MIXING AND AERATION IN AN AIR-LIFT FERMENTER ADAPTED FOR FED BATCH OPERATION

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1 Introduction

Air-lift fermenters have been proposed for large and small scale cultures especially of shear sensitive microorganisms (e.g. filamentous bacteria and fungi) or shear sensitive support particles in which microorganisms are immobilized. The external or internal draught tube achieves a good control of the mixing at the reactor scale. The local intensity of mixing is rather uniformely distributed in the fermenter, avoiding the presence of dead zones as well as of regions of too high energy dissipation as it may occur in mechanically agitated vessels. A lot of hydrodynamic studies have been published and reviewed in the literature [1,2,4].

Despite these above mentioned advantages, the use of air-lift fermenters is limited to continuous or strictly discontinuous cultures. The fed batch operation mode is impossible because of the presence of the draught tube. The initial and minimum liquid level is indeed fixed by the height of the draught tube which is always greater than 70 % of the total reactor height. In this paper, we present an analysis of mixing conditions and aeration rate in an air-lift fermenter adapted to overcome this drawback : it is equiped with an internal perforated draught tube. The holes distributed along the tube allow the liquid recirculation at different levels, starting from approximately 1/3 of the fermenter height.

2 Experimental

2.1 Apparatus

The experiments reported in this paper were carried out with a stainless steel fermenter developed in our laboratory and currently used for the production of exocellular enzymes by *Streptomyces* strains [3]. This fermenter has a total working volume of 30 liters, with an internal diameter equal to 0.15 m and a total height of 2.2 m. Four standard lateral 25 mm ports are provided at the basis of the fermenter (0.35 m from the bottom), allowing the insertion of probes such as dissolved oxygen and pH probes as well as an optical fiber probe. The air sparger is a sintered stainless steel cylinder having a surface of 173 cm^2 allowing an air flowrate up to 3 vvm. The mixing conditions are characterized by the distribution of internal circulation times, determined by tracer experiments. The tracer is a dye : rhodamine WT. It has been shown to be very weakly adsorbed on the biomass. It is consequently a tracer well adapted to the study of mixing in bioreactors even though the work reported in this paper was carried out in the absence of microorganisms. The tracer concentration is continuously monitored with an optical fiber spectrophotometer.

The aeration rate is characterized by the oxygen transfer coefficient k_La. This parameter is determined by gassing-in dynamic step changes between air and nitrogen. The dissolved oxygen concentration is monitored by a fast response polarographic electrode.

Table 1: Ranges of parameters

Draught tube diam. (m.)	Area void fraction (%)	Liquid level (% of total height)	Gas flowrate (vvm)
0.09 - 0.125	0 - 30	50 - 100	0.5 - 1.5

2.2 Operating conditions

The objective of is work was to answer two questions about the use of a perforated draught tube in a air-lift fermenter :

- Is it possible to operate this type of fermenter at different height of liquid i.e. under a fed batch operating mode ?
- What is the influence of this design on mixing and aeration especially at its full height of liquid ?

To answer these questions, we have investigated the influence of design parameters such as the diameter and area void fraction of the draught tube as well as the influence of the gas flowrate and the liquid level. The ranges of parameters are given in table 1. The dissolved oxygen and optical fiber probes are inserted in the 25 mm lateral probes located at 0.35 m from the bottom of the fermenter. The tracer is injected by one of the ports i.e. at the same level. The signals coming from the oxymeter and the spectrophotometer were collected using a microcomputer-based data acquisition system, prior to transfer to a mainframe for data processing.

3 Data analysis

3.1 Phenomenological interpretation

A series of experiments based on a Box-Benkhen (three levels) design was carried out to determine the influence of the design parameters and the gas flowrate. These experiments indicate a definite influence of the area void fraction and the draught tube diameter as illustrated by figure 1. The main effect of the holes in the draught tube is to damp out the oscillations classically observed in an air-lift and, consequently, to reduce the mixing time.

Actually, the effect of the design parameters is a little bit more complex. When the fermenter is completely filled, the mixing time presents a minimum located around an area void fraction of about 20 % and a draught tube diameter of 0.11 m. i.e. 60 % of the fermenter diameter. For a classical air-lift, this mixing time is at least 2 times greater. If the fermenter is half filled, the difference is even greater. The mixing time in the classical air-lift is indeed almost infinite because of the absence of liquid circulation.

The influence of the design parameters on k_La is less important. k_La decreases progressively as the area void fraction increases from 0 to 30 %. The aeration is thus better (about 20 - 30 %) in a classical air-lift. However, for the half filled fermenter, k_La in the classical air-lift, drops to very small values due to the absence of mixing.

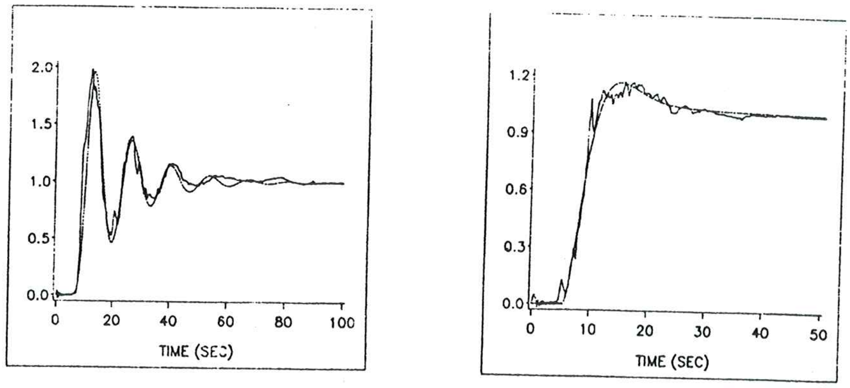

Figure 1: Tracer responses in air-lift fermenters with a area void fraction equal to 0 (left) and 30% (right) Comparison with the model predictions.

3.2 Model of internal fluid circulation

In order to understand the influence of the design parameters on both the intensity of mixing and the aeration rate, we developed a model of the distribution of the internal circulation times. This model results from an inspection of the liquid circulation currents visualized e.g. by following the movement of gas bubbles or by the injection of dye. In a classical air-lift (area void fraction equal to 0), the liquid flow pattern is directly determined by the length of the draught tube. The intensity of mixing in the downcomer and riser is very limited. Good mixing arises essentially in the gas-liquid separator at the top of the fermenter [2].

The presence of holes in the draught tube, causes a flow transfer between the riser and the downcomer. These flow currents create circulation loops as illustrated in figure 2. As the void fraction increases, the liquid flow pattern looks more and more like the flow pattern prevailing in bubble columns [2]. The model resulting of this phenomenological analysis is also illustrated in figure 2. Three parameters are involved : the flow circulation rate V_0 at the bottom of the fermenter, the fraction A of flowrate interchanged between the riser and the downcomer and the number N of perfectly mixed cells in series. A plug flow zone is assumed in the inferior part of the fermeneter (below the perforated zone) in order to account for the delay time observed with all the tracer experiments (see figure 1). The volume of this first cell is fixed by the geometry of the fermenter. The gas-liquid separator is represented by a perfectly mixed cell. Its volume is also fixed by the height of liquid above the draught tube. The quality of fitting is illustrated in figure 1.

The fraction A of lateral flow transfered through the draught tube, increases with the area void fraction and the tube diameter. For example, A equals approx. 0.5 for a tube diameter of 0.125 m. and an area void fraction of 30 % (at 1vvm). It obviously equals 0 for the classical air-lift. This increase of the lateral flow transfer amplifies the intensity of mixing in the riser ans the downcomer : N equals 12 for a classical air-lift (at 1 vvm) whereas it drops to 3 - 7 when the flow transfer takes place. Similarily, the liquid flowrate V_0 decreases from approx. 2 l/s to 1 l/s.

These results may be interpreted in terms of circulation times defined at the fermenter

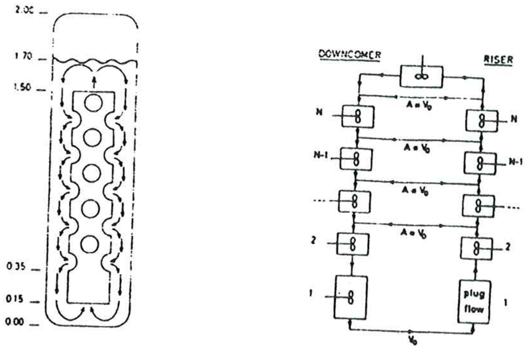

Figure 2: Correspondence between the model of fluid circulation and a visualization of the fluid flow pattern

scale ($t_{C,OVER} = V_R/(1-A)V_0$) and the scale of one circulation loop ($t_{C,LOC} = V_R/NAV_0$). According to these definitions, $t_{C,LOC}$ must decrease and $t_{C,OVER}$ increase as the lateral flow transfer takes place. These opposite effects explain the existence of an optimum for the quality of mixing and thus for the mixing time t_m.

The variations of k_La may also be interpreted in terms of circulation times. The criterion proposed by Siegel et al. [4] to determine whether a system can be considered as perfectly mixed ($t_c\ k_La$) is indeed satisfied (< 1) at the scale of one circulation loop but not at the overall scale (> 1). The mixing at the local scale has thus no effect on k_La. On the contrary, the mixing at the overall scale will reduce the apparent value of k_La calculated assuming a perfect mixing.

In conculsion, the model of liquid flow circulation presented in this paper, describes satisfactorily the behaviour of the modified air-lift and its ability to operate at different liquid levels. It explains also the existence of optimal values of the design parameters.

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