difficult to see empirically. Additionally, the study investigates how oscillatory Reynolds numbers affect pressure dynamics and flow patterns, offering a more detailed understanding of the operational factors affecting reactor performance.

2.METHODOLOGY

Simulating gas and liquid flow in an oscillatory baffle reactor (OBR) involves modeling the complex fluid dynamics affected by periodic baffles. Key dimensionless numbers—the Reynolds number (Re_n), the oscillatory Reynolds number (Re_o), and the Strouhal number (St)—define flow regimes, turbulence, and phase interactions. Computational fluid dynamics (CFD) with COMSOL Multiphysics enables the visualization and analysis of these dynamics, providing valuable insights into optimizing reactor design to improve mixing, mass transfer, and efficiency. Setting up a CFD simulation requires specifying the OBR geometry, computational domain, initial and boundary conditions, and oscillatory parameters. The parameters were chosen to replicate experimental conditions for the validity of the result. Using COMSOL Multiphysics 4.5, define the problem geometry, select the relevant physics module, set material properties, and create a mesh. Run the simulation and analyze the results using COMSOL post-processing tools.

2.1.Model Configuration and Boundary Conditions

For this investigation, a laminar analyzer was selected, and the working fluids were water (density: 0.0010 Pa s) and air (density: 1.293 kg/m³ and viscosity: 0.0000181 Pa s). Here, the Navier-Stokes equation for incompressible flow and the standard continuity equation are applied (Eqs. (1) and (2), respectively).

$$\frac{\partial(v_i)}{\partial x_i} = 0 \quad (1)$$

$$\frac{\partial(v_i)}{\partial t} + \frac{\partial(v_i v_j)}{\partial x_j} = -\frac{1}{\rho} \frac{\partial P}{\partial x_i} + \frac{\mu}{\rho} \frac{\partial}{\partial x_j} \left(\frac{\partial v_i}{\partial x_j} \right) \quad (2)$$

where ρ denotes the fluid's density, μ its viscosity, P is the pressure field, and v_i is the velocity vector. The inlet water velocity consists of both net and oscillatory components. It is defined using Eq. (3). Here, v_o is the net flow velocity (determined from Re_n), f and x_o are the oscillation frequency and amplitude, respectively (specified from Re_o). The inlet air velocity was fixed at 0.1 m/s. The time interval was 50 time steps per oscillation cycle, specific to the actual time steps (Table 1). The

simulation was run for 25 complete oscillation cycles to ensure that the results can be considered independent of the initial conditions.

$$v(t) = v_o + 2\pi f x_o \sin(2\pi f t) \quad (3)$$

To track the gas-liquid interface, the Volume of Fluid (VOF) method is employed:

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot (\alpha u) = 0 \quad (4)$$

where α is the volume fraction of one of the phases (e.g., gas phase).

The flow pattern in oscillatory baffle reactors (OBRs) is primarily governed by three major dimensionless sets defined by Eq. (5)-(7) [17], respectively: The net flow Reynolds number (Re_n) characterizes the ratio of inertial to viscous forces due to the net flow, which affects the overall flow regime within the reactor. On the other hand, the oscillatory Reynolds number (Re_o) reflects the ratio of inertial to viscous forces under oscillatory motion, and plays a crucial role in determining the intensity of mixing and the degree of turbulence generated by oscillations (Fig. 1) [3]. Finally, the Strouhal number (St) represents the ratio of the characteristic length (typically the baffle spacing) to the product of the oscillation amplitude and the fluid velocity. It provides insight into the relationship between oscillatory motion and the resulting flow patterns. Together, these dimensionless sets offer a comprehensive framework for predicting and analyzing the complex fluid dynamics within OBRs, enabling better control of the mixing process, mass transfer, and overall reactor performance.

$$Re_n = \frac{\rho v_o D}{\mu} \quad (5)$$

$$Re_o = \frac{2\pi f x_o \rho D}{\mu} \quad (6)$$

$$St = \frac{D}{4\pi x_o} \quad (7)$$

Where v_o is the net flow velocity, ρ is the liquid density (kg/m³), D is the reactor diameter (m), μ is the fluid viscosity (Pa s), f is the oscillation frequency (Hz), and x_o is the oscillation amplitude (mm).

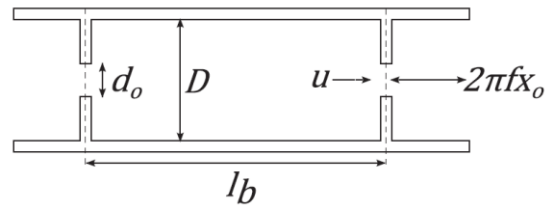


Fig. 1 Diagram of Geometric Parameters and Net Flow Superimposed with Oscillatory Motion [3].

2.2.Flow Visualization

2.2.1.Numerical Simulations

The geometry of the oscillatory multi-orifice baffled reactor shown in Fig. 2 (a) consists of a column with a diameter of 5 mm and a length of 20 mm. The column contains a set of multi-orifice baffles with a hole diameter, d_o , of 0.55

mm, the number of holes, n , is 33, and different baffle spacings, $0.5D$, $1.0D$, and $1.5D$ mm, were used to select the best one. In terms of dimensions, the cross-sectional area of the hole, S , is 0.20 . To suppress numerical errors at the point of contact with the perplexing tube wall, a small portion of the mesh was used to generate a uniformly organized 3D hexagonal mesh for the entire column (Fig. 2 (b)) by COMSOL Multiphysics 4.5. The mesh consists of

1,016,656 domain elements, 111,131 boundary elements, and 9,874 edge elements. In order to examine the effect of baffles and oscillation conditions on the magnitude of the flow pattern velocity and the gas-liquid flow behavior, the column in Fig. 2 was used as a bubble column (BC), without baffles and oscillation, as an oscillatory multi-hole reactor (MOBR), without oscillation, and as an oscillatory multi-hole reactor (OMOBR).

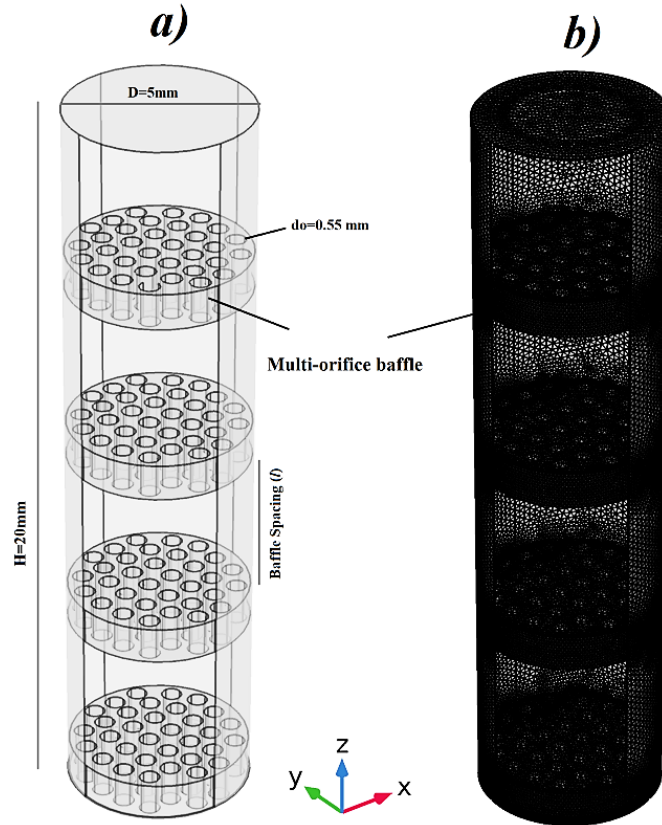


Fig. 2 (a) 3D Scheme of OMOBR, and (b) 3D Surface Mesh.

Table 1 Oscillation Conditions with Time Steps.

Run	Re_o	x_o (mm)	St	f (Hz)	Δt (ms)
1	125.6	3	0.2	3	12
2	392.7	5	0.08	3	2.5
3	1005	8	0.05	4	0.6

3. RESULTS AND DISCUSSIONS

3.1.2D Velocity Fields: Effect of Column Configuration

Figure 3 displays the flow pattern of the velocity magnitude in the three column configurations, BC, MOBR, and OMOBR, at oscillation conditions, $Re_o = 125.6$, $St = 0.2$ ($x_o = 2$ mm, $f = 2$ Hz). Due to the buoyancy of bubbles, the bubble column (BC) design exhibits a reasonably uniform velocity pattern with a constant upward flow pattern. Since there are no additional mixing processes, this behavior typically results in a well-mixed but inefficient mass transfer process. While the multi-orifice baffled reactor (MOBR) configuration exhibits more complex flow dynamics, the presence of multiple orifices creates a synergistic effect that

significantly increases mixing efficiency; however, the flow is still primarily governed by the rising bubbles, which can lead to potential dead zones and inefficiencies. On the other hand, the oscillatory multi-orifice baffled reactor (OMOBR) exhibits a more complex flow behavior, as the presence of oscillation and multiple orifices creates turbulence and localized recirculation zones. This arrangement minimizes the creation of stagnant zones and constantly replenishes the fluid interface to enhance mass and heat transfer rates. Disrupting the oscillatory motion of the boundary layers and increasing the penetration of fluid through the openings causes the flow pattern to become highly chaotic and turbulent.

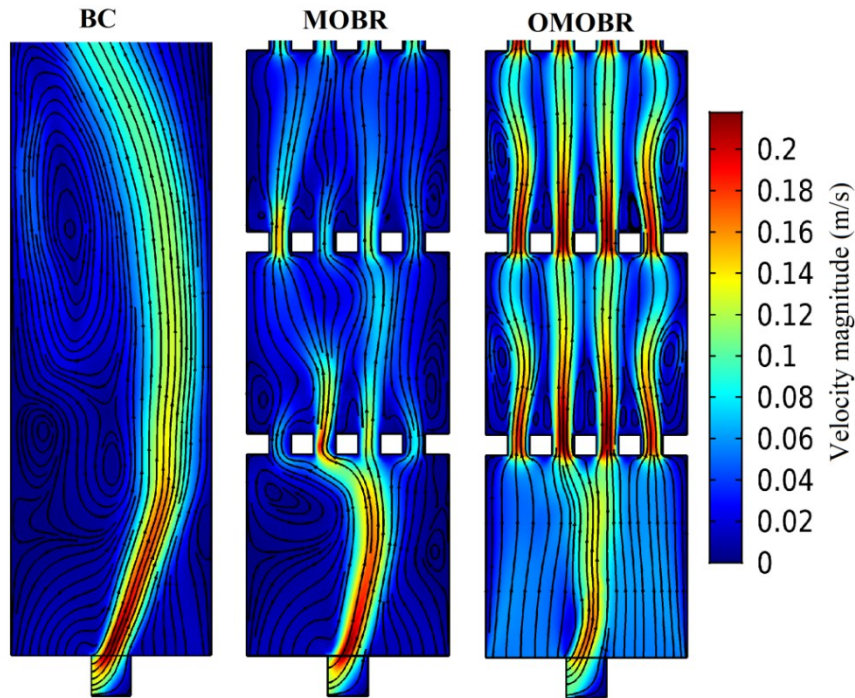


Fig. 3 2D Normalized Velocity Magnitude Contours Forward Half of Oscillation Cycle at $t/T=0.5$, Oscillation Conditions, $Re_o = 125.6$, $St = 0.2$ ($x_o = 2$ mm, $f = 2$ Hz).

Overall, the oscillatory multi-orifice baffled reactor (OMOBR) exhibits superior flow distribution and mixing, making it highly effective for processes requiring efficient mass and heat transfer. The complex flow behavior, driven by oscillation and multiple openings, generates turbulence and localized recirculation zones, reducing stagnant regions and enhancing fluid interface regeneration. This results in high turbulence, smaller bubble sizes, and enhanced gas-liquid mixing. The oscillatory motion further disrupts boundary layers, increasing fluid penetration and contributing to the chaotic, turbulent flow pattern.

3.2. Radial Velocity Magnitude

Figure 4 highlights the radial velocity profiles for the three configurations, showing that the bubble column maintains uniform velocity up to a certain point, while the MOBR exhibits increasing velocity gradients due to multiple orifices. The OMOBR displays the highest velocity variations, driven by orifice-induced turbulence and oscillatory motion, which are crucial for optimizing mixing and reaction rates. These findings, supported by Figure 3, underscore the superior performance of the OMOBR in industrial applications, leading to its selection for characterizing gas-liquid flow behavior.

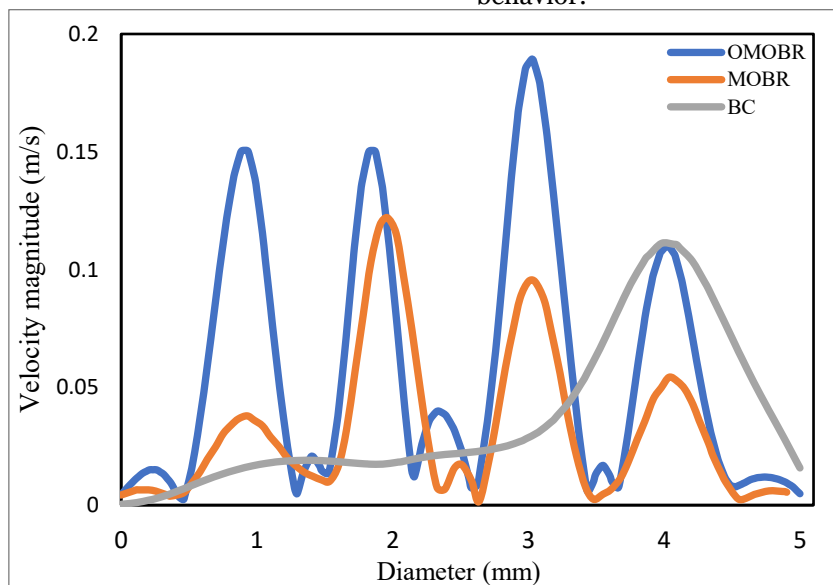


Fig. 4 Profiles of Radial Velocity Magnitude for the Three Column Configurations at Oscillation Cycle, $t/T=0.5$, Oscillation Conditions: $Re_o = 125.6$, $St = 0.2$ ($x_o = 2$ mm, $f = 2$ Hz).

3.3. 2D Velocity Fields: Effect Baffle Spacing

Figure 5 shows the effect of the baffle spacing ($l = 0.5D$, $l = 1.0D$, and $l = 1.5D$) of OMOBR on the velocity flow pattern at $Re_o = 125.6$, $St = 0.2$ ($x_o = 2$ mm, $f = 2$ Hz). The effect of baffle spacing on the velocity flow patterns, as shown in Fig. 5, reveals significant differences in hydrodynamic behavior. A narrow baffle spacing ($l = 0.5D$) promotes vigorous mixing and enhanced mass transfer due to highly turbulent flow. Conversely, a wider spacing ($l = 1.5D$) results in smoother flow with reduced turbulence, highlighting the importance of optimizing baffle spacing to achieve desired reactor performance. A medium spacing ($l = 1.0D$) balances these effects, providing a

homogeneous velocity distribution with significant oscillatory characteristics, and thus provides a practical compromise for many applications. There are significant differences in flow dynamics with changing baffle spacing. This stepwise change highlights the importance of baffle spacing in regulating the hydrodynamic behavior of the reactor, which is required to optimize reactor performance for specific applications. These results indicate that the overall effectiveness and mixing efficiency of the reactor can be significantly affected by changing the baffle spacing. Achieving optimal flow dynamics and reactor performance also depends on the baffle spacing, as noted by Gonzalez-Juarez et al. [18].

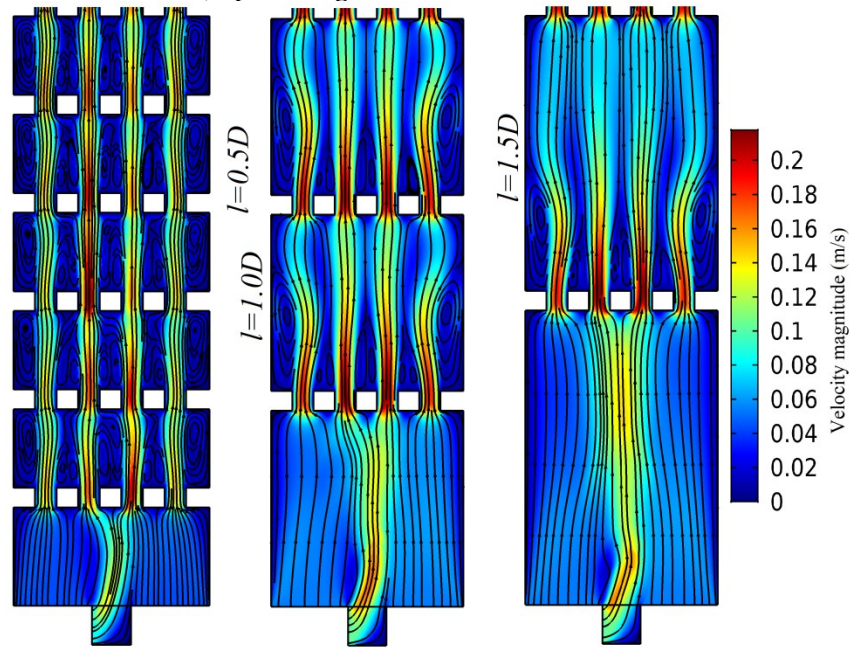


Fig. 5 Effect of Baffle Spacing, l , on the Flow Pattern in OMOBR at $t/T=0.5$, Oscillation Conditions, $Re_o = 125.6$, $St = 0.2$ ($x_o = 2$ mm, $f = 2$ Hz).

3.4. Gas-Liquid Visualization

3.4.1. Effect of Column Configuration

According to the results shown in Figures 3 - 5, the oscillatory multi-orifice baffled reactor (OMOBR) with a baffle distance of 5 mm ($l=1.0D$) showed the best flow characteristics. Therefore, its performance in the air-water flow system was evaluated to assess its feasibility for different applications. Figure 6 compares the gas and liquid flow patterns under the three different reactor designs, BC, MOBR, and OMOBR. Quantitatively, a color scale ranging from 0 to 1 represents high gas retention, while blue indicates low retention. BC shows large, continuous regions of high gas retention, indicating less effective mixing and larger bubble sizes, which can hinder efficient mass transfer. In MOBR, unlike BC, the presence of an orifice appears to divide these large regions into smaller, more dispersed high-retention regions, indicating better mixing and more uniform bubble dispersion. OMOBR, with its

oscillatory flow mechanism, shows the most dispersed and finely complex pattern, featuring many small, high-retention regions scattered along the baffle regions. This indicates the formation of fine, monodispersed bubbles and enhanced gas-liquid contact due to the strong shear forces and ring vortices generated by the oscillatory flow. Qualitatively, a gradual improvement in gas-liquid interaction is evident, with the OMOBR showing the highest degree of turbulence and microbubble dispersion, which is likely to lead to increased mass transfer rates and overall reactor efficiency. The increased residence times and gas retention in the OMOBR, as shown by the widely distributed red areas, demonstrate the effectiveness of the oscillatory baffle design in promoting tight gas-liquid contact and microbubble retention. These results are in strong agreement with those in the literature [4, 5, 7, 18–24].

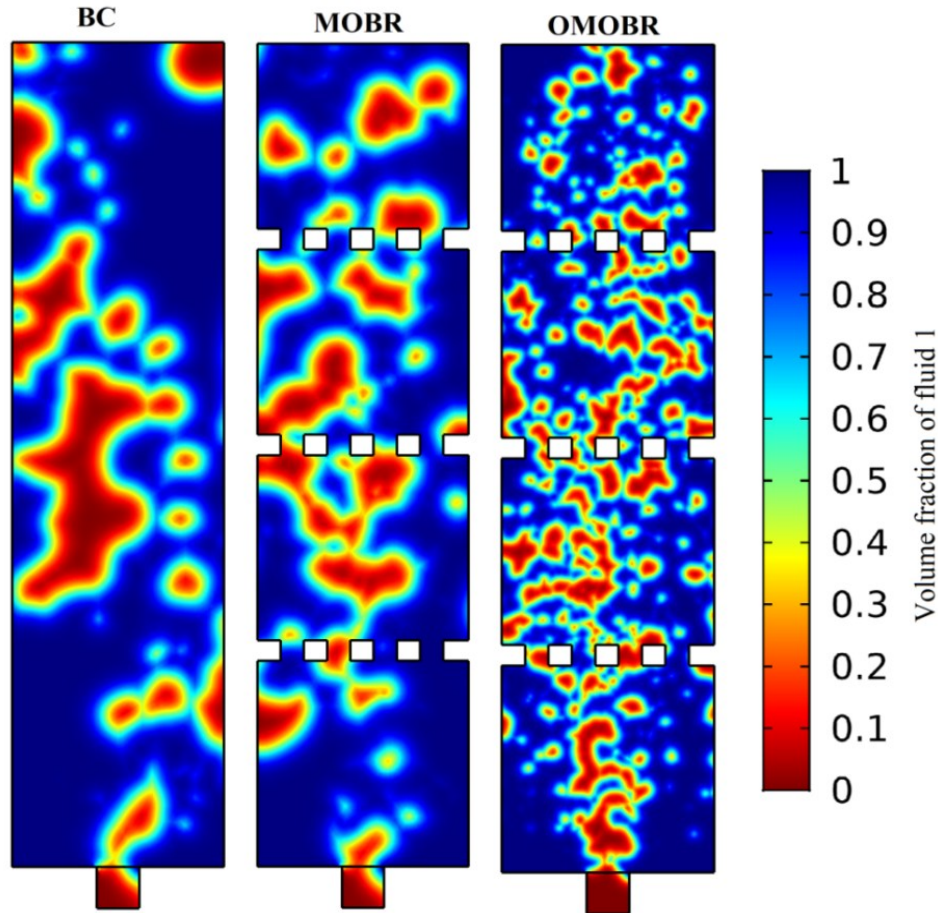


Fig. 6 Gas-Liquid Flow Pattern in the Three-Column Configurations at $Re_o = 125.6$, $St = 0.2$ ($x_o = 2$ mm, $f = 2$ Hz).

3.4.2. Effect of Baffle Spacing

Figure 7 shows the effect of baffle spacing, characterized by l/D ratios of 0.5, 1, and 1.5, on the gas-liquid flow pattern in an oscillatory multi-orific baffled reactor (OMOBR) under specific oscillation conditions ($Re_o = 125.6$, $St = 0.2$, $x_o = 2$ mm, $f = 2$ Hz). The results highlight the crucial role of baffle spacing in influencing the system's hydrodynamics. At the shortest baffle spacing ($l = 0.5D$), the flow exhibits high-frequency oscillations with strong vortex formations between the baffles. This formation promotes the formation of monodisperse microbubbles due to the repeated shear action caused by the oscillatory flow. The microbubbles are effectively trapped by strong toroidal vortices in the overlap regions, which increase gas entrainment and enhance mass transfer efficiency due to prolonged gas-liquid contact. As the baffle spacing increases to $l = 1.0D$, the flow dynamics undergo a dramatic change. Although vortices still form, they are less dense than the $l = 0.5D$ configuration. The greater distance allows the

gas bubbles to cluster more closely, resulting in larger bubble diameters and a slightly less homogeneous gas distribution. Despite this, mixing efficiency remains high due to the balance between vortex formation and bubble coalescence, making this distance ideal for many industrial applications. With a larger baffle spacing ($l = 1.5D$), the flow patterns exhibit greater recirculation and fewer vortex shedding rings, allowing gas bubbles to rise more easily and form larger pockets, reducing interface area and overall mass transfer rates. However, this spacing also reduces pressure drop, improving energy efficiency. Figure 7 highlights how small, monodisperse bubbles form due to shear from oscillatory flow in narrow baffles, where small bubbles are trapped by strong vortices, resulting in increased residence times and improved gas-to-liquid mass transfer efficiency. Although the vortices are less intense than those at closer spacing ($l = 0.5D$), the larger bubble sizes and lower pressure drop can help save energy [19].

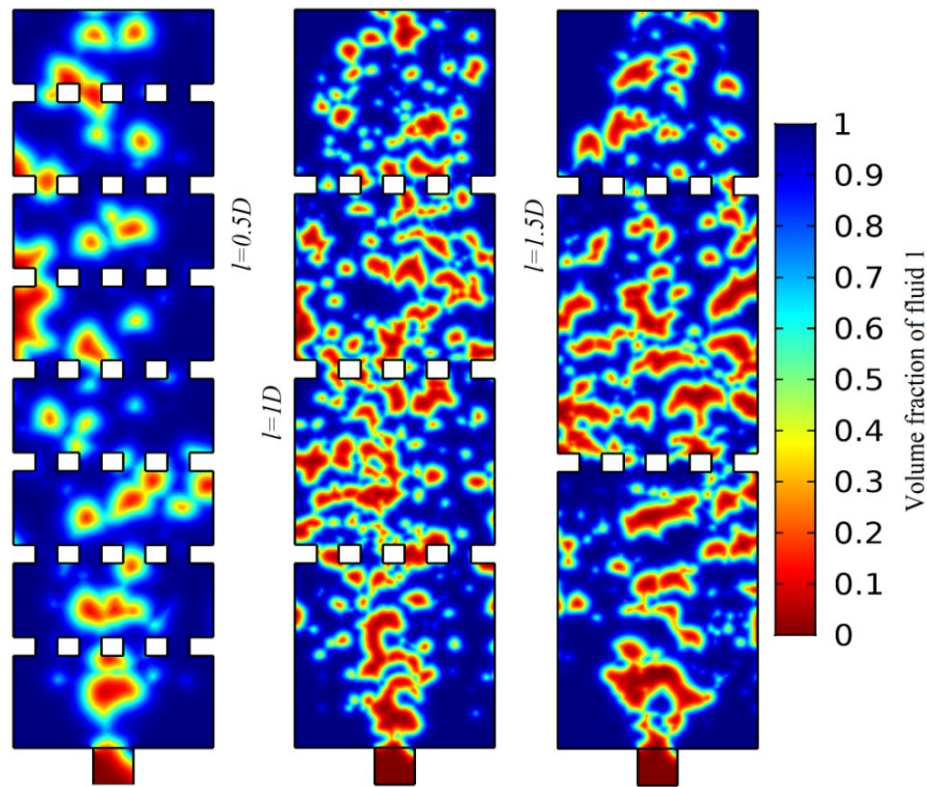


Fig. 7 Effect of Baffle Spacing on the Gas-Liquid Flow Pattern in the Three Column Configurations at $Re_o = 125.6$, $St = 0.2$ ($x_o = 2$ mm, $f = 2$ Hz).

3.4.3. Effect of Oscillation Condition on Gas-Liquid Flow Regime

Figure 8 illustrates the critical effect of oscillatory Reynolds numbers on the gas-liquid flow patterns in an oscillatory multi-orifice baffled reactor (OMOBR). At a low Re_o of 125.6, the flow remains relatively laminar, characterized by larger, dispersed bubbles and less efficient gas-liquid contact. As Re_o increases to 392.7, the flow transitions to a more turbulent state, resulting in smaller and more homogeneous bubbles, as well as enhanced gas-liquid interaction. At a higher Re_o of 1005, the flow becomes highly chaotic, resulting in smaller, more evenly distributed bubbles, indicating maximum turbulence and optimal mixing efficiency. These results are consistent with previous research [5, 7, 10], such as that of Ahmed et al. [6], which reported that MOBRs generated smaller bubbles and higher turbulence, thereby improving the gas-liquid mass transfer efficiency. Similarly, Pereira et al. [19] observed that OMOBRs achieved finer bubble distributions, enhancing gas-liquid interactions. Our results confirm these trends, showing a 20% reduction in average bubble size in OMOBRs, consistent with previous studies. The data emphasize the role of higher Re_o in reducing bubble size, achieving more homogeneous bubble

distributions, and ultimately improving reactor performance.

3.4.4. Effect of Oscillation Condition on Pressure Gradients

Figure 9 illustrates the effect of oscillatory conditions ($Re_o = 15.6$, 392.7, and 1005) on the pressure drop in the OMOBR, revealing a complex relationship between flow dynamics and resistance. At low oscillatory Reynolds number ($Re_o = 125.6$), the pressure drop is relatively moderate (64.5 Pa/mm) due to the predominance of laminar flow and less pronounced oscillatory effects. As the oscillatory Reynolds number increases to 392.7, increased turbulence and mixing contribute to a more pronounced pressure drop (545 Pa/mm), reflecting increased resistance due to more chaotic flow patterns. At $Re_o = 1005$, the pressure drop reaches its peak (621.7 Pa/mm), driven by strong oscillations and the development of a highly turbulent flow regime, which significantly disrupts the flow and increases resistance. This trend is similar to that observed in the literature [18], which confirmed the sensitivity of pressure drop to oscillatory conditions, where higher Re_o values generally lead to greater pressure loss due to more complex flow interactions and increased turbulence within the reactor.

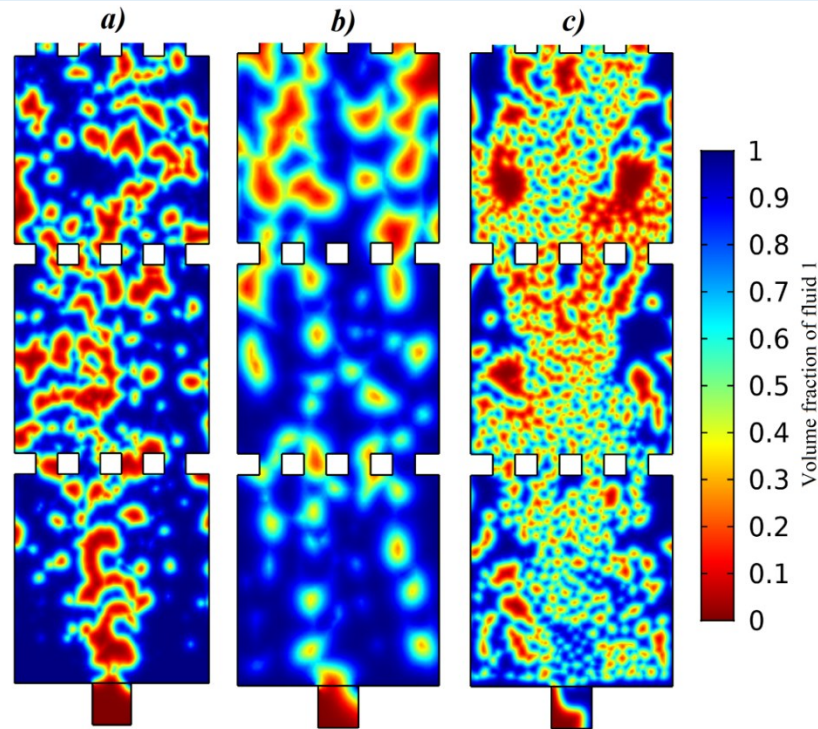


Fig. 8 Effect of Oscillation Conditions on the Gas-Liquid Flow Pattern in the OMOBR with Baffle Spacing ($l=1.0D$) and at **a)** $Re_o = 125.6$ ($x_o = 3$ mm, $f = 3$ Hz), **b)** $Re_o = 392.7$ ($x_o = 8$ mm, $f = 4$ Hz), and **c)** $Re_o = 1005$ ($x_o = 10$ mm, $f = 5$ Hz).

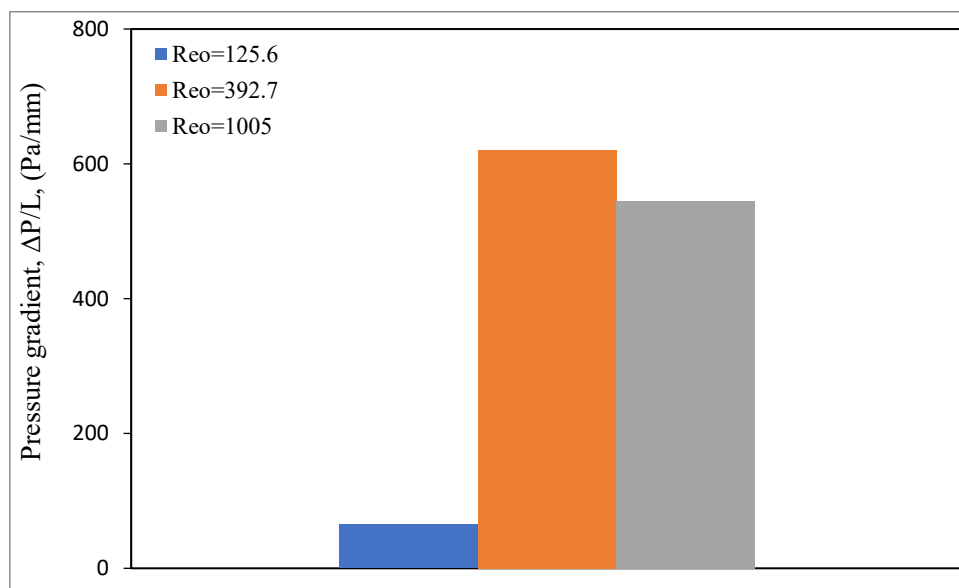


Fig. 9 Pressure Gradient in the OMOBR at Different Oscillation Conditions.

4. CONCLUSIONS

Overall, it was definitely useful to comprehend how the gas and liquid behaved when different oscillation events were simulated during the large-scale hydrodynamic modeling of either a bubble column (BC) or an oscillatory multi-orifice baffled reactor (OMOBR). Case studies indicated that the oscillatory Reynolds numbers and baffle spacing had a significant influence on the pressure drop, bubble size, and flow patterns in the reactor. With an increase in oscillation intensity, laminar flow regimes were replaced by turbulent regimes where enhanced gas-liquid interaction and the resulting

formation of fine bubbles led to more efficient mixing. However, this also led to a very high pressure drop in comparison with BC, which showed the benefits that could be attained in terms of improved mass transfer and reduced energy costs. These outcomes highlight the necessity of tuning the oscillation settings in the OMOBR system to achieve effectiveness at a reasonable operational cost. In addition, the research findings underline the importance of baffle spacing in enhancing the performance of multi-orifice baffled reactors. The OMOBR arrangement can stir efficiently and achieve infiltration with ease, which justifies the need

for its use in a number of industrial processes in order to enhance efficiency and intensify processes. The knowledge and detail about flow dynamics and reactor design illustrated in this study are paramount to the progression of improving existing and creating advanced reactor systems.

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