Performance Study of an Airlift Pump with Bent Riser Tube

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Abstract: - Airlift pump is a type of deep well pumps. Sometimes, it is used for removing water from mines or pumping slurry of sand and water or other solutions. This work presents a numerical investigation into necessary ways to reduce momentum loss associated with local bends of the riser tube section of the airlift pump and consequently an improvement in pump performance would be attained. The investigated local tube bend are in the form of an S-shaped like duct. A numerical model of airlift pump, with bent riser tube, based on the concept of momentum balance was developed and validated against available experimental data. Parametric predictive studies on model airlift pumps with different riser tube configurations, including position, orientation, and graduation of the S-bend straight tube section, were carried out. The numerical results showed that gradually enlarging the riser tube S-bend straight section would significantly improve the airlift pump discharge rate. This is attributed to reduced acceleration loss followed the expansion of air phase in the enlarged S-bend section of the riser tube. Increasing the degree of tube expansion of the gradually enlarged S-bend straight tube section, the predicted results illustrated an improvement in the pump discharge rate that is limited by the value of tube expansion ratio. On the other hand, the numerical results showed that setting local S-bend of the riser tube at different positions from the air injector has a negligible effect on the pump performance.

Key-Words: - Airlift pumps, two-phase flow, pumping devices, bent riser tube, S-bend

1 Introduction

Airlift pumps are means of artificially lifting liquids or liquid-solid mixtures (slurries) from deep wells or vessels. Use of airlift pump has been promoted for a number of reasons such as: lower initial cost and maintenance, easy installation, small space requirements, simplistic design and construction, ease of flow rate regulation, and ability to handle corrosive, highly toxic and radioactive fluids. In the airlift system, air (or gas) is injected through an injection system at (or near) the base of a vertical pipe (the riser tube) that is partially submerged in a liquid or slurry. Bubbles, therefore, form and expand as they rise in the riser tube. A two- (or three-) phase column containing air phase has a lower density than a column of liquid alone and therefore the mixture formed in the airlift tube rises and is expelled at the top of the pump.

Numerous publications were published related to theoretical and experimental analysis of the airlift pump performance. Parker [1] made a comprehensive experimental study to determine the effects of foot piece design on the lifting characteristics of the airlift pump used for hydraulic transport of liquids. The effects of air injection method on the airlift pump performance were experimentally investigated by Mansour and Khalil [2] and by Khalil et al. [3]. It was concluded that, initial bubble size and distribution in the riser tube could have great effects on the pump performance. Khalil and Mansour [4] carried out an experimental investigation on the airlift pump performance by studying the effect of introducing a surfactant to the pumped liquid. Results showed that an improvement in the pump capacity and pump efficiency can be obtained when using a surfactant with low concentration. They studied the influence of riser tube diameter and injector design on the efficiency characteristics of the airlift pump. Mahrous [5] numerically investigated the performance of airlift pump lifting solids under various geometrical and operational conditions. The predictive studies showed that the solid particles volumetric concentration in the suction section of the airlift

The development of air phase in the riser tube at different degrees of S-bend β ratio is shown in Fig.7 in terms of variations in the gas holdup at j_{Ga}(based on diameter D_U)=5 m/sec. For a constant value of the expansion ratio, the gas holdup is gradually increasing as the air rises in the riser tube. Results in Fig.7 demonstrate that gradually enlarging the S-bend straight section of the riser tube decreases the volumetric fraction of the gas phase along the riser tube and therefore reduces the acceleration loss. Incremental reduction in the air volumetric fraction due to bend tube expansion is high at lower degrees of tube expansion ratio. As explained earlier, increasing the degree of S-bend tube expansion ratio could cause flow separation due to adverse pressure gradient in the diffusing section.

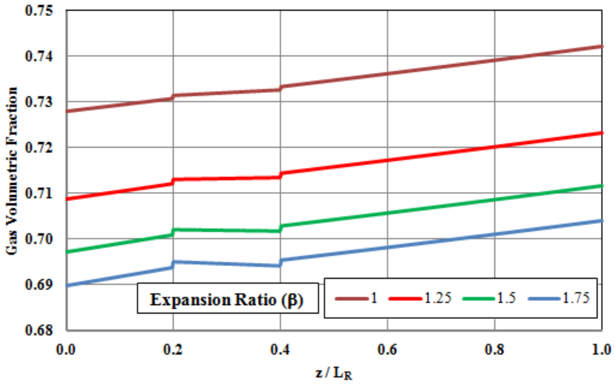

Fig.7: Variation of gas volumetric fraction along flow path line of the riser tube for the case of non-uniform S-bend cross section at j_{Ga}(based on D_U)=5 m/s (L_B=61mm, D_U=18mm, α=70%, and γ = 0.25).

Fig.8 shows the predicted effect of the S-bend section orientation on the pump discharge rate. Three S-bend sections with uniform cross-sectional area and having same projected distance of 0.61m were numerically tested at different bend angles. As can be seen in Fig.8, the water-pumping rate is improved to some extent by increasing the degree of bend angle. This can be attributed to the reduced energy loss associated with large bend angles and reduced tube total length over which frictional resistance of flow takes place.

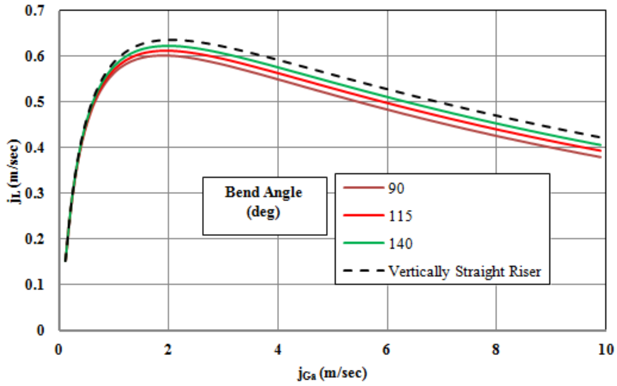

Fig.8: Effects of bend angle (θ) on water discharge rate (D_U=18mm, γ=25%, β = 1, and α=70%).

The effect of the bend section position (the γ-ratio) on the pump discharge rate at 70% of submergence ratio is predicted and plotted in Fig.9. The S-bend section with a uniform diameter was numerically located at three different positions from the injection level, namely at 25%, 50%, and 75% of the riser tube height. As depicted in Fig.9, the position of the S-bend section of the riser tube has a negligible effect on the pump performance. It is worth noting that data measured by Mahrous [21] demonstrated the same result. Although slight improvement in the water-pumping rate can be obtained when setting the S-shaped bend section close to the air injection level, the effect of bend section position of the riser tube under the current specified working conditions has an insignificant contribution to the improvement in the pump discharge rate. Fig.10 illustrates variations in the air volumetric fraction along the riser tube at different vertical positions of the bend section and at a constant value of j_{Ga}. As shown in Fig.10, the variation in air volumetric fraction due to expansion of air is not considerable. All cases almost exhibit same flow regime at pump exit section.

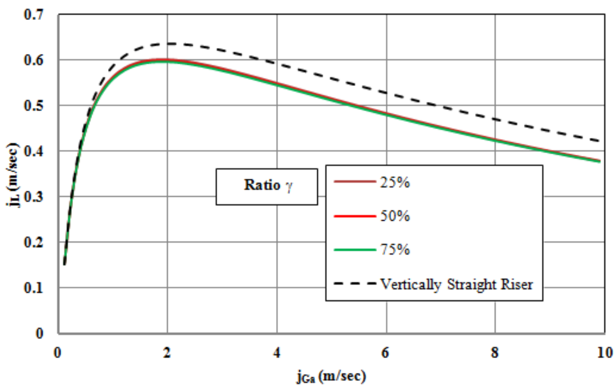

Fig.9: Effects of the γ-ratio on the water discharge rate (L_B=0.61m, D_U=D_D=18mm, and α=70%).

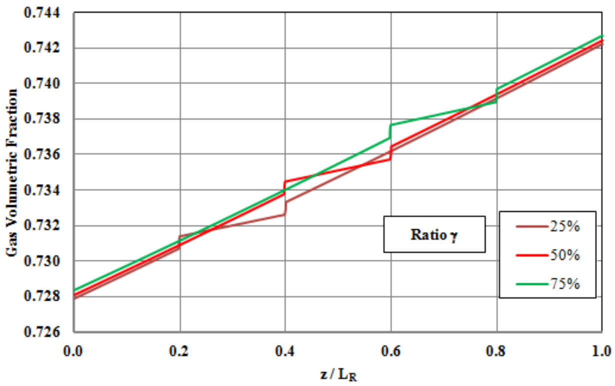

Fig.10: Variation of gas volumetric fraction along the riser tube at different S-bend positions where j_{Ga}=5 m/s (L_B=61mm, D_U=18mm, α=70%, and β = 1).

4 Conclusions

The performance of airlift pumps depends mainly on two groups of parameters. The first group is the geometrical parameters such as pipe diameter, pump height, design of injection system, and entrance geometry of the lifting pipe, while the other group is the operational parameters like the submergence ratio, injected gas flow rate and its corresponding pressure, and nature of lifted phase. This research presents a numerical predictive study of the effects of riser tube configuration on the airlift pump performance. Changing diameter, position, and tube orientation of riser pipe local S-bend straight tube section of the airlift pump was numerically investigated. The numerical model was assessed and verified through a comparison with available experimental data. Numerical results presented so far showed that the airlift pump performance is improved by gradually enlarging the straight tube section of the S-shaped bend of the riser tube. The results additionally proved an improvement in the pump discharge rate when increasing the angle of the S-bend tube section.

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List of Symbols

***Roman Symbols*:**

A Pipe cross sectional area.

D Pipe diameter.

g Acceleration due to gravity.

j Average volumetric flux.

L_B Length of S-bend tube section.

L_D Riser tube length downstream of the S-bend section.

L_I Submergence height.

L_R Riser tube length.

L_S Suction tube length.

L_U Riser tube length upstream of the S-bend section.

P Pressure.

Q Volumetric flow rate.

u Velocity.

z Elevation of the mixture level in the pipe.

***Greek Symbols*:**

α Submergence ratio (L_I / L_R).

β Expansion ratio (D_D / D_U).

ε Volumetric fraction.

γ Ratio (L_U / L_R).

θ Bend angle.

ρ Density.

τ Shear stress.

***Subscripts*:**

2 Two-phase air-water mixture.

a Atmospheric conditions.

B S-bend section.

D Downstream of bend.

E Pipe inlet section.

G Gas (air) phase.

i Index denotes the type of phase.

L Liquid (water) phase.

O Pipe outlet section.

s Surface.

U Upstream of bend.