LIQUID VELOCITY CONTROL IN EXTERNAL - LOOP AIRLIFT BY MEANS OF MAGNETIZABLE PARTICLES

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ABSTRACT The communication describes the idea to apply a magnetically stabilized bed as liquid control element in an airlift with an external loop. The experiments reported demonstrate the effect of the particle bed parameters and the field intensity on the liquid flowrate. The suitable fluidization mode and field orientations are discussed.

INTRODUCTION

The airlift reactors with external loops have wide applications in the chemical and biochemical industries [1,2]. In these devices the liquid velocity depends both on the gas velocity and the hydraulic resistance of the downcomer (Fig. 1-left). The latter affects the regimes and the stability of fluidization [3]. The idea of the present study is that the liquid velocity may be controlled by means of a particle bed in the bottom of the riser. The approach requires a controllable particle arrangement and mobility. The solution was found by employing a magnetizable particle bed and a magnetic field. Figure 1-right explains the idea.

Fig. 1  Airlift with an external loop.
Left - liquid circulation control by means of a mechanical valve [4].
Right - replacement of the mechanical valve by a magnetizable particle bed
The magnetic field and the fluidizing flow (gas, liquid or gas-liquid mixture) act on the particles independently. Two operation modes are possible [5]. The idea to control the liquid circulation rate in an airlift by a magnetizable particle bed requires the “Magnetization FIRST” mode [5]. This mode is classical [6-8] and presumes the appliance of the magnetic field on a fixed bed and a fluidization after that (see Fig.2). It has been investigated at large with two-phase fluidization, but has not been applied to three-phase airlifts.

![Fig. 2 The figure illustrates the application of a transverse magnetic field, \( H \). FB - fixed bed; MSB- magnetically stabilized bed; Comments on the terminology are available in [5].](image)

EXPERIMENTAL

The airlift (Fig.1) consisted of a riser 140 mm I.D. and 2 in height. The downcomer had a 50 mm internal diameter. The gas (air) was introduced into the riser through a supporting bed of lead particles (1.0 - 1.4 mm). Thus the supporting bed plays two roles: it supports the magnetizable bed and produces a gas-liquid flow. The liquid (water) rate in the downcomer was measured by a calibrated fine screen (0.2 mm aperture and 0.1 mm wire diameter) and differential liquid manometer. Saddle coils similar to those in [8,9] were used for generating a steady transverse field (see Fig.1). The coils have a height of 1500 mm and I.D. of 205 mm. The maximum field intensity created was about 50 kA/m.

Iron oxide (metallurgical dross) was used as magnetizable solids. The properties are summarized in Table 1. All the experiments were carried out at ambient temperature (16-20 °C).

Table 1. Properties of the magnetizable particles

<table>
<thead>
<tr>
<th>Density ( \text{kg/m}^3 )</th>
<th>Size ( \text{mm} )</th>
<th>Shape</th>
<th>( \text{Ms} ) ( \text{kA/m} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2100</td>
<td>0.8-1.0</td>
<td>near spherical</td>
<td>277</td>
</tr>
<tr>
<td>height, ( h_{bo} )</td>
<td>100 mm</td>
<td>expansion</td>
<td>100 - 140 mm</td>
</tr>
</tbody>
</table>

![Fig. 3 Experimental set-up](image)
RESULTS

With the increasing gas flow the particle bed passes consequently through three principle states illustrated in Fig. 2: initial static bed, stabilized bed and a three-phase fluidized bed (TPFB). The point of view of the of the present study was commented above. Thus the efforts will be concentrated on the magnetically stabilized regime. It is bounded by the velocities $U_e$ (gas or liquid) and the minimum fluidization point - $U_{mf}$ (gas or liquid) [9]. However, in an airlift the liquid velocity depends on the gas flow rate in the riser. In this case it is not possible to determine the critical velocities like in the case of three-phase MSB [9] with independent gas and liquid flows.

Liquid circulation velocity

- Hydraulic resistance in airlifts

Liquid velocity is the essential quantity of the airlift hydrodynamics [1,2]. It is determined by the volumetric flow rate of the circulating liquid. The driving force of the liquid circulation is the unbalance of hydrostatic pressure between downcomer and riser. This hydrostatic pressure is due to the difference gas hold-up, i.e. in overall density of the fluid in two zones. The resistance to the circulating of the circulating flow of liquid is determined by the friction losses in the loop, which depends on the liquid velocity.

With complete degassing the gas hold-up in the downcomer is zero. In accordance with Onken and Trager [10] the hydrostatic pressure between downcomer and riser, $\Delta P_H$ is

$$\Delta P_H = \rho_L \cdot c_g \cdot g \cdot (H_o - H_r) \quad (1)$$

The hydrostatic pressure difference as the driving force is equal to the sum of the dynamic pressure drops in the loop

$$\Delta P_H = \sum \Delta P_i = \Delta P_T + \Delta P_{B+F} \quad (2)$$

where $\Delta P_T$ is the pressure drop in the tubes (riser and downcomer) and $\Delta P_{B+F}$ is due to particle bed and fittings. Figure 4 shows the hydraulic and the equivalent electric circuits.

Fig. 4 Schematic presentation of the hydraulic remittances in the airlift loop

The individual pressure drops can be presented with the aid of friction factors $f_i$ in the form
\[ \Delta P = \frac{f_l}{2} \rho_l U_{Lr}^2 \]  

Combination of Eqs. (1) - (3) yields [10]

\[ U_L = \sqrt{\frac{2 \varepsilon g (Ho - H_r)}{\sum f_i}} \]  

Taking into account that the common relationship between the gas velocity and the gas holdup is in the form [11]

\[ \varepsilon_G = C U_G^n \]  

The relationship (4) may be expressed as

\[ U_L = U_G^{\frac{n}{2}} \sqrt{2Cg(Ho - H_r)} \]  

\[ \Omega = \sqrt{\frac{2Cg(Ho - H_r)}{\sum f_i}} \]  

where

\[ \Omega = \sqrt{2Cg(Ho - H_r)} \]  

The shorter form of Eq. (6a) has been used by Onken and Weiland [1] with \( n = 0.4 \) and Kawagoe and Robinson [12] \( n = 0.48 \) for external loop airlifts. In both cases : \( \Omega = 1 \) .

On the other hand for airlift's with \( H_r/D_r > 1 \) the ratio \( A_d/Ar \) is an important hydraulic factor.

Using this ratio Bello et al. [13] proposed the relationship

\[ U_{Lr=1.55} \left( \frac{Ad}{Ar} \right)^{0.74} U_G^{0.5} \]  

Equations (6) and (7) are valid for \( Ad/Ar = 0.10 - 0.44 \) [2].

- **Relationship for external loop airlift with a magnetically stabilized bed**

The airlift investigated here has \( Ad/Ar = 0.108 \) and \( Ho = 2.0 \) m. Thus the conditions are close to those under which the Eqs. (6)- (7) are valid. Taking into account the simultaneous effect of the ratio \( Ad/Ar \) and the magnetic field intensity effect the following relationship was developed in the present study

\[ U_L = \Omega_M \left( \frac{Ad}{Ar} \right)^{0.74} U_G^{0.4} \]  

where \( \Omega_M \) represents the hydraulic effect of the magnetizable bed. The power-law form was chosen to express \( \Omega_M \)

\[ \Omega_M = \omega_c \left( \frac{H}{Ms} \right)^K \]  

where \( H/Ms \) is the dimensionless field intensity [14]
• Liquid velocity - experimental data

Results of the superficial liquid velocity, obtained at various field intensities and gas velocities are shown in Fig. 5. The liquid velocity increases with increasing gas velocity and field intensity. The former effect is consistent with the well-known results available in the literature. The second is specific and is strongly related to the phase holdups in the magnetizable bed (Fig. 6). Figures 7 and 8 present the variations of $U_L$ and $\Omega_M$ according to Eqs. (8) - (9).

The non-linear regression analysis gave that $K = 1.59$ and $\omega_o = 0.935 \pm 0.95$. From practicable point of view $\omega_o$ may be accepted $\omega_o = 1$. The data treated to obtain coefficients

![Fig. 5](image1.png) Liquid velocity as function of the superficial gas velocity. Effect of the field intensity.

![Fig. 6](image2.png) Schematic presentation of the hydraulic resistances of MSB.

![Fig. 7](image3.png) Variations of $U_L$ with the gas velocity - according to Eq.(10). Effect of the field intensity The arrows show the values of $\Omega_M$.

in Eqs. (8) - (9) cover the bed expansion in the range $(1.0 - 1.4) \times h_{bo}$, i.e. under the circumstances of the present study - $100 \div 140$ mm. This range covers the regimes of the initial static bed and the stabilized state. The maximum error of the approximation is about 8%.
SHORT CONCLUSIONS

The study investigated the hydrodynamics and liquid circulation in an external-loop airlift assembled with a magnetically stabilized bed at the riser bottom. The height of the magnetizable bed does not exceed 5% of the riser length. Thus in the upper section of the airlift riser may be assumed as two-phase (gas-liquid). The non-conventional approach do permit to achieve several effects on the airlift hydrodynamics:

- The magnetic field, i.e. the controllable bed structure, allow a control of the liquid velocity at a fixed gas superficial velocity in the riser. This an opportunity to change the gas holdup in the riser rather that by the gas velocity only like in conventional airlifts.
- There is no need of mechanical valves in downcomer, which increases the hydraulic resistance of this part of the loop.
- The magnetically stabilized bed may be employed with a height that is comparable with the riser height. In this way the airlift becomes to a three-phase upflow reactor with a controllable movement of the solid phase. The latter will affects the bubble coalescence and particle liquid mass transfer.

![Graph](https://via.placeholder.com/150)

\[ \Omega_M \text{ v/s } \left( \frac{H}{Ms} \right) \]

**Fig. 8**

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ad ( Ar)</td>
<td>Cross-sectional area of the downcomer (riser), m²</td>
</tr>
<tr>
<td>C</td>
<td>Constant in Eq.(5)</td>
</tr>
<tr>
<td>h</td>
<td>Bed height, m; hbo - initial bed height, m</td>
</tr>
<tr>
<td>H</td>
<td>Magnetic field intensity, A/m</td>
</tr>
<tr>
<td>Hr</td>
<td>Height above sparger, m</td>
</tr>
<tr>
<td>Ms</td>
<td>Magnetization at saturation, A/m</td>
</tr>
<tr>
<td>UGr (ULr)</td>
<td>Gas (liquid) superficial velocity (in the riser), m/s</td>
</tr>
<tr>
<td>UL-e</td>
<td>Liquid velocity at the onset of L-S MSB, m/s</td>
</tr>
<tr>
<td>P</td>
<td>Pressure, Pa</td>
</tr>
</tbody>
</table>

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