PRESSURE DISTRIBUTION IN THE AIR-SPARGED HYDROCYCLONE①

Chu, Liangyin Luo, Qian
Mineral Engineering Department,
Northeastern University, Shenyang 110006

ABSTRACT

Theoretical analysis and experimental study on the pressure distribution in the air-sparged hydrocyclone were made for the first time in this paper. The relationship between the pressure distribution and the driving force in separation process in the air-sparged hydrocyclone was investigated, from which the motion of the bubbles including mineralized bubbles was described.
Key words: air-sparged hydrocyclone pressure distribution froth flotation centrifuge process

1 INTRODUCTION

As a kind of new efficient mineral processing equipment, air-sparged hydrocyclone (ASH) is getting more and more attentions[1]. ASH connects hydrocyclone flow phenomena with froth flotation ingeniously, and at the same time results in some important aspects of the flow characteristics in it. Pressure distribution is one of the aspects. It affects not only the discharge of froth products[2, 3] but also the movement process of bubbles including mineralized bubbles, in other words, pressure distribution is directly related with the driving force and directly influences the separation efficiency. In addition, pressure distribution also characterizes the pressure loss in ASH , the power of slurry pump and the energy consumption. Therefore , ascertaining the pressure distribution in ASH is beneficial to understand the separation behavior and improving the separation efficiency. Unfortunately, there isn't any systematic idea about the pressure distribution in ASH up to now.

In this paper, theoretical analysis and experimental study on the pressure distribution in ASH were made, and the relationship between the pressure distribution and the driving force in separation process was presented, in order to ascertain the separation behavior in ASH thoroughly.

2 THEORETICAL ANALYSIS

The fluid flow characteristics in ASH are definitely different from that in conventional hydrocyclone. In ASH, there exist swirl layer region, froth core region and liquid column region[4]. So the pressure distribution in ASH would be different from that in the conventional hydrocyclone.

In the rotating liquid area in ASH, there is a radial pressure difference which is due to the radial transference of centrifugal force. Taking a tiny volume from the rotating liquid, as shown in Fig. 1, with vertical section area dA, thickness dr and density ρ, the centrifugal force that tiny volume bears would be formulated as:

$$dF = \rho dA dr \frac{u_t^2}{T} \quad (1)$$

where u_t stands for the tangential velocity, and r for radius

The pressure at r is p_r, and the pressure at $r + dr$ is $p_r + dp_r$, the net pressure acting radially on the tiny volume is:

$$dP_r = dp_r dA \quad (2)$$

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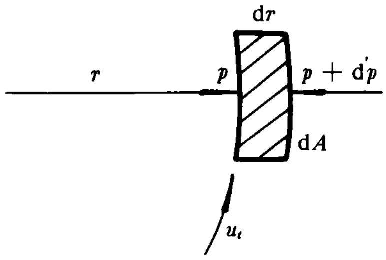

Fig. 1 Scheme of a tiny volume taken from rotating liquid

Based on the equilibrium law, dF should be equal to dp_r, hence:

$$\frac{dp_r}{dr} = \rho \frac{u_t^2}{r} = \rho\omega^2 r \tag{3}$$

where ω is the angular velocity of rotating liquid

The above equation indicates that the radial pressure gradient of the rotating liquid depends on the centrifugal acceleration. The radial distribution of pressure in ASH would conform to the above equation. But the froth phase in the froth core is not rigorously continuous medium, the pressure distribution in froth core should be considered specially.

The space in ASH is not full of liquid as seen in a conventional hydrocyclone. Froth phase occupies the upper central space in ASH, and communicates with atmosphere. Therefore, the axial distribution of pressure in ASH may be described as

$$\frac{dp_z}{dz} = \rho g \tag{4}$$

where z is the axial distance from the top on, and g is gravity acceleration.

3 EXPERIMENTAL STUDY

3.1 *Experimental*

3.1.1 Geometry of ASH and Distribution of Measured Points in ASH

The geometry of the ASH used in the experiment and the distribution of measured points for pressure in ASH are shown in Fig. 2. The ASH was made of transparent perspex with several pieces of porous polyethylene wall. Through these pieces of porous polyethylene wall, compressed gas could be sparged into ASH. In the experiment the total air flowrate was 0.12 m^3/h. The measured points for surveying pressure distributed in such a way that the radial interval of each point is 5 mm, and the axial interval is 50 mm.

3.1.2 Experimental Scheme

Because the pressure distribution has little relationship with the solid concentration in feed, so no solid particles were added in the feed in this experiment. The feed was water, and the frother was turpentine with concentration of 40 mg/L. Pressure was measured with a U-tube gauge. To make the flow pattern in the experimental ASH similar to that in a well operated ASH, i. e. to make froth phase occupy the most space in ASH and make the froth products continuously discharge from the vortex finder, the experimental parameters were optimized. In the first group the underflow pipe diameter was selected 18 mm and the feed flowrate 400 mL/s. In the second group the underflow pipe diameter was selected 12.5 mm and the feed flowrate 280 mL/s.

3.2 *Results and Discussion*

3.2.1 Radial Distribution of Pressure in ASH

The measured radial distribution of pressure in ASH is shown in Fig. 3. As mentioned in Ref. [4], the swirl layer occupies the upper circumferential space, the froth core is in the upper central space, and the liquid column locates at the lower section in ASH. From Fig. 3, it can be seen that, in the section from Z = 250 mm to Z = 100 mm which is occupied by swirl layer and froth core, the radial distribution of pressure is somewhat complicated. The pressure drops slowly to a minimum and then increases rapidly with the radius increased, and the pressure at the circumference is higher than that in the centre. This saddle-like radial distribution of pressure is due to the existance of froth phase. Near the inlet in swirl layer the tangential velocity of liquid is relatively high due to the inlet kinetic energy, so the pressure is also relatively high there. Based on the pressure equation on the phase interface, the pressure on the interface between swirl layer and froth core should be relatively high. And the pressure in the upper froth core gradually approaches to atmospheric pressure. Therefore, the pressure in the centre is lower than that at the circumference in the upper section in ASH. Bubbles including mineralized ones in the liquid column move upwards into froth core from the central area of liquid column because of the centripetal buoyancy[5], so that the froth is crowded in the centre of froth core , resulting in a relatively high pressure there. This indicates that the main force driving bubbles upwards in the froth core exists in the centre, in other words, bubbles including mineralized bubbles in froth core are transferred upwards mainly in the centre. This is why there is no froth in the annular space between the swirl layer and the vortex finder wall.

Fig. 3 also shows that, in the section from Z = 300 mm to Z = 550 mm which is mainly occupied by liquid column, the pressure increases radially from the centre to ASH wall and the increasement law satisfies Eq. (3) with different values of ω. The pressure in ASH is always higher than atmospheric pressure, so there is no air core existing in

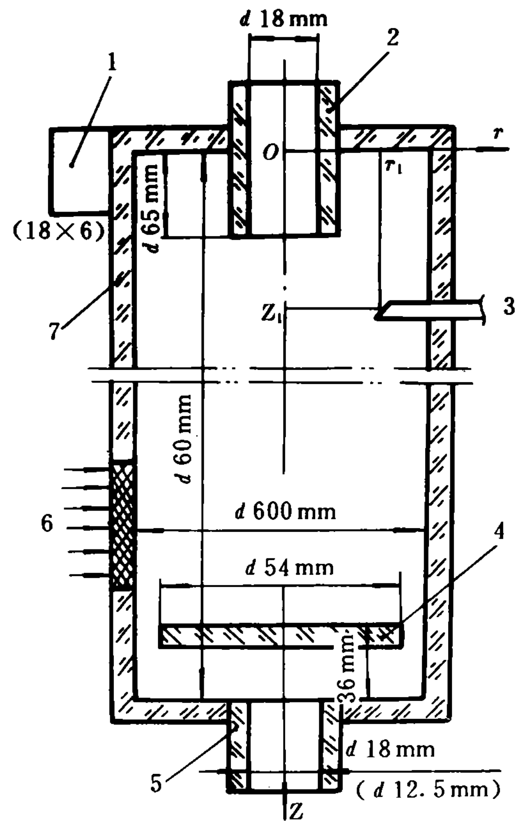

Fig. 2 Geometry of ASH and distribution of measured points

1—inlet; 2—vortex finder wall; 3—probe of pressure gauge; 4—pedestal baffle; 5—underflow pipe wall; 6—sparging compressed gas through porous wall into ASH; 7—ASH wall

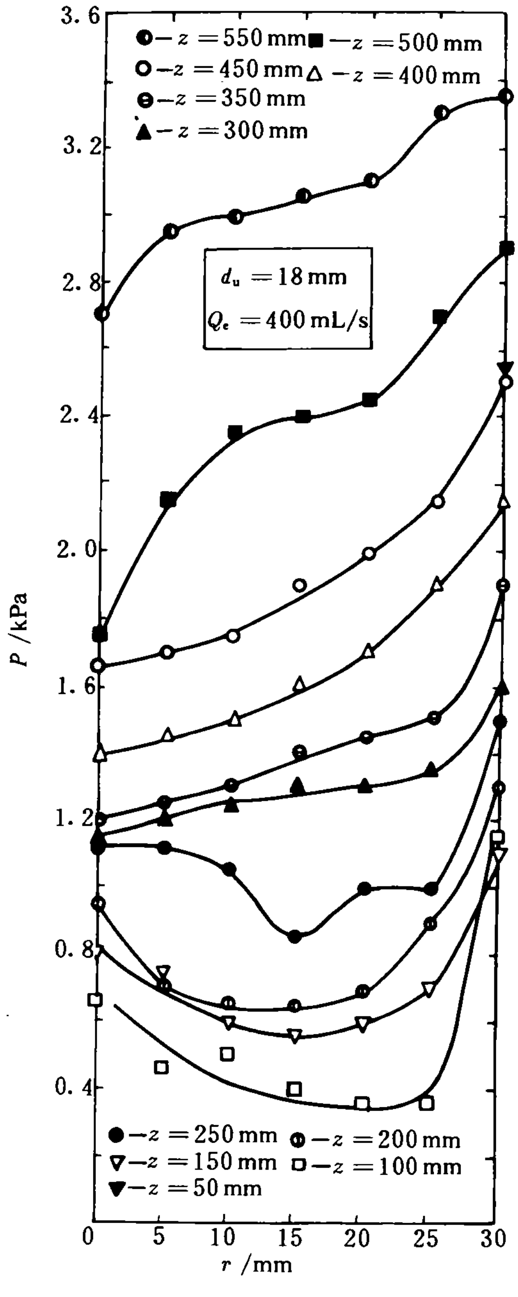

Fig. 3 Radial distribution of pressure in ASH

the centre of ASH. The bubbles in ASH are all formed on the porous wall.

3. 2. 2 Axial Distribution of Pressure in ASH

The measured axial distribution of pressure in ASH is shown in Fig. 4. From Fig. 4, we can see pressure increases axially from Z = 100 mm to Z = 550 mm and the increasement law conforms to Eq. (4). This indicates that the axial pressure gradient results mainly from the gravity. While in swirl layer the pressure drops rapidly from Z = 50 mm to Z = 100 mm. The point of Z = 50 mm is located above the end of vortex finder and does not contact with froth phase, whereas the point of Z = 100 mm is below the end of vortex finder and contacts with froth phase, and because the pressure in the froth core at the end of vortex finder approaches to atmospheric pressure, the pressure in swirl layer below the end of vortex finder would be lowered to approach the pressure in adjacent froth phase space. Fig. 4 also shows that the pressure at the circumferential point of r = 30 mm is higher than that at any other points with the same axial position. This phenomenon is due to the flow characteristics in ASH. It has been verified that the circumferential flow layer with thickness of 2～3 mm belongs to outer helical flow while the inner liquid flow belongs to inner helical flow[4]. Because the energy for liquid flow comes from the outer helical flow, the pressure in outer helical flow would be higher than that in inner helical flow.

3. 2. 3 Effects of Geometry and Operation Parameters on Pressure Distribution

Fig. 5 shows the pressure distribution at r = 0 mm and r = 30 mm with different geometry and operation parameters. It is clear that the pressure distributions in ASH in different cases are similar to each other. When feed flowrate is 280 mL/s and underflow pipe diameter is 12. 5 mm, the axial pressure gradient is larger than that in the case of Q_e = 400 mL/s and d_u = 18 mm. This indicates that smaller feed flowrate and smaller underflow pipe diameter result in larger axial pressure loss. The lower the feed flowrate, the smaller the tangential velocity liquid flow, and the more notable the gravity, so the larger the axial pressure gradient. Larger pressure gradient will result in faster movement and shorter residence time for bubbles.

4 PRESSURE DISTRIBUTION AND DRIVING FORCE IN SEPARATION PROCESS

The separation process in ASH includes the collision and adherence of bubbles with solid particles, the entrance of bubbles including mineralized bub-

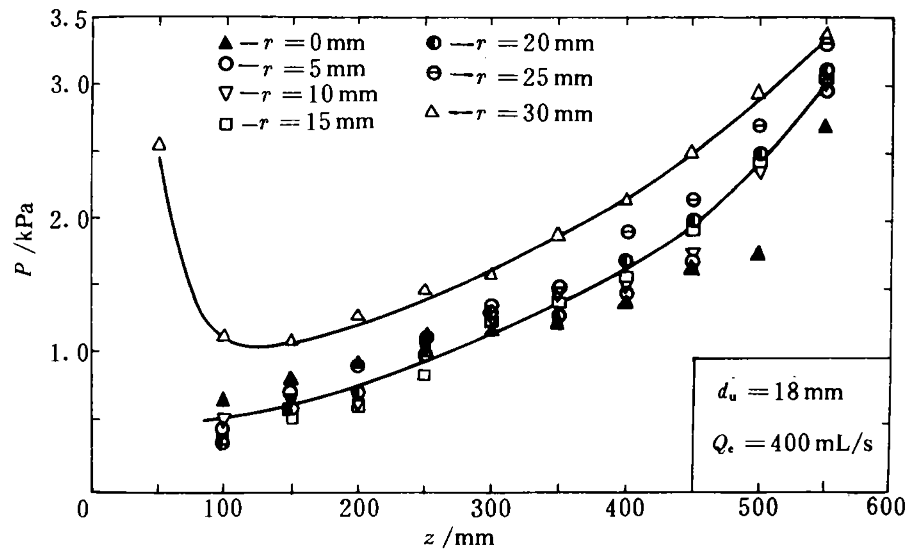

Fig. 4 Axial distribution of pressure in ASH

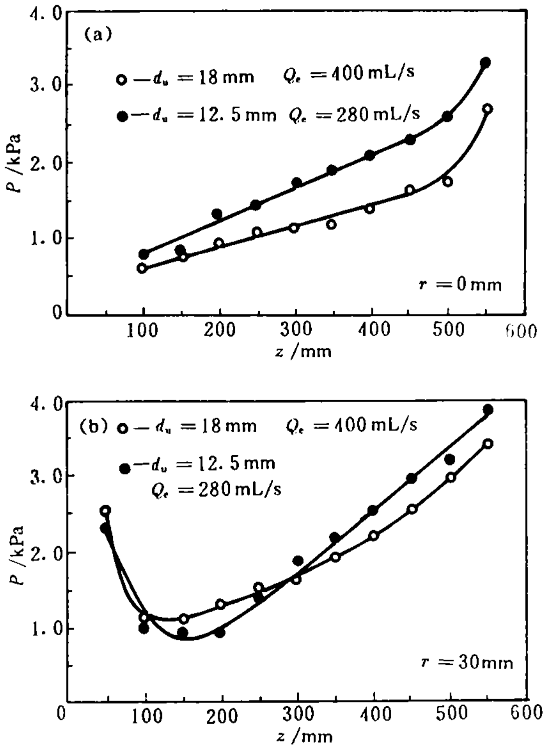

Fig. 5 Effects of geometry and operation parameters on pressure distribution in ASH.

bles into froth core and the discharge of froth products, in which the collision and adherence processes exist mainly in the swirl layer. Because the swirl layer is too thin to radially get two or more measured points for pressure values, it is hard to discuss the relationship between the collision and adherence processes and the pressure distribution in swirl layer. In this paper, authors mainly discuss the relationship between the pressure distribution and the driving force in the latter two processes.

The bubbles generated on the inner surface of ASH porous wall will be finally discharged through the vortex finder as froth products. In the whole process the bubbles need a driving force to move from their generated points to the outside of vortex finder. It has been proved that[2, 3], the driving force for the discharge of froth products is attributed to the pressure difference between the bottom of froth core and atmosphere. The larger the pressure difference, the stronger the driving force for discharging froth products.

When bubbles are generated on the surface of porous wall in ASH, at first they will move with the fluid due to the drag force of liquid. Because in rotating liquid there exists a radial pressure gradient always increasing with the radius, the bubbles rotating with liquid should bear a centripetal buoyancy[5] (in fact, buoyancy will exist in such cases where there is a pressure difference between two opposite surfaces of any objects). The centripetal buoyancy F_r is in direct proportion to the radial pressure gradient in fluid, i. e.

$$F_r \propto \frac{\mathrm{d}p_r}{\mathrm{d}r} \tag{5}$$

This centripetal buoyancy is the main driving force for bubbles including mineralized bubbles to move radially from the circumference to the central froth core. Therefore, a large radial pressure gradient in fluid, leads to a large driving force for the centripetal movement of bubbles. From Fig. 3, the radial pressure gradient between $r = 30$ mm and $r = 25$ mm drops with increasing axial coordinate z. This indicates that bubbles in the circumferential flow layer bear larger centripetal buoyancy in the upper section of ASH than that in the lower section. In other words, the bubbles in swirl layer bear larger radial driving force than in the circumferential flow layer of liquid column.

Some bubbles, which move down with fluid to the circumferential layer near the pedestal baffle because of the drag force of liquid, will move inwards to the centre with the liquid transportation from outer helical flow into inner helical flow relying on both the centripetal force and radial drag force of liquid flow.

As mentioned in Ref. [4], in the liquid column there exist outer helical flow which moves downwards and inner helical flow which moves upwards. The bubbles in the lower section of the inner helical flow will move upwards depending on both the upward buoyancy which is due to the axial pressure gradient and the axial drag force of inner helical flow. In liquid column there exist radial pressure gradients as shown in Fig. 3, so the bubbles move upwards into froth core mainly from the centre of liquid column.

To sum up, there are two main routes for the bubbles including mineralized bubbles to enter the froth core, the first one is radially moving inwards

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brium composition of spinodal line. With the temture increasing, the two minima close and combine into one at last, which is just corresponding to the critical point T_c and x_c. When the contribution of elastic energy is added into the total Gibbs energy as shown by the dotted line in Fig. 2, the curve becomes a concave curve with only one minimum. The calculated results show that while using epitaxial method to produce Ⅲ-Ⅴ compound, the miscibility gap would be restrained by lattice elastic energy induced by the mismatch of epitaxial layer and substrate crystal.

4 CONCLUSION

The phase diagram of pseudobinary GaAs-InAs was studied using the thermodynamic and phase equilibrium information available. The calculated results show that , when using epitaxial method to produce Ⅲ-Ⅴ compound, the lattice elastic strain energy of epitaxial layer induced by the mismatch of epitaxial layer and substrate lattice has great restraint effect on the formation of miscibility gap.

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(*From page 24*) into froth core from swirl layer, and the second one is axially moving upwards into froth core from the centre of liquid column. In both routes, the bubbles always bear buoyancy which is due to the pressure gradient in liquid as a driving force.

5 CONCLUSSIONS

(1) The pressure in liquid column increases radially from the centre to the circumference with a fixed axial position. In the upper section of ASH, where the froth core and swirl layer occupy, the pressure drops radially to a minimum and then increases. The pressure in outer helical flow is larger than that in inner helical flow.

(2) The pressure in the fluid below the end of vortex finder, including froth core, swirl layer and liquid column, increases axially with increasing axial coordinate z.

(3) The driving force for bubbles including mineralized bubbles to enter froth core is mainly contributed by the centripetal buoyancy and the upward buoyancy which are both due to the pressure gradients in fluid. Pressure distribution heavily affects the magnitude of the driving force. There are two routes for bubbles including mineralized bubbles to enter froth core, the first one is radially moving inwards into froth core from swirl layer, and the second one is axially moving upwards into froth core from the centre of liquid column.

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