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Preface

Non-Newtonian Flow and Applied Rheology covers a considerably broader range of topics including computational fluid dynamics modeling techniques, liquid/solid flows and applications to areas such as food processing, among others. In the first chapterof this book, we describe one of the most promising bioreactors for their processing qualities, good mixing, low shear, easy to operate with immobilized microorganisms, low consumption of energy, we are talking about the airlift bioreactors. Second chapter contains the most important information on the structure of greases along with the discussion of the influence of the thickener's microstructure on the behavior of the lubrication formula mainly in lubrication systems, but also in reception points, namely in the friction nodes. It also refers to the problems of the influence of the mechanical stability of a thickener's microstructure on the quality of lubricating the roller bearings and their service life. Additionally, the chapter presents works on generating the lubrication film on the friction nodes working surface. Fouling in membrane filtration and remediation methods has been described in chapter three and fourth chapter describes the history of fracturing fluids, the types of fracturing fluids used, the engineering requirement of a good fracturing fluid, how viscosity is measured and what the limitations of the engineering design parameters are. The purpose of chapter five is to provide some initial results for hydraulic fracture growth through a natural fracture network. Fracture growth is allowed and is based on a local failure criterion and fracture coalescence can take place to form a path through an existing network of natural fractures. Six chapter describes the development of a 2D coupled displacement discontinuity numerical model for simulating fracture propagation in simultaneous and sequential hydraulic fracture operations. The sequential fracturing model considers different boundary conditions for the previously created fractures (constant pressure restricting the flow back between stages and proppant-filled). A series of examples are presented to study the effect of fracture spacing to show the importance of spacing optimization. Seven chapter is focused on the laminar regime, in order to investigate non-Newtonian effects (non-constant fluid viscosity). The relevance of non-Newtonian effects for hemolysis parameters is discussed. In chapter eight, we have carried out the influence of temperature dependent viscosity on thin film flow of a magnetohydrodynamic (MHD) third grade fluid past a vertical belt. The physical characteristics of the problem have been well discussed in graphs for several parameter of interest.

Contents

Chapter 1

AIRLIFT BIOREACTORS: HYDRODYNAMICS AND RHEOLOGY APPLICATION TO SECONDARY METABOLITES PRODUCTION

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INTRODUCTION

The bubble column and airlift bioreactors are pneumatically agitated and often employed in bioprocesses where gas-liquid contact is important. The role of the gas is to provide contact with the liquid for mass transfer processes such as absorption or desorption and to provide energy through gas expansion or bubble buoyancy for liquid mixing. In these two pneumatically agitated reactors, gas is sparger usually through the bottom and the buoyancy of the ascending gas bubbles causes mixing. The main difference between these two pneumatically agitated reactors is in their fluid flow characteristics. The flow in the airlift is ordered and in a cyclic pattern like in a loop beginning from top through to bottom. The airlift differs from the bubble column by the introduction of inner draft tubes which improves circulation, whereas the bubble column is a simple tower. In the airlift, liquid recirculation occurs due to the four distinct sections; the riser, downcomer, gas separator and bottom or base. The bubble column is a simple vessel without any sectioning making the flow rather a complex one.

Some attractive features of the airlift are the low power consumption, simplicity in construction with no moving parts, high mass and heat transfer rates and uniform distribution of shear [1, 2].

The advantage of its low power consumption is of particular importance in effluent (e.g. wastewater) treatment where the product value is comparatively low. Therefore, operational cost (efficient use of energy) is greatly considered since corresponding applications are usually on a large scale. Homogenous shear is particularly important for biological processes that are shearing sensitive. In the conventional stirred tank, shear is greatest at the stirrer and decreases away from it to the walls of the vessel. This creates a gradient of shearing which can have adverse effect on the morphology or sometimes can damage cells (e.g. animal and plant cells). The simple construction of the airlift without shafts makes it not only aesthetically pleasing to look at but also eliminates contamination associated with the conventional stirred tank which is a major drawback in the production of microorganism. A sterile environment is crucial for growing organisms especially in the bioprocesses since contamination reduces product quality, generates wastes, also more time and money are spent to restore the whole process.

In addition to the previously described, the development of new biotech products: drugs, vaccines, tissue culture, agrochemicals and specialty chemicals, biofuels and others have had a major breakthrough during the last decade. But engineering to scale these developments to the production phase is lagging far behind in advances in the efficient development of bioprocesses. Normally these processes are complicated because they are conducted in complex systems, three or four phases, microorganisms that are susceptible to large shear produced by stirring; require high airflow rates, and changes in rheology and morphology cultures through the time. The soul of a bioprocess is still the bioreactor, since it determines the success of a good separation and therefore the cost of the product. In this chapter we describe one of the most promising bioreactors for their processing qualities, good mixing, low shear, easy to operate with immobilized microorganisms, low consumption of energy, we are talking about the airlift bioreactors. In this context the parties will start from basic engineering bioreactors: mass balances, mass transfer, and modelling and to cover the hydrodynamics and rheology of the process. Finally we will present two cases of application on the production of Bikaverin (a new antibiotic), and L-lysine.

HYDRODYNAMIC CHARACTERISTIC OF AIRLIFT REACTORS

Fluid mixing is influenced by the mixing time and gas holdup which defines the fluid circulation and mass transfer properties. The fluid recirculation causes the difference in hydrostatic pressure and density due to partial or total gas disengagement at the gas separator (top clearance, *tt*). Studies have been documented during the last two decades with various correlations applicable for hydrodynamic parameters [3-5]. This implies that for a successful design, fundamental understanding of mixing parameters is important for industrial scale-up.

It is difficult to generalize the performance of the bioreactor according to the process for which the airlift will be employed. For example, in aerobic fermentation, oxygen is important for mass transfer and therefore, it is imperative to consider a design where there will be less disengagement of gas resulting in higher gas holdup for a higher mass transfer rate. In this case, the liquid circulation velocity is low because less gas is disengaged at the top resulting in a lower differential density. Furthermore, other processes require good mixing other than a high mass transfer rate. However, provision can be made by increasing the gas disengagement at the top to improve the liquid recirculation as in the case for anaerobic fermentation. Therefore, it is safe to conclude as have been confirmed [3, 6, 7] that, the geometry parameters such as the top clearance (*tt*), ratio of cross sectional area of the downcomer to the riser (*Ad/Ar*), bottom clearance (*tb*), the cross sectional areas of riser (*Ar*) and that of the downcomer (*Ad*), draft tube internal diameter (*Dd*), and height of the column (*H*) and superficial gas velocity (*Ug*) have an influence on fluid hydrodynamics. There is extensive information on the measurement of fluid hydrodynamics published with a handful of equations. However, most of them Gumery et al.: Characteristics of Macro-Mixing in Airlift Column Reactors 7 Published by The Berkeley Electronic Press, 2009 cannot be correlated due to the different medium (Newtonian versus non-Newtonian) used and various assumptions made. The different measuring techniques often used cannot discriminate diffusion and convection for mixing whiles others disturb process flow.

On the other hands the interconnections between the design variables, the operating variables, and the observable hydrodynamic variables in an airlift bioreactor are presented diagrammatically in Figure 4 as has been reported by [8]. The design variables are the reactor height, the riser-to-downcomer area ratio, the geometrical design of the gas separator, and the bottom clearance (C_b, the distance between the bottom of the reactor and the lower end of the draft tube, which is proportional to the free area for flow in the bottom and represents the resistance to flow in this part of the reactor). The main operating variables are primarily the gas input rate and, to a lesser extent, the top clearance (C_t, the distance between the upper part of the draft tube and the surface of the non-aerated liquid). These two independent variables set the conditions that determine the liquid velocity in the airlift bioreactor via the mutual influences of pressure drops and holdups, as shown in Figure 1 [9]. Viscosity is not shown in Figure 1 as an independent variable because in the case of gas–liquid mixtures, it is a function of the gas holdup (and of liquid velocity in the case of non-Newtonian liquids), and because in a real process, it will change with time due the changes in the composition of the liquid.

FLOW CONFIGURATION

Riser

In the riser, the gas and liquid flow upward, and the gas velocity is usually larger than that of the liquid. The only exception is homogeneous flow, in which case both phases flow at the same velocity. This can happen only with very small bubbles, in which case the free-rising velocity of the bubbles is negligible with respect to the liquid velocity. Although about a dozen different gas–liquid flow configurations have been developed [10], only two of them are of interest in airlift bioreactors [11, 12]:

- Homogeneous bubbly flow regime in which the bubbles are relatively small and uniform in diameter and turbulence is low.
- Churn-turbulent regime, in which a wide range of bubble sizes coexist within a very turbulent liquid.

The churn-turbulent regime can be produced from homogeneous bubbly flow by increasing the gas flow rate. Another way of obtaining a churn-turbulent flow zone is by starting from slug flow and increasing the liquid turbulence, by increasing either the flow rate or the diameter of the reactor, as can be seen in Figure 5 [12]. The slug-flow configuration is important only as a situation to be avoided at all costs, because large bubbles bridging the entire tower cross-section offer very poor capacity for mass transfer.

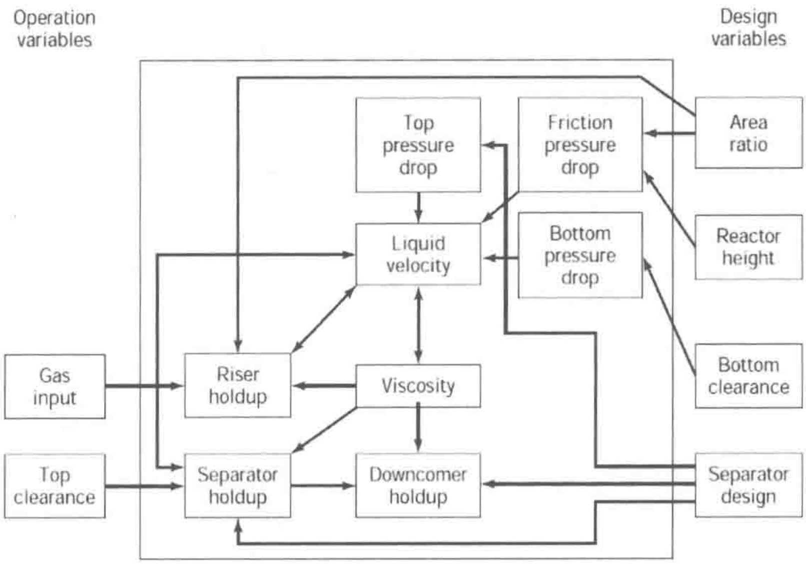

FIGURE 1. Interaction between geometric and fluid dynamic variables in an airlift bioreactor [9].

Downcomer

In the downcomer, the liquid flows downward and may carry bubbles down with it. For bubbles to be entrapped and flow downward, the liquid velocity must be greater than the free-rise velocity of the bubbles. At very low gas flow input, the liquid superficial velocity is low, practically all the bubbles disengage, and clear liquid circulates in the downcomer. As the gas input is increased, the liquid velocity becomes sufficiently high to entrap the smallest bubbles. Upon a further increase in liquid velocity larger bubbles are also entrapped. Under these conditions the presence of bubbles reduces the cross-section available for liquid flow, and the liquid velocity increases in this section.

Bubbles are thus entrapped and carried downward, until the number of bubbles in the cross-section decreases, the liquid velocity diminishes, and the drag forces are not sufficient to overcome the buoyancy. This feedback loop in the downcomer causes stratification of the bubbles, which is evident as a front of static bubbles, from which smaller bubbles occasionally escape downward and larger bubbles, produced by coalescence, escape upward. The bubble front descends, as the gas input to the system is increased, until the bubbles eventually reach the bottom and recirculate to the riser. When this point is reached, the bubble distribution in the downcomer becomes much more uniform. This is the most desirable flow configuration in the downcomer, unless a single pass of gas is required. The correct choice of cross-sectional area ratio of the riser to the downcomer will determine the type of flow.

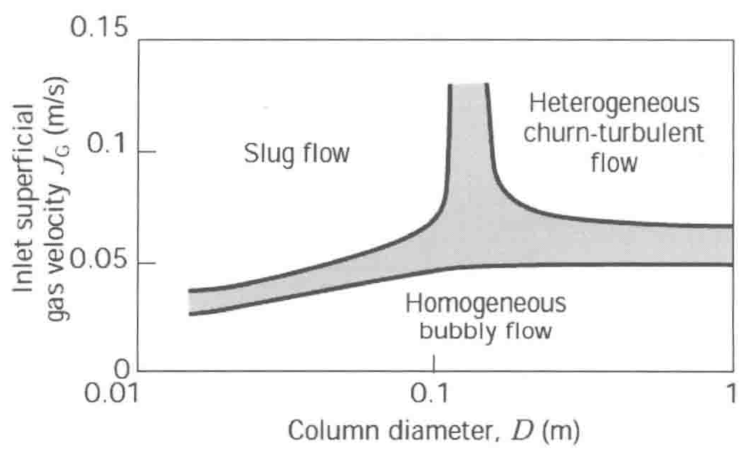

FIGURE 2. Map of flow configurations for gas–liquid concurrent flow in a vertical tube [12].

Gas Separator

The gas separator is often overlooked in descriptions of experimental airlift bioreactor devices, although it has considerable influence on