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Experimental investigation of characteristic curve for gas-lift pump

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ABSTRACT

Using gas–liquid lifting pumps is a quite different technology for pumping two or three phase flows rather than other types of pumping systems. Therefore, finding performance characteristic chart for this type of pumping system seems to be necessary. In this type of pumping system, the liquid phase is pushed upward by the compressed air which has been injected in the bottom of upriser pipe of the pump. Therefore, compressed air acts as the driving force in gas lifting pumps instead of moving parts in ordinary pumps. It can be concluded that the definition of characteristic curve used for ordinary pump is not very appropriate for this type of pumping system.

In this study, it has been attempted to propose a new definition of performance characteristic for a gas–liquid lifting pump. The definition is based on the actual physical behavior of the pump and the measured experimental data during its operation. The experimental data have been collected from a gas lifting pump with the height and diameter of 6 and 0.05 m, respectively. It seems better to define a dimensionless number as the head of the pump to be more appropriate for its application. Hence, several charts have been prepared according to the collected data and the best definition for performance characteristic has been suggested. Also, the effect of important parameters such as superficial slip ratio, submergence ratio and two phase flow regimes is investigated on the pump performance.

1. Introduction

Gas lift two phase pumps lift liquid or mixture of liquid and solid by injection of compressed air bubbles into the pump's main pipe. This pipe has two principal parts: one part is situated between the bottom of the pipe and air injection port called suction pipe, and the other part is located between discharge point and air injection port called upriser pipe. These pumps are applied for lifting materials in corrosive, explosive and abrasive medium. Although the efficiency of these pumps is less than that of other ordinary pumps, they are getting more common especially in applications since they do not have any moving mechanical parts. Simplicity and easy manufacturing process are the other reasons for wide usage of these pumps. Gas lift pump has two different types: internal gas line and external gas line. Internal gas line is more common because of its versatility and ease of assembling. However it has got lower efficiency than the external one.

Although gas lift pumps have been used for many years (Castro et al., 1975), the performance of these pumps has remained a great interest to researchers so far. Various studies that have tried to simulate the behavior of gas lift pumps are found in literature. Kato et al. (1975) studied an air lift pump experimentally for solid particles and proposed a model based on the momentum equation. Parker et al. (1984) used an airlift pump for aerating warm water ponds. Apazidis (1985) considered the influence of bubble expansion on the performance and stability of an airlift pump. He considered the stability condition of an airlift pump within the frame of more general flow model with the assumption of single-phase flow of an ideal incompressible liquid and taking into account the effect of the expansion of gas bubbles during their lift. Wicomb et al. (1985) used an airlift system for perfusion storage of the isolated heart. Parker and Suttle (1987) designed an airlift system for aquaculture applications. Chisti (1989) derived theoretical equations for airlift loop reactors, which described the relation between superficial gas velocity and liquid circulation velocity. Reinemann et al. (1990) experimentally considered the effect of the tube diameter on the performance of 3–25-mm airlift pumps. They extended Nicklin's theory into this range of tube diameters by taking into account the effect of surface tension on the bubble velocity. They also claimed that airlift efficiency and optimal submergence ratio (which is defined by the ratio of water level to the height of the pipe before the pump operation) increase in the range of tube diameter. Zenz (1993) used various correlations to simulate airlift pumps. De Cachard and Delhaye (1996)

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Nomenclature

Notion

A cross sectional area of riser, m^2
A_a air cross sectional area, m^2
C_Q capacity coefficient
D impeller diameter, m
g gravitational acceleration, m s^{-2}
H^* pump's dimensionless head
J_a air superficial velocity, m s^{-1}
J_w water superficial velocity, m s^{-1}
m_a air mass flow rate, kg s^{-1}
m_w water mass flow rate, kg s^{-1}
n pump's shaft speed
P_{in} inlet pressure, Pa
P_{out} outlet pressure, Pa
Q_w water volumetric flow rate, m^3 s^{-1}
Q_a air volumetric flow rate, m^3 s^{-1}
SR submergence ratio
SSR superficial slip ratio
T temperature, K
V_{in} inlet velocity, m s^{-1}
V_{out} outlet velocity, m s^{-1}

Greek symbols

α void fraction
ρ_a air density, kg m^{-3}
ρ_{TP} two-phase density, kg m^{-3}
ρ_w water density, kg m^{-3}
Ψ_{in} inlet exergy of fluid, J
Ψ_{out} outlet exergy of fluid, J

proposed a model to predict pressure gradient for slug flow in the airlift pump. Margaris and Papanikas (1997) introduced a pseudo-liquid, which was defined by liquid and solid phases, for analyzing a three-phase flow airlift pump. Nenes et al. (1997) simulated an airlift pump numerically for deep water well, which was based on the interspersed continua approximation and used appropriate friction correlation for specified flow regimes. Their model could predict either water or air flow rate. Saito et al. (1999) investigated the hydrodynamic of a gas-lift system for deep sea applications. They obtained a maximum liquid flow rate for each pump for the range of gas injection rates studied. Moreover, the liquid-phase hold-up was adequately modeled based on a gas-phase Froude number and applying 1-D drift-flux analysis in their literature. Kumar et al. (2003) reported a simple way to improve the importance of an airlift pump. They fitted the pump with a tapered upriser pipe. The main reason for such an improvement is discussed as an adverse pressure gradient in the tapered upriser pipe on the two-phase flow regime transition and slug flow parameters. Utility of stepped upriser was explored in their work, too. Awari et al. (2004) evaluated the performance of an airlift pump under predetermined operating conditions and optimized the related parameters. They focused on the general mathematical functions applicable to the airlift pump installations. Samaras and Margaris (2005) analyzed the transformation of the flow regime maps into a selected coordinate system for airlift pumps. Their work presents a very simple map, directly showing the measured data and the flow regime transition. They indicated four different regimes, slug, churn, annular and wispy annular as the applicable regimes in airlift pumps. Dare and Oturuhoyi (2007) introduced Lift Dimensionless Number (LDN) and Pump Dimensionless Number (PDN) to capture all the flow parameters. They observed that airlift pumps with smaller riser pipe diameters yield higher lifts. They also found out that fluid with better adhesive properties produces higher lift. They concluded that for all cases the lift is increased by increasing submergence ratio. Pougatcha and Sulcudean (2008) simulated deep sea air-lifting with a mathematical model of a three-phase flow in an upward pump. In their article, the influence of the pipe diameter on the air-lift efficiency was studied. They found that lifting efficiency increases with the increase of the pipe diameter due to the reduction of the influence of wall friction on the flow. Kassab et al. (2009) evaluated the performance of an airlift pump under predetermined operating conditions and optimized the related parameters. In this work, pump was tested under different two-phase flow patterns. Also a theoretical model was proposed in this study taking into account the flow pattern at the best efficiency range where the pump is operating. Results showed that the best efficiency range of the airlift pumps operation is in slug and slug–churn flow regimes. Hanafizadeh et al. (2010) developed a new numerical approach, called physical influence scheme, to simulate two-phase flow in the airlift pump's upriser pipe. This method couples the continuity and momentum equations and enforces the role of the pressure directly into the continuity equations. Hanafizadeh et al. (2011a) analyzed the gas liquid upward two-phase flow regime in the upriser pipe of airlift pump experimentally by the image analysis technique. They detected three main flow regimes, namely slug, churn and annular in the airlift and found the slug flow regime the most appropriate one for this type of pumping system. Hanafizadeh et al. (2011b) used an exergy analysis to model an airlift pump. They calculated the entropy generation in different flow regimes in airlift pump and discovered the least entropy generation in slug flow regime. Hanafizadeh et al. (2011c) considered the effect of step geometry on the performance of the airlift pump. They observed the improvement in the performance of step airlift pump in comparison with ordinary type. They also considered the effect of height of steps and secondary diameter for steps on this improvement and realized that there are optimum heights and diameters for steps in which the pump performance is maximized in the constant air flow rate.

One of the most important parameters of a pump is its performance characteristic. This parameter is used to determine whether a pump is appropriate for a special application or not. Like other types of pumps, it is necessary to obtain this character for airlift pumps. Since the performance and the process in an air lift pump are different from an ordinary pump, a new definition for performance characteristic of air lift pump is needed. In order to reach to a convenient definition, several experiments have been conducted on a typical airlift pump at laboratory and several data have been collected. In this article some different definitions are proposed and the most appropriate one according to the application of the pump is selected. Moreover, this character is shown for different flow regimes in an airlift pump and the agreement between experiment and theory is proved.

2. Experimental setup

The experiments of this study are conducted on an airlift pump shown schematically in Fig. 1. Air and purified water are used as the gas and liquid working fluids in all experiments respectively. The water is pumped upward by the buoyancy force caused by the injected compressed air. The water flow rates are measured by the calibrated magnetic flow meter with an accuracy of 0.5% of