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An Intermittent Flow Structure in Airlift Pump by Using an Annular Venturi Injector

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ABSTRACT

An annular venturi injector (AVI) was proposed to form an intermittent flow structure in airlift pump for a good pump performance. Experiments were conducted to investigate the performance of the airlift pump with this AVI by comparing with pump performance with traditional injectors, at a series of air flow rates . It was found that airlift pump with AVI had higher flow rates of output liquid and particle, than those with the traditional injectors. This AVI promoted the gas core to collapse and formed an intermittent flow structure in rising pipe. For this intermittent structure, its slug length, firstly increased to a maximal value with increasing gas flow rate and then remained stable even under a high gas flow rate, while its slug frequency decreased with gas flow rate and then remained to a minimal value under a high gas flow rate.

Keywords: Airlift pump; Venturi injector; Flow structure; Three-phase flow.

NOMENCLATURE

f	slug frequency	U_S	slug velocity
f_c	frame frequency	z_1	location of the first measure point
L_s	slug length	z_2	location of the second measure point
N	slug number		
Nof_{1-2}	frame number	Δt	time interval

1. INTRODUCTION

Airlift pumps lifts the liquid or slurry by the buoyancy force of high-speed gas flow. It is a simple device, consisted of a rising pipe, a suction pipe and an air injector. Comparing with other mechanical pumps, airlift pump has no mechanical moving parts and has no need for lubrication or strict seal. This pump is especially suitable for some harshest environment, such as lifting corrosive, toxic liquid, or waste-water treatment (Wang *et al.* 2020, Obaidi *et al*. 2019, Momen *et al.* 2016).

Airlift pumps have been widely used for many years. But a big problem is still exited that its pump efficiency is very low. Many researchers investigated the flow structure of airlift pump and found that the pump performance greatly depends on flow regime in airlift pump. It was found that there are four typical flow regimes (Hanafizadeh *et al*. 2010, Kassab *et al*. 2007): bubbly flow, slug flow, churn flow, annular flow, appeared in rising pipe with the increasing of gas flow rate. Bubbly flow was found to have no pump capacity, because its drag force is so small under an extremely low gas flow rate. Slug flow, is an intermittent flow, characterized by a Taylor bubble and a liquid slug. It has a high pump efficiency because only little liquid film falls down along the pipe. Churn flow is also an intermittent flow and it is characterized by big gas blocks with some distorted shapes around which liquid film does some complex oscillation motions. This flow regime could also produce a high output liquid flow rate. Annular flow is a continuous film flow, which is not beneficial to pump liquid or particles, and most of its gas in gas core directly runs out without pumping liquid because it never contacts with the liquid or

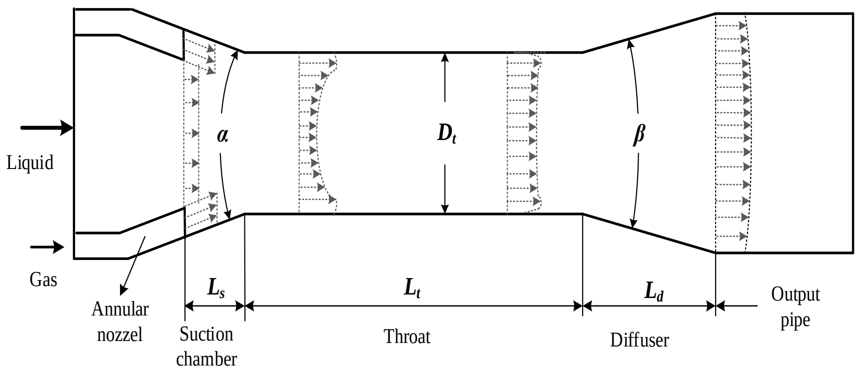


Fig. 1. AVI structure.

particles. Although there are some debates about weathering the best flow regime for airlift pump is slug flow or churn flow, it is confirmed that the suitable flow regime for pumping is intermittent flow because gas showed a sufficient contact areas with liquid-particle phase in this flow structure (Hanafizadeh *et al*. 2011, Kassab *et al*. 2009).

Many researchers tried to keep pump working in intermittent flow regime for a better performance by optimizing the geometry structure. In terms of rising pipe, Hanafizadeh *et al*. (2010, 2011) found that the step geometry on airlift pump could break film structure in airlift pump. Mahrous *et al*. (2013) found that gradually enlargement structure in the riser tube could minimize the transition to annular flow regime, and significantly improves the discharge rate. Fan *et al*. (2013) and Qiang *et al*. (2018) found that a large pipe diameter is benefit to improve pump performance, because annular flow is hard to be formed in a pipe with large diameter. In terms of air injector, Parker *et al*. (1980), Khalil *et al*. (1999), Hu *et al*. (2012) found that the air injector affects the initial bubble shape. Parker *et al*. (1980) compared the pump performance using two different air injection foot-piece designs: an air-jacket design where air is injected in radial direction and a nozzle design where air is injected in axial direction. He found that the nozzle design shows a greater pumping capability at high air flow rate. Khalil *et al*. (1999) studied the effect of the number of orifices in a desk-type injector on the performance of an airlift pump at different submergence ratios. In his study, the disk with three holes was found to show the highest efficiency. Hu *et al*. (2012) investigated the effect of air exit ports on the pump performance in transporting river sands. He found that the pumping efficiency is very low when the number of air exit ports exceeds 3.

Although the above researchers proposed a lot of optimized geometry structures for airlift pump, the pump performance is still not good, because existing method can hardly prevent the formation of annular flow, especially under a high gas flow rate. To solve this problem, Ahmed *et al*. (2012, 2016) proposed a pulsating air injection mode by employing a pneumatic reversing system before the air injector. His result showed that the performance of airlift pump with a pulsating axial injection operating in a frequency of 1 Hz has improved by 60% over that of typical steady axial injection, and that the pump efficiency with a dual injector is greatly improved by synchronizing the injected air at both axial and radial injection ports. This pulsating method is a useful way to keep intermittent flow in airlift pump and can also achieve a good performance. But additional pneumatic reversing system is not convenient and not economic in practical engineering.

It is meaningful for proposing a convenient and economical way for keeping an intermittent flow in airlift pump. As we know, the intermittent flow could be formed by increasing turbulent mixing, and the fluctuating pressure. Venturi tube is a common mixer and has been widely used in fluid engineering. It is reported to have strong capacity for transferring energy from the high-speed jet to low-velocity stream (Xiao *et al*. 2016, Asfora *et al*. 2019, Shimizu,1987). It is a good idea to use this venturi tube as the air injector because it greatly improves the momentum exchange among gas-liquid-solid phases and may be helpful for forming an intermittent flow in airlift pump.

Herein, an annular venturi injector (AVI) with a suction chamber, a throat, a diffuser was designed and was used in airlift pump. The corresponding performance was also investigated under various working conditions with different air flow rates and submergence ratios.

2. THEORY AND STRUCTURE OF AVI

The AVI, used in this study mainly, is composed of an annular aperture, a suction chamber, a throat pipe and a diffuser, as shown in Fig. 1. Gas is injected into the suction chamber from the annular aperture, resulting in a pressure drop and promoting the entering flow of outside liquid-particle mixture. This liquid-particle flow was further sucked into the throat with an increasing velocity under the friction effect of gas interface. In this process, momentum is transported from gas flow to liquid-particle flow

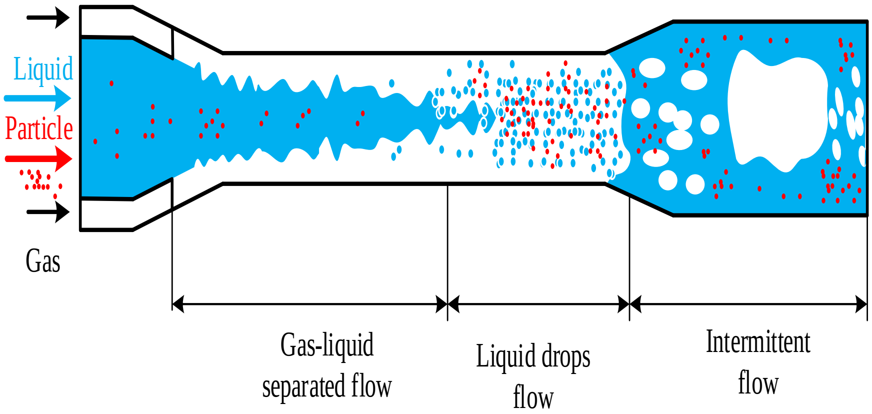


Fig. 2. Gas-liquid distribution in AVI.

until their velocity reached to the same one in the rear of the throat. With the effect of the diffuser, the static pressure increased and promoted the movement of mixture flow.

In an AVI, liquid-particle as a secondary flow was continuously entrained by the gas flow. The flow structure in AVI could be divided into three states: gas-liquid separated flow, liquid drops flow, and intermittent flow, as shown in Fig.2. In gas-liquid separated flow, gas, injected from the annular aperture, drives the liquid-particle from the suction chamber into the throat by the shear stress in the gas-liquid boundary. With the development of this separated flow, its gas-liquid interface becomes more and more fluctuated in the flow direction. Once this interface wavy amplitude exceeded the radius of liquid core, continuous liquid flow would be sheared into discrete liquid drops scattering in gas flow, as shown in the throat rear in Fig. 2. This greatly improves the momentum transfer from gas flow to liquid and particle phases and further enhances the instability of continuous gas flow. As the mixture entered into the diffuser, pressure suddenly increased with the enlarged structure of diffuser, and it would crush the continuous gas flow from the throat and form an intermittent flow structure in the downstream of output pipe.

Compared with the ordinary air injectors, AVI has a lot of advantages. Firstly, its annular aperture increased the shear areas between gas and liquid flow. Secondly, its throat is benefit for scattering the liquid phase into drops and enhanced the instability of continuous gas flow. At last, its diffuser increases the local pressure and collapse this continuous gas flow. All in all, this AVI is good for forming an intermittent flow and for increasing the contacted area among gas liquid particle phases, which would finally improve the performance of airlift pumps.

The specific structure of AVI used in this study was shown in Fig.3(a). To compared with the performance of this injector, an axial injector and a radial injector were also employed, as shown in Fig.3(b)(c).

3. Experimental Setup and Measurement

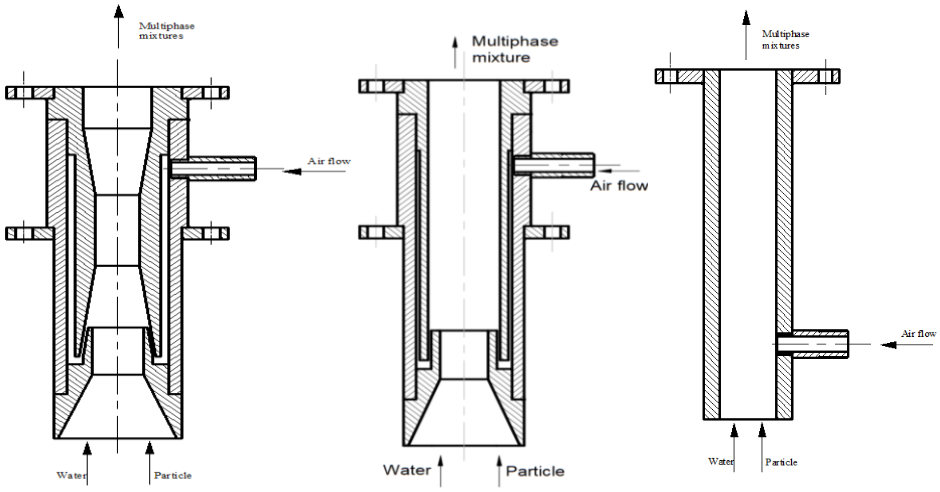
3.1 Experiment Setup

Figure 4 shown the experimental apparatus and it was mainly composed of long pipe which could be divided into two parts: suction pipe and rising pipe. An air injector was used to connect these two pipes and supplied continuous gas flow from the air compressor. In this device, lifting pipe was about 2500 mm in length with an inner diameter of 40 mm and it was made of transparent Plexiglas for better visually studying the gas-liquid-solid flow structure. On the upper end of rising pipe, an air separator was also mounted for exhausting the gas into atmosphere and draining the rest liquid-solid flow into the strainer and water collecting tank. The strainer was a wire mesh which could separate the solid from the liquid-solid flow. The supply tank could be moved up and down by a lift mechanism to change the submergence ratio defined as $\gamma = H_1/H$ (in Fig.4).

Experiments were performed using river sand with a density of 2.65 kg/m^3 and a diameter range of 0-3 mm. The compressed air was continuously fed to the bottom of rising pipe through an air filter, a regulator valve, and the air injector. The used sand was fed to the bottom of suction pipe through a particle feeder, and an inclined pipe to form a gas-liquid-solid flow in rising pipe. To avoid the decrease of the submergence ratio caused by the loss of output water, a centrifugal pump with a control system was employed to keep the height of water in the supply tank.

3.2 Measurement Strategy of Intermittent flow

In this experiment, the submergence ratio varied from 0.4 to 0.7, and the air discharge varied from 0 to 70 m^3/h. A gas turbine flow meter (type: LUGB25) with an accuracy of ±1% was mounted near the air injector to get the inlet air flow rate.The water flow rate and the particle flow rate were



(a) AVI (b) Axial injector (c) Radial injector

Fig. 3. Air injectors of airlift pump.

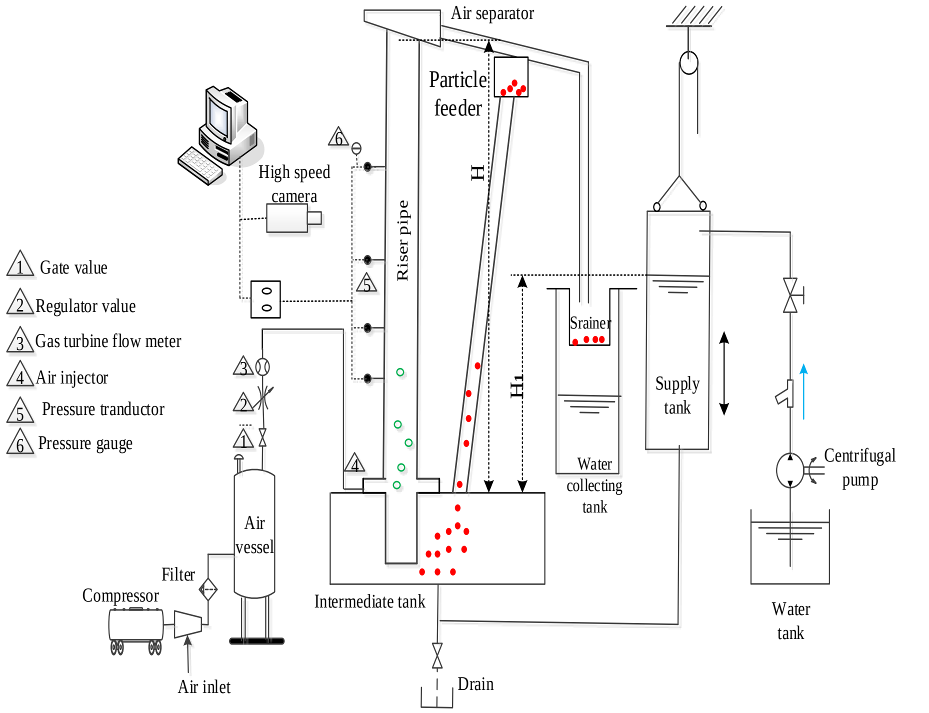


Fig. 4. The schematic of airlift pump.

measured 5 times from the water collecting tank and the strainer respectively by artificial weighing method. And the mean flow rates could be averaged from the 5 sample values.

To measure flow parameters of intermittent flow in airlift pump, two high speed cameras were mounted at the measurement points (z_1 and z_2) about 54 D, 60 D away from the air injector, as shown in Fig.5, to capturing the gas-liquid-solid flow in airlift pump with a frame frequency 1000 Hz. Referring to the measurement method of slug flow proposed by Cely *et al*. (2018), Hout *et al*. (2002), the interface between the wake of Taylor bubble and its adjacent liquid slug was obvious in captured in images as shown in Fig. 6. Cely *et al*. (2018), Van Hout *et al*. (2002) chose this interface to analyze the hydrodynamics of intermittent flow. The frame numbers of this interface arriving these two measurement points could be recorded from the high speed camera, and its time interval could be calculated by the difference of these two frame numbers and the frame frequency, as follows:

$$\Delta t_{1-2} = \frac{Nof_{1-2}}{f_c} \tag{1}$$

Where, Δt_{1-2} and Nof_{1-2} were the time interval, the number of frames for the slug travelling between the two measurement points, respectively, f_c the frame frequency.

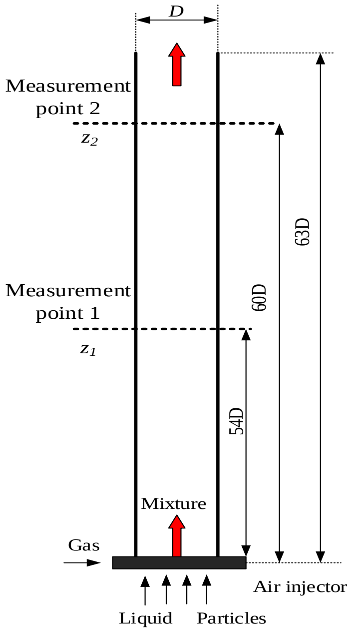


Fig. 5. Measurement points in rising pipe.

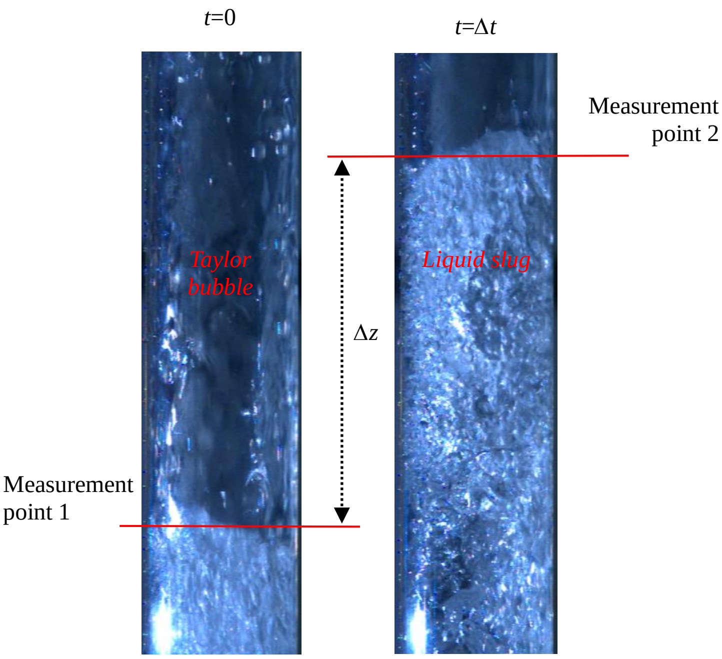


Fig. 6. Measurement of flow parameters by two cameras.

The slug velocity could be estimated from the distance between two measurement points, as follows:

$$U_s = \frac{z_2 - z_1}{\Delta t} \tag{2}$$

Where, z_1 and z_2 were the two measure points, U_S the slug velocity.

For slug, its crossing time through measurement point 1 could also be calculated from camera 1,

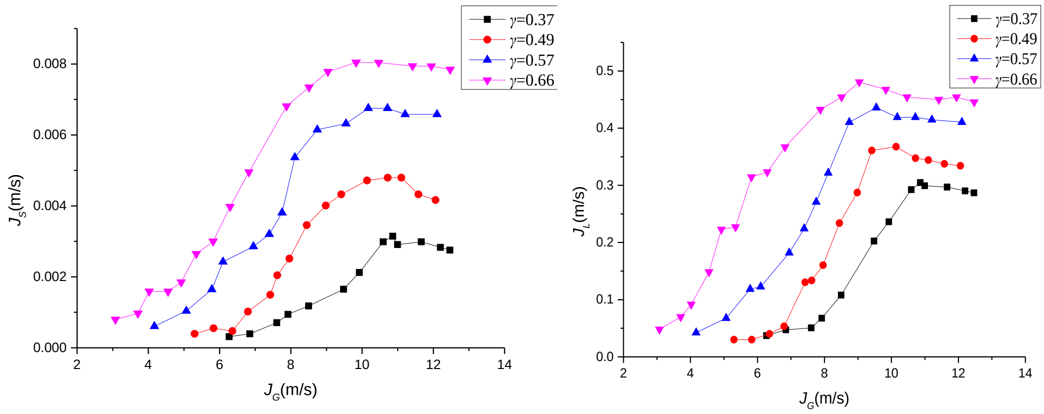
$$\Delta t_1 = \frac{Nof_1}{f_c} \tag{3}$$

Where, Δt_1 and Nof_1 were the time interval, the number of frames for the slug nose and tail passing through the first measurement point.

Thus, the slug length could be estimated from the time interval for the slug nose and tail passing through the first measurement point and its slug velocity.

Table 1 Dimensions of the AVI

Parameters	Output pipe diameter	Throat diameter	Throat length	Suction chamber angle	Diffuser angle	annular aperture
Dimension	40 mm	26 mm	60 mm	14º	14º	2 mm



(a)Superficial particle velocity (b)Superficial liquid velocity

Fig. 7. Phase velocities versus superficial gas velocity at different submergence ratios using AVI.

$$L_s = U_s \Delta t_1 \quad (4)$$

Where, L_s was slug length.

The slug frequency, defined as the number of slugs passed across the two measurement points and its consuming time, could be calculated as follows:

$$f = \frac{1}{N}\sum_{n=1}^{N}\frac{1}{\Delta t_{1-2}} \quad (5)$$

Where, f was slug frequency, N slug number.

4. Results And Discussion

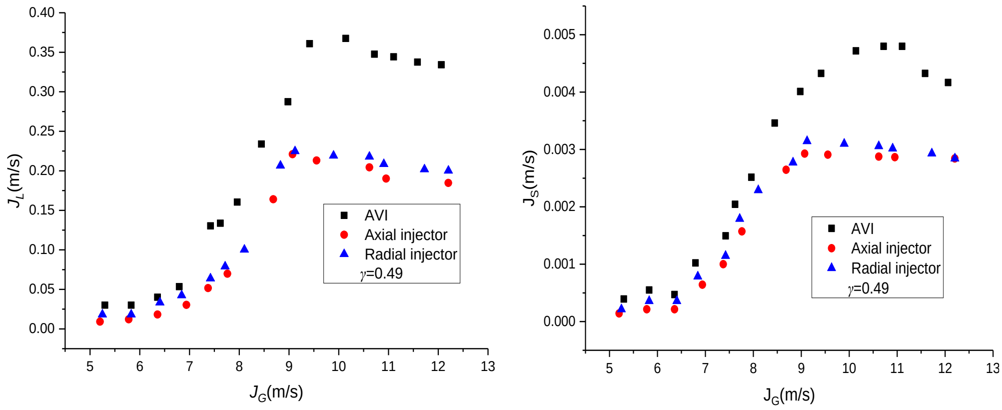
4.1 Performance of Airlift Pump using AVI

The effect of AVI on pump performance at different submergence ratios of 0.37, 0.49, 0.57 was investigated, as shown in Fig. 7. The main parameters of this AVI were following: throat diameter 26 mm, throat length 60 mm, suction chamber range 14^0, diffuser angle 14^0, annular aperture 2 mm, as shown in Table 1. It was found that the superficial particle and liquid velocity continuously increased until to their maximum ones, beyond which the particle and liquid velocity slowly decreased, when increasing the superficial gas velocity. For submergence ratio γ=0.49, liquid and particle velocities quickly increased with the gas velocity in a range of 4 m/s <J_G<13 m/s. This could be explained that the inlet liquid velocity became quickly caused by the pressure drop when increasing gas velocity from the annular aperture. For J_G>13 m/s at γ=0.49, liquid and particle velocities slowly decreased with the gas velocity, because the void fraction increased in AVI which would generate a series of long bullet-shaped bubbles as said by Duan *et al.* (2018). Ahmed *et al.* (2016) further explained that the long bullet-shaped had no benefit for pump performance because only a thin liquid film around this bubble rose along the pipe wall.

It also could be found a high submergence ratio was also good for pump performance with this AVI. Ahmed *et al.* (2016), Wang *et al.* (2020), Hanafizadeh *et al.* (2010) claimed that a large submergence ratio directly increased the mixture pressure in its mixture chamber and shortened the lifted height of liquid away from its liquid surface. For a high pressure in AVI, gas-liquid interface becomes more fluctuated and was easily broken up and form a homogeneous flow which greatly improved the momentum transfer from gas flow to liquid and particle phases.

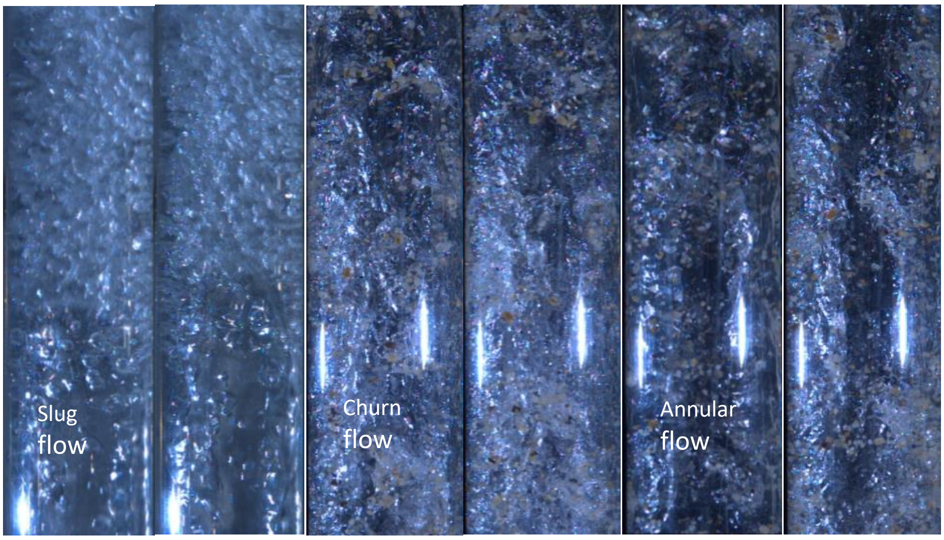
4.2 Comparisons of Pump Performance With Different Injectors

In order to compare the pump performance with this AVI and those with the traditional air injectors. We conducted the pump experiments using the above three air injectors (in Fig.3) under the same experimental conditions. The used axial air injector had an annular aperture of 2 mm, which was equal to that of AVI. As demonstrated by Amhed *et al.* (2012), Moses *et al.* (2018), Deendarlianto *et al.* (2019), the size of radial hole had little effect on its pump performance. Thus, we just used a radial injector with a large hole of 10 mm in this experiment.



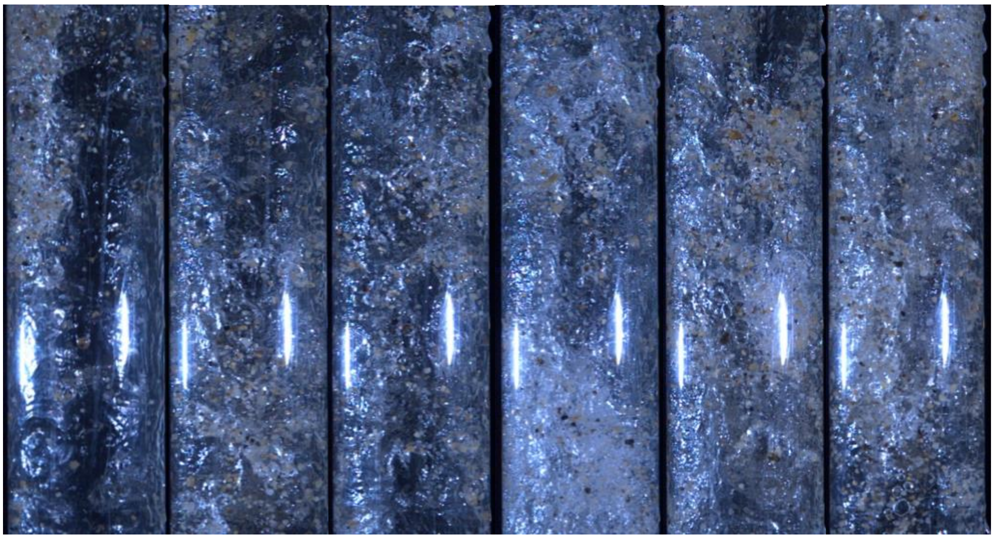
Particle velocity versus gas velocity (γ=0.49)   (b)Liquid velocity versus gas velocity (γ=0.49)

Fig. 8. Comparisons of pump performance using annular, axial, radial injectors at different submergence ratios.



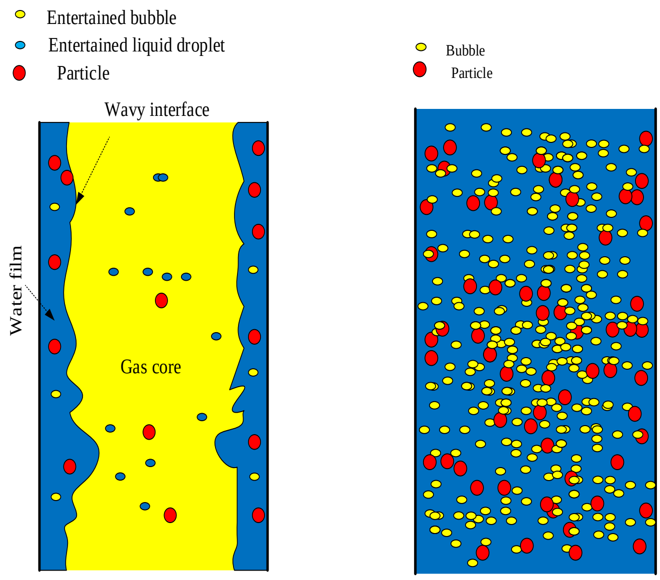
(a) J_G=5m/s (b)J_G=6m/s (c)J_G=7m/s (d)J_G=8m/s (e)J_G=9m/s (f)J_G=10m/s

Fig. 9. Gas-liquid-solid flow in airlift pump using radial injector (or axial injector) at γ=0.49.



(a)t=0 (b)=0.3s (c)=0.75s (d)=0.85s (e)=0.9s (f)=1.1s

Fig. 10. Gas-liquid-solid flow in airlift pump with AVI at JG=11m/s, γ=0.49.



(a)Film flow. (b)Bubble-liquid-particle mixture flow
Fig. 11. Flow states of gas-liquid-solid flow in airlift pump.

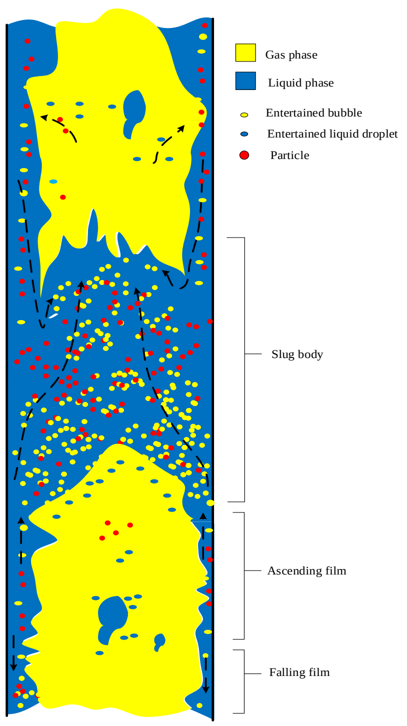


Fig. 12. Flow structure of gas-liquid-solid flow in airlift pump using AVI.

Figure 8 presented experiment result of pumped liquid and particle superficial velocities with different air injectors under submergence ratio 0.49. It was clear that both the liquid and particle superficial velocities of the AVI were larger than those of other twos. When the supplied gas superficial velocity was below to 9 m/s, the pump performance with AVI was slightly better than those with the other two injectors. When gas superficial velocity was above 9 m/s, the pump performance with AVI was obviously better than those of other twos. For the annular, the axial and the radial injector, their maximal liquid superficial velocities were 0.37 m/s, 0.22 m/s, 0.22 m/s, and their maximal particle superficial velocities were 0.0048 m/s, 0.0029 m/s, 0.0031 m/s. In other words, the maximal liquid velocity using the AVI was about 1.68 times of those using traditional injectors, while, its maximal particle velocity was about 1.54 times of those using traditional injectors.

The main factor accounted for this result, the flow structure in airlift pump. According to our experiment in axial and radial injectors, it was found that slug flow, churn flow, and annular flow appeared in airlift pump when increasing gas flow rate, as shown in Fig. 9, and this was also consisted with the results of Kassab *et al*. (2007), Shallouf *et al*. (2019), Cho *et al*. (2009). Moreover, our experiment and those of Kassab *et al*. (2007), Amhed *et al*. (2012) proved that there was little difference in flow regimes in airlift pump with an axial injector or a radial one. When the supplied gas superficial velocity was below to 9 m/s, it was an intermittent flow (slug flow, or churn flow) dominated the pump performances with the three different injectors because bubbles were still not large enough to generate a continuous gas core. But for the AVI, the liquid slug was longer than that of the other twos, because this AVI broken down the continuous gas flow and created some large gas-liquid, and gas-particle interface areas. Moreover, these interface areas in airlift pump with the AVI greatly increased with the increasing gas flow rate. That was why pump with that AVI had a better performance than those with traditional injectors. When gas superficial velocity was above 9 m/s, an annular flow regime dominated the pump performance with the traditional air injector, as said by Yoshinaga *et al*. (1996), Tighzert *et al*. (2013). However, the flow rates of pumped liquid and particle with AVI still increased when gas superficial velocity exceeded 9 m/s, which implied that the flow regime still not transformed into annular flow.

Figure 10 showed the flow structure in the airlift pump with the AVI at a location above 2520 mm away from the air injector at J_G=10 m/s, γ=0.49. It was clear that the flow regime in airlift pump was still intermittent flow rather than the annular flow in airlift pump with the traditional air injectors, even under a high gas flow rate.

During t=0-0.75 s, the film flow structure appeared in the airlift pump. It could be described as a sketch map in Fig. 11 (a) that gas core and liquid film showed a stratified flow in airlift pump, while particles scattered in gas core and liquid film. During t=0.85-1.1 s, many discrete bubbles appeared in Figs.9 (d)-(f). This phenomenon could be described as a sketch map in Fig. 11 (b) that gas liquid particle showed in a homogeneous flow in airlift pumps. The main reason for this intermittent phenomenon was that the AVI, which broken down the continuous gas flow from the air injector.

According to the flow images captured by high speed camera, we obtained a whole flow structure of airlift pump with this AVI under all kinds of gas flow rates, as shown in Fig. 12. For the gas phase, it mainly appeared in a form of discrete dense bubble and gas block. For the liquid phase, it was mainly consisted of liquid slug and liquid film.

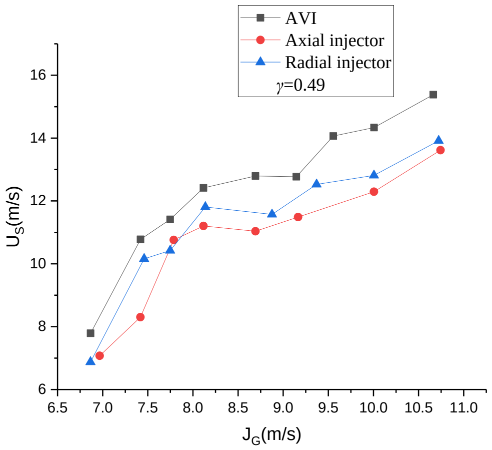


Fig. 13. Slug velocity versus superficial gas velocity using different injectors at γ =0.49.

Figure 13 showed the slug velocity at different superficial gas velocities using the above three air injectors. It was found that the slug velocity quickly increased at a midden gas velocity (J_G<8.5 m/s) and then it slowly increased if gas velocity continuously increased. The slope of slug velocity versus gas velocity suddenly decreased in J_G=8.5 m/s. This was caused by the flow regime transition from slug flow to churn flow, as said by Kassab *et al*. (2007), Hanafizadeh *et al*. (2010), Richardson *et al*. (1962), Moreover, the AVI seemed to produce a larger slug velocity especially when superficial gas velocity was larger than 8.5 m/s. The reason for this phenomenon was that the AVI promoted the momentum exchanges among these three phases, and produced higher liquid and particle velocities.

Figure 14 showed the slug length versus superficial gas velocity at submergence ratio 0.49 by using three injectors. It was obvious that the slug length firstly increased and then decreased with the increasing gas velocity for the axial and radial injectors. But, for AVI, its slug length increased with gas velocity until to a maximal value and then remain it even if gas velocity continuously increased. Usually, for a large gas flow rate in a vertical pipe, slug flow transformed into churn flow because discrete bubble in slug body coalesced into the adjacent Taylor bubble. Its slug length gradually decreased until zeroing and finally formed an annular flow, as said by Kassab *et al*. (2007). For AVI, its flow reached a developed flow at a high gas flow rate, because its slug length almost kept constant even at a large gas velocity. This indicated that the flux of bubble coalescence and bubble breakup in AVI was almost kept in the balance. Compared with the traditional injectors, there were mainly two reasons for a balance in AVI. First, liquid increased its velocity due to a pressure drop in suction chamber and an entrainment of liquid drop and particle into gas phase. Second, the static pressure increased in the diffuser. These two effects accelerated the breakup velocity of gas phase, which finally equaled to the coalescence velocity under a large gas flow rate. As it could be seen in Fig. 12 that the length of slug body would determine the pump performance because its high liquid and particle fractions in this segment than those in film segment. Thus, it could be deduced that the fully developed flow in AVI was benefit for keeping a high output flow rate of liquid-particle flow.

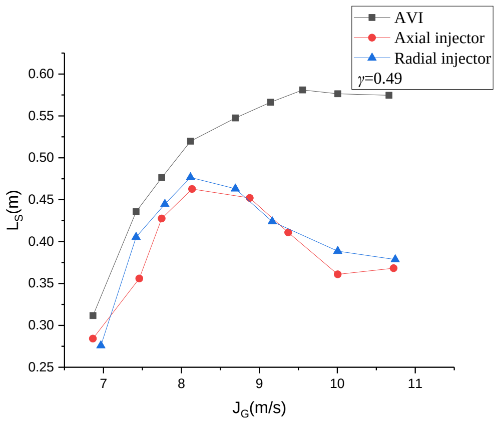


Fig. 14. Slug length versus superficial gas velocity using different injectors at γ=0.49.

Figure 15 showed the slug frequency versus gas velocity using three different injectors. It was found that the slug frequency continuously decreased in airlift pump using traditional injector. This also indicated that the intermittent flow trended to translate into a continuous flow with the increasing of gas flow rate. Compared with these two injectors, the slug frequency by using AVI was slightly larger than those of traditional injectors in a superficial gas velocity below to 10 m/s, but it was obviously larger than those with the traditional injectors when superficial gas flow rate was larger than 10 m/s. For a large gas flow rate, gas phase was easy to form a continuous gas core in traditional injectors. But in this AVI, a mass of liquid drops and particles were entrained into gas phase in the throat, which promoted the collapse of gas core under a sudden-increased pressure in the diffuser of AVI. This also indicated that the AVI was very useful to form an intermittent flow in high gas flow rates.

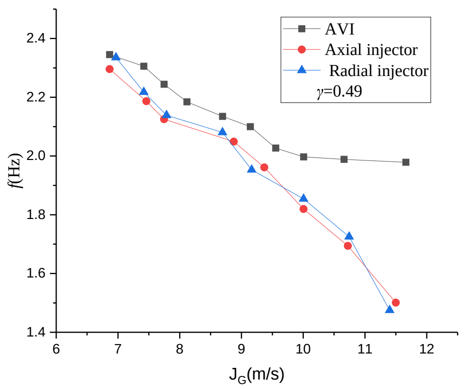


Fig. 15. Slug frequency versus superficial gas velocity using different injectors at γ=0.49.

4.3 Effects of AVI Geometry on Pump Performance

The geometry parameters of AVI may affect the pump performance. The effects of the throat length of AVI on the pump performance were shown in Fig.16. It could be found that a longer throat distance was benefit for pump performance. As we know, the momentum exchange between gas and liquid was done in this place. Thus, a longer throat should produce a more sufficient momentum exchange. However, the throat length was not suit to be too long, as said by Long *et al*. (2016) who did some experiments in water-water annular jet pump (water as working fluid) and found that a long throat produced a large pressure drop throughout the throat. But in our experiment, it could be found that the maximal throat length 75 mm showed the best pump performance because the gas, liquid, solid phases were still not fully mixed in such a long throat.

Figure 17 described the pump performance at a series of suction chamber angle, 5°, 14°, 20°, 30°. It could be found that a larger suction chamber angle was slightly benefited for pump performance. In fact, a large suction chamber angle could enhance the shear area between gas and liquid phase, which finally improved the momentum exchange among these three phases.

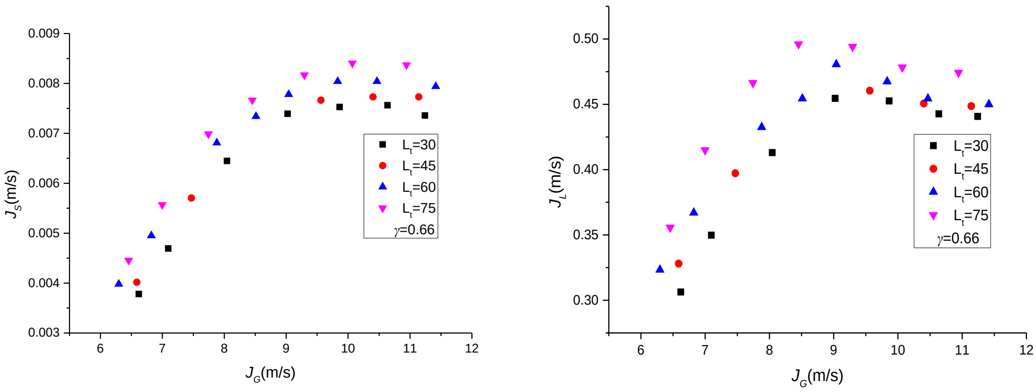
The diffuser angle also affected the pump performance as shown in Fig.18. A large diffuser angle also resulted in high superficial velocities of particles and liquid. As we know, diffuser was useful for rectifying the mixture velocity and enhancing the output pressure of mixture. It also found that the increased output pressure was more benefit for pumping particle and liquid in some extent. In fact, Hanafizadeh *et al*. (2010) also investigated the effect of this gradually enlargement structure in rising pipe and found that this diffuser could prevent the formation of annular flow in airlift pumps. Thus, it could be deduced that the annular flow was harder to be formed when using a bigger diffuser angle.

5. Conclusions

An annular venturi injector (AVI) with a structure of a suction chamber, a throat, and a diffuser was firstly designed for forming an intermittent flow in airlift pump.The pump performance of this AVI was compared with those of traditional injectors. The main conclusions were obtained as follows:

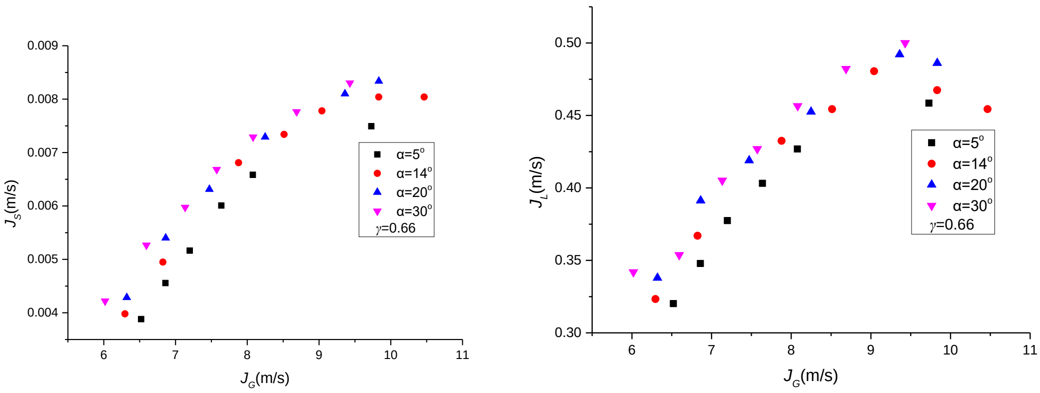
(1) The AVI had a higher flow rates of output liquid and particles, comparing with the traditional injectors. This AVI improved the momentum transfer from gas phase to liquid and particle phases in the throat, promoted the gas core to collapse and finally formed an intermittent flow structure in rising pipe.

(2) An intermittent flow structure of gas liquid solid three-phase flow in airlift pump using AVI was mapped. This intermittent flow consisted of liquid film flow and a gas-liquid-particle slug flow.



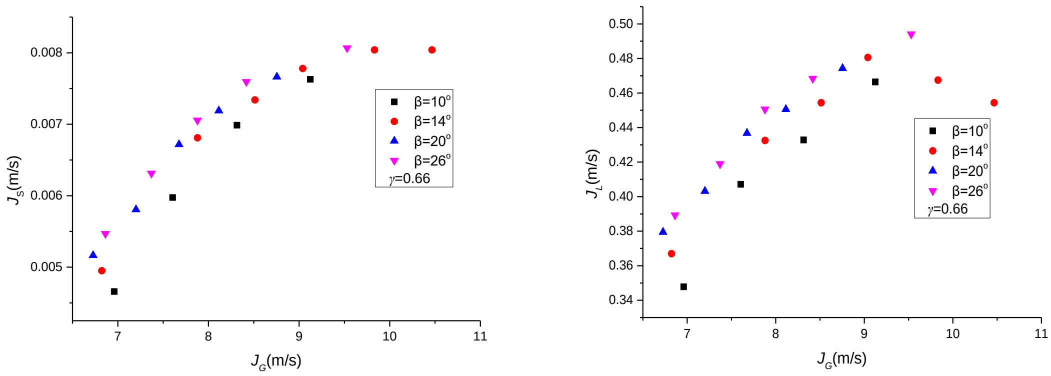
(a)Superficial particle velocity (b) Superficial liquid velocity

Fig. 16. Pump performance of AVI with different throat lengths (γ =0.66).



(a)Superficial particle velocity (b) Superficial liquid velocity

Fig. 17. Pump performance of AVI with different suction chamber angles (γ =0.66).



(a)Superficial particle velocity (b) Superficial liquid velocity

Fig. 18. Pump performance of AVI with different diffuser angles (γ =0.66).

(3) The hydrodynamics of this intermittent flow in airlift pump were investigated. Its slug velocity increased with the gas flow rate. Its slug length increased with gas flow rate to a maximal value and then remain it even under a high gas flow rate. Its slug frequency decreased with gas flow rate and then remain to a minimal value under a high gas flow rate.

(4) A long throat could be chosen for better pump performance because of the sufficient momentum exchange of gas-liquid-solid flow in a long throat. The suction chamber angle affected the shear area between gas and liquid phase. And a large suction chamber angle of 30^0 could slightly improve the pump performance.

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