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HYDRODYNAMIC EVALUATION OF A SQUARE CROSS-SECTION SPLIT AIRLIFT USING CFD

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ABSTRACT

Airlift bioreactors are an interesting alternative to conventional stirred tank bioreactors and its hydrodynamics has been evaluated generally using experimental approach, demanding time, energy, and reagents. In this scenario, Computational Fluid Dynamics (CFD) has emerging as an important and valuable tool for the analysis and design of these devices, saving time and experimental effort and providing a large amount of information. In this study, a square cross-section 10-L split airlift bioreactor operating with distilled water was simulated using CFD and the hydrodynamics variables gas hold-up and liquid velocity were evaluated. A grid sensitivity analysis was performed and results indicated the best mesh structure to be used further, combining accuracy and less computational effort. Comparison between predicted and experimental results indicated a good agreement for riser gas hold-up, while liquid velocities exhibited errors up to 33,7%.

1. INTRODUCTION

Airlift bioreactors are an interesting alternative to conventional stirred tank bioreactors due to its high oxygen transfer capability associated to low power input. The performance of these equipment is dependent of the airflow rate employed, bioreactor geometry and liquid-phase properties (density and rheological parameters) (Merchuk et al., 1996), being described using variables such as gas hold-up (ε), liquid velocity (V_L), among others.

Airlift hydrodynamics has been traditionally evaluated applying experimental methods for the determination of the performance variables. However, Computational Fluid Dynamics (CFD) has emerging as an important and powerful tool to this task, providing information such as gas fraction contour plots, liquid velocity profiles, and shear rate distribution.

Mesh generation is an important step of CFD simulations. In the present work, a grid independence study was performed in a split airlift bioreactor, quantifying the numerical uncertainty of riser gas hold-up (ε_R) and liquid velocity using the Grid Convergence Index (GCI) method (Celik et al., 2008).

2. MATERIAL AND METHODS

2.1. CFD simulations

A 10-L square cross section split airlift was evaluated (Figure 1a), operating with distilled water as liquid phase (32°C) at 1,27 vvm. Detailed information about airlift geometry can be found in Esperança et al. (2016). Computational geometry and numerical mesh were generated using GAMBIT v. 2.4 (Figure 1b). Three mesh structures were generated using hexahedral and tetrahedral elements (concentrated around sparger region – Figure 1c). CFD simulations were performed using ANSYS FLUENT® 14.5, and the mathematical model was the same applied by Rodriguez et al. (2015).

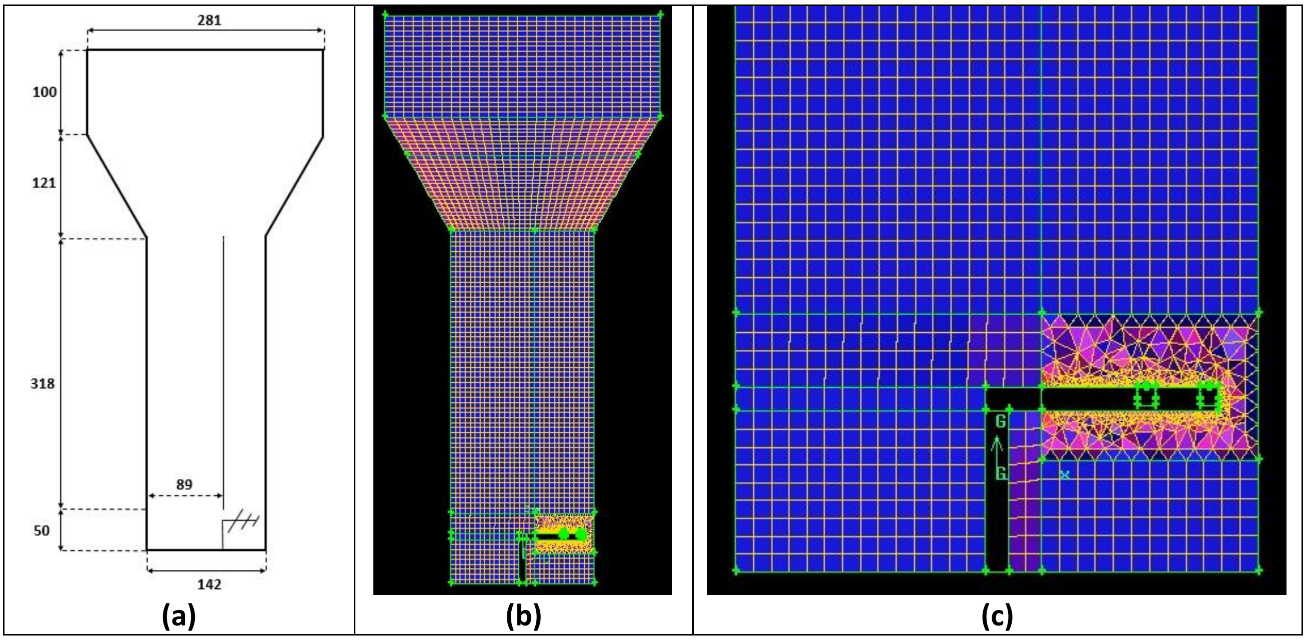

Figure 1. Split airlift bioreactor: (a) main dimensions (lengths in mm); (b) general mesh overview; (c) mesh details around sparger region.

2.2. Grid Convergence Index (GCI) method

Grid Convergence Index (GCI) method consists in quantifying numerical uncertainty, choosing a mesh structure which results in higher precision and lower required machine effort. The procedure consists in generate three different mesh structures (fine, intermediate, coarse), defining for each one a characteristic mesh size *h* as:

$$h = \left[\frac{1}{N}\sum_{i=1}^{N} \Delta V_i\right]^{1/3} \quad \textbf{(1)}$$

where N is the total number of elements present in the mesh and ΔV_i is the volume of the i^{th} element. Then, a grid refinement factor (r_{ij}) between two mesh structures is defined as:

$$r_{ij} = \frac{h_j}{h_i} \quad \textbf{(2)}$$

Where h_j and h_i corresponds to higher and lower characteristic mesh size, respectively. Simulations were then performed for the three mesh structures, and the data was analyzed, allowing the calculation of the GCI index, following the protocol presented by Celik et al. (2008).

2.3. Performance parameters

CFD mean values of the riser gas hold-up ($\varepsilon_{R,CFD}$) and riser and downcomer interstitial liquid velocities ($V_{LD,CFD}$ and $V_{LR,CFD}$) were determined as the volume average in the correspondent region. Experimental riser gas hold-up ($\varepsilon_{R,exp}$) and interstitial liquid velocities ($V_{LD,exp}$ and $V_{LR,exp}$) were obtained according to Mendes and Badino (2016).

3. RESULTS AND DISCUSSION

A grid-size sensitivity test was performed using CGI method to choose a mesh structure with the best accuracy-computational effort relation. Table 1 presents mesh characteristics, processing time (time required to complete the simulation, t) and results of riser gas hold-up, and riser and downcomer interstitial liquid velocities in a split airlift at 1,27 vvm, for the three mesh structures.

Table 1. CFD results of ε_R, V_{LD} and V_{LR} for different mesh structures.

Mesh	h (mm)	N (-)	t (days)	ε_R (-)	V_{LR} (m/s)	V_{LD} (m/s)
Mesh 1 (fine)	2.29	1,610,511	71	0.0308	0.205	0.092
Mesh 2 (intermediate)	3.18	602,954	9	0.0307	0.199	0.089
Mesh 3 (coarse)	4.35	235,074	7	0.0325	0.192	0.082

Riser gas hold-up exhibited an uncertainty of 0.43% between coarse and intermediate meshes (GCI_{23}), and 0.02% between intermediate and fine meshes (GCI_{12}), presenting the numerical stable value of 0.0307 (Table 2). For V_{LD} and V_{LR} results, stable values were 0.199 and 0.089 m/s, respectively, with GCI_{12} values of 20.13% and 5.79%, respectively. In spite of the lower GCI_{12} values observed, processing time showed that Mesh 2 combined the best accuracy-computational effort relation, since Mesh 1 processing time was prohibitive to apply this mesh grid in the next simulations. Based on these results the Mesh 2 were used for running simulations at 3,82 and 6,37 vvm in split airlift operating with distilled water. Figure 2 presents CFD and experimental results for ε_R, V_{LD} and V_{LR}.

Figure 2 showed that CFD simulations correctly predicted the trend of performance parameters. Riser gas hold-up relative error ranged from 10,4 to 16,7%. For riser and downcomer interstitial liquid velocities, relative error ranged from 13,4 to 33,7%, and from 19,7 to 28,2%, respectively. Results showed that application of Mesh 2 to the prediction of riser gas hold-up was suitable and provided accurate results. However, predicted liquid velocities were underestimated.

Table 2. Numerical uncertainty calculation applied to the grid under analysis.

GCI/Variables	ε_R	V_{LR}	V_{LD}
GCI_{12}	0.02%	16.47%	2.12%
GCI_{23}	0.43%	20.13%	5.79%

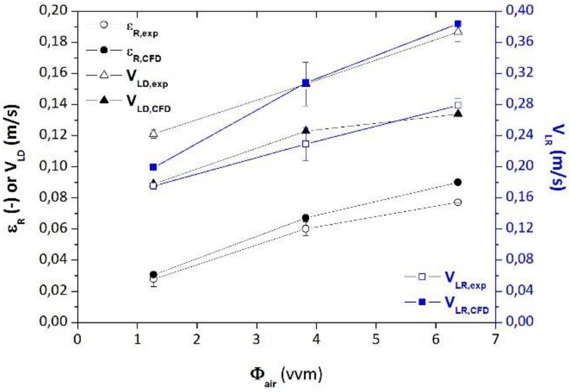

Figure 2. Experimental and CFD results of ε_R, V_{LD} and V_{LR} as function of specific airflow rate (Φ_{air}).

4. CONCLUSIONS

Grid sensitivity analysis in split airlift bioreactor showed that fine mesh (Mesh 1) exhibited the lowest uncertainties for riser gas hold-up and interstitial liquid velocities. However, Mesh 2 was chosen for CFD simulations, since it presented the best accuracy/computational effort relation. Using Mesh 2, predicted riser gas hold-up exhibited good agreement with experimental results, while predicted liquid velocities presented relative errors up to 33,7%. Results showed the potential application of Computational Fluid Dynamics for prediction of square section airlift hydrodynamics.

5. REFERENCES

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