INVESTIGATION OF GAS SEPARATION IN INVERTED-SHROUD GRAVITATIONAL SEPARATORS OF DIFFERENT GEOMETRIES

Marcel Cavallini Barbosa, marcelcavbar@gmail.com
Luis Enrique Ortiz-Vidal, leortiz@sc.usp.br
Oscar Mauricio Hernandez Rodriguez, oscarmhr@sc.usp.br
Sao Carlos School of Engineering University of Sao Paulo - Av. Trabalhador Sao-Carlense, 400, 13566-590, Sao Carlos, SP, Brazil
Valdir Estevam, vestevam@petrobras.com.br
Exploration and Production, E&P-ENGP/IPP/EE, PETROBRAS, Av. Rep. Chile, 330 – 7º, 20031-170, Rio, RJ, Brazil
Divonsir Lopes, divonsir@petrobras.com.br
Exploration and Production, E&P-PDP/CTPDP/SUB, PETROBRAS, Av. Rep. Chile, 330 – 29º, 20031-170, Rio, RJ, Brazil

Abstract. *Gas separation has been a great concern for the oil industry in pumping operations that involve centrifugal submersible pumps. Free gas released from the well can severely harm pumps due to cavitation effects and thus can generate excessive maintenance costs. One solution for this problem is the inverted-shroud gravitational gas separator (IS-separator), that consists of a cylindrical container positioned between the well casing and the production pipe. The literature shows information on the performance of small-scale IS-separators at several inclination angles and flow conditions. Studies on IS-separators on real-scale geometry had not yet been reported. In this study we present experimental data of gas-separation efficiency obtained with a real-scale IS-separator. Tests were performed on a test loop at the Thermal-Fluids Engineering Laboratory of the University of Sao Paulo (LETeF-USP). The radial real-scale geometry consists in a 10.5-m test line with three concentrical glass tubes of internal diameters equal to 158 mm for the well casing, 138 mm for the shroud and 111 mm for the production pipe. Working fluids are air and water, with water flow rates ranging from 5 to 80 l/min. Maps of gas separation efficiency for the inclination angles of 45º and 60º in relation to the horizontal are presented. Gas-separation efficiency results are being confronted against small-scale data and phenomenological-model predictions reported on previous studies. The phenomenological model when compared to the new data is found to accurately predict the conditions for total separation efficiency in the radial real-scale IS-separator, thus showing consistency with varied geometries. Comparisons between new and previously reported gas-separation efficiency data will be also presented.*

Keywords: *Two-phase flow, Gas-separation efficiency, Annular channel, Gravitational gas separator, Inclined flow*

1. INTRODUCTION

The presence of free gas in directional wells is a common occurrence in the oil industry. In well operations, where a submersed centrifugal pumping system is used, preventive measures must be taken so that the free gas does not reach the suction of the pump. Failure to do so could cause cavitation problems, resulting in added maintenance costs and a loss of production days. Several kinds of inline gas separators have been employed in order to avoid this problem, with the best performance being achieved by fixed-helical and centrifugal separators (Alhanati 1993; Serrano 1999). However, the former presents high construction costs and a reduced cross-sectional area, compromising the production rate. The latter requires expensive maintenance due to moving parts. Recent studies show that the Inverted-Shroud gravitational gas separator (IS-separator) avoids the mentioned problems while achieving total gas separation (Mendes 2012; Ortiz Vidal et al. 2012). The aim of the present study is to compare new data of Efficiency of Gas Separation (EGS) obtained with an IS-separator built according to radial real-scale geometry to data previously collected in another IS-separator of different geometry. We also use the collected data to verify the reliability of a phenomenological model proposed in previous studies, which predicts operational conditions of total gas separation in the IS-separator.

2. NOMENCLATURE

a	length (m)
$\dot{m}$	air mass flow (kg/min)
Q	water volumetric flow (l/min)

Greek symbols

η	gas separation efficiency (%)
β	inclination angle (º)

Subscripts

IAL	inner annular level
IN	air inlet
OUT	air outlet
W	water

3. SEPARATOR PHENOMENOLOGY

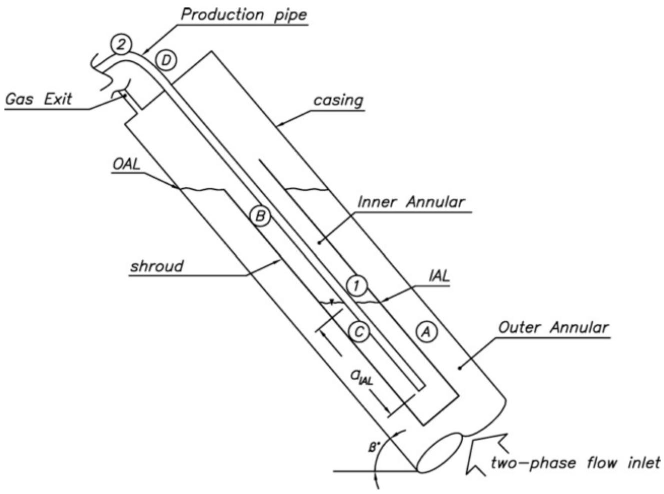

Fig. 1 – Schematic description of the IS-separator, extracted from Ortiz-Vidal et al. (2012)

The IS-separator consists of a cylindrical container with a sealed bottom, enclosing the production tube, as seen in Fig. 1; its phenomenology was described by Ortiz-Vidal et al. (2012). A multiphase gas-liquid mixture, rising from the bottom of the well, flows through Region "A". Upon reaching the top of the shroud (Outer Annular Level, or OAL), the mixture becomes segregated due to gravitational forces acting on the liquid phase. Liquid enters the shroud creating free-surface flow in the annular channel located between the shroud and the production pipe (Region "B"). The mentioned behavior only occurs when the shroud separator is installed in a directional well. The collision between the free-surface flow and the liquid interface of the Inner Annular Level (IAL) generates bubble entrainment in the liquid phase. The rate of entrained gas is not dependent on the gas flow rate, but on the kinetic energy dissipated in the collision, which is determined by the velocity of the downwards free-surface flow. Entrained bubbles travel towards the entrance of the production pipe (Region "C"). The bubbles travel describing *quasi*-parabolic trajectories due to inertial, buoyancy and drag forces, until they reach the bottom of the shroud. At this point, they can coalesce into larger bubbles that should float towards the IAL. In order to ensure total gas separation, a minimal a_{IAL} length between the IAL and the entrance of the production pipe must be kept so that the bubbles cannot reach the suction of the pump. In well operation conditions, this can be done by controlling the differential pressure (DP) between regions "B" and "D". A lower DP makes the a_{IAL} length increase and *vice versa*. This process is continuous and occurs until a stable level of liquid is naturally found.

4. EXPERIMENTAL WORK

4.1 Experimental Setup

The experimental apparatus installed at the Thermal-Fluids Engineering Laboratory (LETeF) of the University of Sao Paulo, at Sao-Carlos *campus* (EESC-USP), was used to collect the EGS data. It consists of a 10.5-m-length IS-separator prototype made of joined glass tube sections. Each section, measuring 1.5m in length, is made of three borosilicate-glass concentric tubes, with the outer and middle tubes (mimicking for the well casing and shroud, respectively), and an inner tube (production pipe analogue) made of PVC. Flanges with O-ring seals are used to join the tube sections while avoiding leakage from one tube to another. This setup is attached to an inclinable metal structure that allows for testing on any angle between 0-90º. The described apparatus was also used by Ortiz Vidal et al. (2012) and Mendes (2012). The separator geometries used in the present and previous studies are shown in Tab. 1. Measured parameters include (but are not limited to) volumetric liquid flow, a_{IAL} length, air mass flow (inlet and outlet) and differential pressure in the separator.

Table 1. Separator geometries for each investigation of the IS-separation

	Production Pipe Diameter (mm)		Shroud Diameter (mm)		Well Casing Diameter (mm)
	Int.	Ext.	Int.	Ext.	Int.
Ortiz Vidal et al. (2012) and Mendes (2012)	17	20	65	75	111
Present Work	66	75	115	125	158

4.2 Efficiency of Gas Separation

The efficiency of gas separation (EGS) is defined by the ratio between downstream and upstream mass air flows,

$$\eta = \frac{\dot{m}_{OUT}}{\dot{m}_{IN}} \tag{1}$$

The air mass flows at the inlet (m_{OUT}) and outlet (m_{IN}) of the separator are obtained indirectly by the product between volumetric flow rate and density. The former is measured by a positive-displacement flowmeter. By assuming the air behavior to be that of an ideal gas, the latter is calculated from temperature and pressure readings.

5. PRELIMINARY RESULT ANALYSIS

The EGS is a function of the a_{IAL} length according to the phenomenology presented in previous studies. Therefore, maps of a_{IAL} *versus* Q_W can be used to present clearly the collected gas separation data. Overall, flow conditions for Total Gas Separation (TGS) and Partial Gas Separation (PGS) are presented in the upper and lower regions of the map, respectively. Some efforts to model the transition between TGS and PGS have been (Mendes 2012; Ortiz-Vidal et al. 2011). This transition is dictated by the minimal a_{IAL} length that ensures TGS, *i.e.* bubbles in Region "C" (Fig. 1) cannot reach the inlet of the production pipe. EGS data and the transition boundary predicted by the model (solid line) for inclination angles of 45º and 60º are presented in the maps of Fig. 2 and Fig. 3, respectively. One can observe that the predictions of the model for the TGS operation region are fairly in favor of safety, since all of the PGS conditions are in the region below the curve generated by the model. Further results will be presented in the full paper, including the comparison of TGS regions from different separator geometries (Tab. 1). The aim is to improve the understanding of the performance of IS-separators.

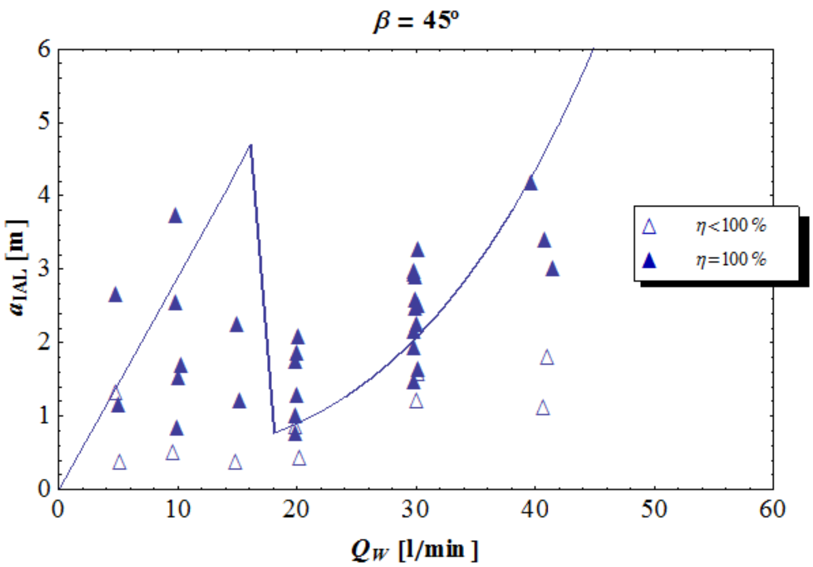

Fig. 2 – Map of efficiency of gas separation as a function of the a_{IAL} length and of the liquid volumetric flow Q_w for a 45º inclination angle (solid line). The solid symbols represent total gas separation and the open symbols stand for partial gas separation. The solid line represents the transition boundary predicted by the model.

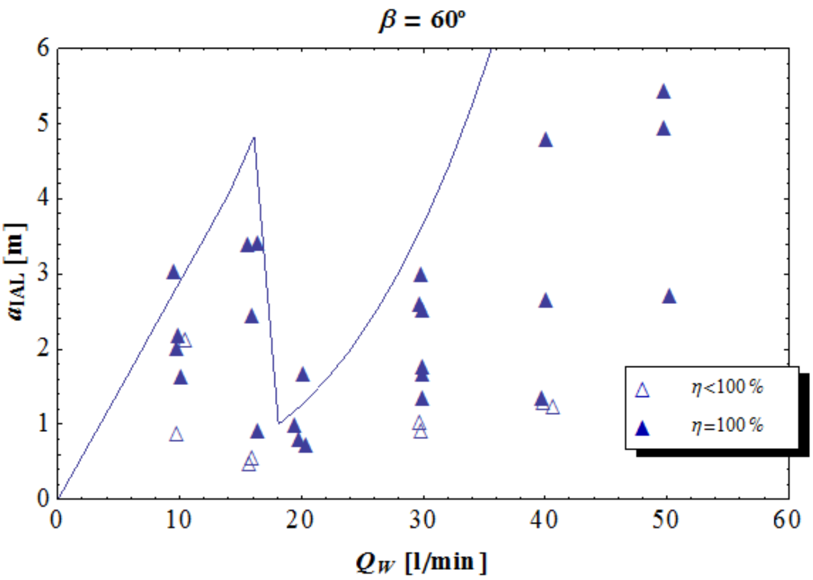

Fig. 3 – Map of efficiency of gas separation as a function of the a_{IAL} length and of the liquid volumetric flow Q_w for a 60º inclination angle (solid line). The solid symbols represent total gas separation and the open symbols stand for partial gas separation. The solid line represents the transition boundary predicted by the model.

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7. REFERENCES

Alhanati, F.J.S. 1993. Bottomhole Gas Separation Efficiency in Electrical Submersible Pump Installations. PhD thesis, University of Tulsa, OK, USA.

Mendes, F.A.A. 2012. Estudo Experimental, Simulação Numérica E Modelagem Fenomenológica Da Separação Gravitacional de Gás No Fundo de Poços Direcionais. University of São Paulo, Engineering School of Sao Carlos, Sao Carlos, SP, Brazil.

Ortiz-Vidal, L.E., Rodriguez, O.M.H., Estevam V., Lopes D. 2012. "Experimental Investigation of Gravitational Gas Separation in an Inclined Annular Channel." Experimental Thermal and Fluid Science, Vol. 39(0), pp. 17–25.

Ortiz-Vidal, L.E., Rodriguez, O.M.H., Estevam V., Lopes D. 2011. "Downhole Total Gas Separation in Pumped Directional Wells." Boletim técnico da Produção de Petróleo, Vol. 5(2), pp. 45–62.

Serrano, J.C., 1999. Natural separation efficiency in electric submersible pump systems. MSc thesis, University of Tulsa, Tulsa, OK, USA

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