R&D NOTES

Effects of Salinity on The Performance of Gas Liquid Cyclonic Separators

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Introduction

In the last few decades the petroleum industry is facing economic and operational restrictions, which dictate the need for production and processing technologies that are cost, operation and deployment efficient. Gas-liquid separation is one of the operations where particular attention was given in order to enhance reliability of early processing stages. The concept of designing an efficient compact gas-liquid separator has received a lot of attention from academic researchers, as well as from applied field operators. The necessity of compact designs comes from the need to deploy separators offshore and potentially subsea in order to enhance the recovery of gas wells especially.[1,2,3] A compact design has the advantage of reducing the separator footprint as compared with conventional gravity separators, which are bulky and have very large footprints. From this perspective, cylindrical cyclones employing a combination of gravity and centrifugal forces to achieve a high-efficient gas-liquid separation are most preferred.

One of the most successful designs in cyclonic separators is the GLCC (GLCC© - Gas-Liquid Cylindrical Cyclone-Copyright, the University of Tulsa, 1994), which stands for gas-liquid cylindrical cyclone separator, implemented in a number of applications as reported recently by Kouba et al.[4] The advantage of the GLCC is its simplicity, reliability and low cost. The early designs and performance analysis of the GLCC were achieved in laboratory studies. Both experimental and numerical investigations were performed in order to understand the effects of geometrical, physical and dynamical parameters affecting the performance of the GLCC.[5,6,7,8] In one of the most relevant works, Movafaghian et al.[9] have discussed geometrical and physical properties of the performance of the gas-liquid separator regarding inlet geometry effects, pressure effects, viscosity and surfactant effects.

Methodology and approach

The performance of a gas-liquid separator can be visually established following the analysis of two important phenomena. The first phenomenon is the liquid carry-over regime in which liquid is carried out in the gas stream. The combinations of liquid and gas flow rates at which the liquid carry over is observed limits the upper operational range or envelope of the separator expressed either in flow rates or in superficial velocities calculated over the body cross sectional area. The superficial velocity is defined as the flow rate of a single-phase flowing alone in the separator body divided by the cross section of the body pipe. An illustration of the liquid carry over operational envelope is shown in Figure 3, for the deionized water case. In the region above the curve, liquid is carried out by the gas stream, while in the region below the curve, the separation is complete. The second phenomenon limiting the performance of the separator is the gas carry-under, which indicates that gas in the form of bubbles being trapped in the liquid downward flowing stream is discharged with the liquid. The combination of liquid-and gas-superficial velocities, where the separator does not show any liquid carry over or gas carry-under defines the operational range of the separator, and represents the principal quality to judge the performance of a gas-liquid separator.

Operational envelopes for liquid carry-over have been presented in many studies. Movafaghian et al.[9] have presented

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operational envelopes for the effects of geometrical parameters, such as the inlet-pipe diameter, and also studied the effect of liquid viscosity, and the presence of surfactant on the performance of the gas-liquid separator. It has been shown that increasing viscosity decreased the performance of the gas-liquid separator. On the other hand adding surfactant to the liquid decreased the surface tension of the liquid and has shown two regions in which the separator behavior was different. For gas-superficial velocities higher than 6 m/s, in the presence of surfactant the gas-liquid separator had a similar performance compared to the tap water case. However, for gas-superficial velocities lower than 5 m/s the performance of the separator was very poor in the presence of surfactant compared to the tap water case. This physical behavior is of particular interest since decreasing surface tension limited the overall performance of the gas-liquid separator.

In most real fluid applications the working solution contains one or several ions. In mixing gas-liquid systems for example, the presence of high-concentrations of ions in the liquid influences the mixing properties of the system. In the case of an offshore processing it is expected that the produced water from a gas well would have a substantial amount of salt. It is well known in the literature that adding salt to pure water increases the surface tension, making bubbles less easy to coalesce.[10] In such case if the gas and liquid are subject to a certain degree of mixing in the work pipe, the gas breakage will result in small gas bubbles trapped inside the liquid, which do not coalesce. In fact, in the presence of ions, two systems exist depending on the ion concentration. The first system is a coalescent system where agitated gas bubbles collide and coalesce. The second system, where ion concentration has reached a critical value, is described as noncoalescent system. The gas is broken into small bubbles which do not coalesce, and even some of the gas becomes dissolved in the liquid phase.[10,11,12] In our knowledge the effect of presence of salt ions on the performance of cyclonic separators has not been studied or reported in the literature.

The aim of this study is to investigate particularly the effects of the presence of high-concentrations of salt ions in the fluid solution on the operational envelope of gas-liquid cylindrical separators.

Experimental Facilities and Arrangements

The experimental test rig consisted of a two-phase flow loop and a gas-liquid cylindrical cyclone separator presented in Figure 1. The flow loop was an air-water system in which water was supplied from a 1.5 m^3 storage tank at atmospheric pressure, and pumped to the waterline with a Dresser monopump with a maximum capacity of 120 L/min. The monopump motor was controlled with a variable speed controller Danfoss VLT-5000 in order to achieve different pumping flow rates. The modeled gas was compressed air supplied by a compressor line at 6 bars, which could deliver up to 1,800 NL/min in the test section. A gas-control valve permitted to adjust the air flow rate to the desired value. The water exit was connected to a storage tank of a capacity of 200 L to allow the water to be recirculated in the flow loop via the pump.

The water stream and the compressed air were injected at the same point in a mixing tee piece just upstream of the multiphase inlet shown in Figure 1. In the upper part of the separator (gas exit) the air could be either recirculated in a loop (Figure 1) or vented to the atmosphere, and in the lower part the liquid was allowed to return to the storage tank and recirculate in the pipe loop. In the case of an open gas exit, no air bubbles were present in the liquid storage tank. The results presented in Figure 3 in this study were conducted with an open gas exit, the separated air being vented to the atmosphere. The gas-liquid cylindrical cyclone body used in this study was formed by a clear PVC pipe of 50.8 mm dia. and 2.8 m height equipped with an inlet inclined with 27° to the vertical made from the same pipe as the body separator. The tangential inlet at the end of the inlet inclined pipe had a discharge section with an area equal to 25% of the cross section of the body pipe. The separator body with the inlet were inserted in a square cross section casing in order to eliminate any optical distortion during flow visualization.

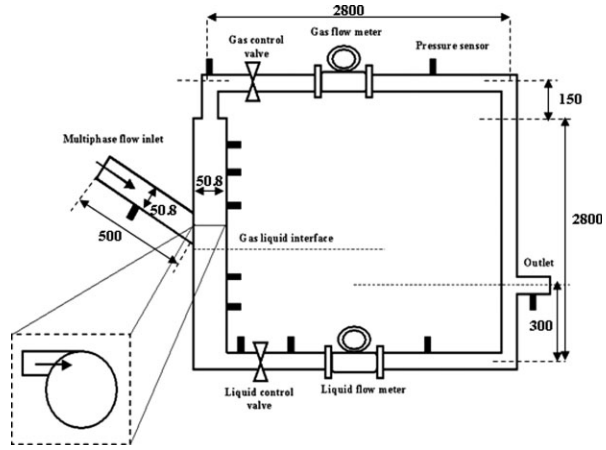

Figure 1. Flow system and experimental arrangements.
Dimensions are given in mm.

The superficial velocities were calculated on the basis of the separator pipe cross area for both gas and liquid. The flow visualization uncertainty depended mainly on the gas flow rate measurements. In the compressed air inlet a pressure gage was used to maintain a constant flow rate. The experimental results obtained visually for the liquid carry over state were repeated in order to estimate the accuracy of the measurements. The liquid-flow rate was fixed and the gas-flow rate was adjusted repeatedly to locate the critical value for liquid carry-over. The error bars shown in Figure 3 on each envelope show that the accuracy of the critical gas-flow rate for liquid carry-over was estimated between 1–3% depending on the range of gas-flow rates. In the study of the salinity effects on the separator performance table salt was added to deionized water gradually, and the salinity concentration of the solution S given in ppm and ppk (1 ppk = 1,000 ppm) of salt contents was measured with a TPS WP-84 conductivity-salinity probe. Even though surface tension, viscosity and electrically repulsive forces were ruled out as possible explanation of the noncoalescence of gas bubbles in high-salinity system by some authors, there is still reference to surface tension as a key parameter.[10] In our system the liquid surface tension was estimated using the correlations of Fleming and Revelle[13] and Houdart.[14] The liquid surface tension without foam increased from 72.76 mN/m for tap water to 73.74 mN/m for a salinity of 35 ppk.

Results and discussion

The liquid carry-over and gas carry-under could be both identified visually as reported by Movafaghian et al.[9] In a study in a similar system, Barbuceanu and Scott[15] identified two mechanisms of liquid carry-over in cyclonic separators according to the position of the liquid interface. If the liquid interface was above the inlet, the liquid carry-over occurs due to liquid churning in the part above the inlet. If the liquid interface was located below the inlet, liquid carry-over occurs when the gas vortex core shears off the liquid in form of droplets or mist depending on the flow rates. In our study only the second mechanism was investigated by fixing the liquid interface at a distance of 500 mm below the inlet for all measurements. Once the liquid and gas flow rates were fixed, the liquid interface was adjusted by the use of the liquid exit valve shown in Figure 1 until the interface stabilizes at the required level.

A flow visualization of the flow vortices developed at the tangential inlet of the gas-liquid separator is presented in Figure 2. The inclination of the inlet has the advantage of stratifying the liquid and gas under the gravity as seen in Figure 2 in the inclined inlet pipe section. At the tangential inlet with a cross section equal to 25% the pipe cross section, a high g-force field is established with the presence of strong swirling vortices. The vortical region is in fact divided into two vortices. The first vortex located on the wall of the separator pipe (outer region) has a downward helical motion and entrains most of the liquid toward to the liquid exit at the bottom of the separator; this vortex is considered as a free type vortex. The high g-force at the inlet permits the extraction of the gas toward the inner region of the pipe due to the centrifugal forces which push the heaviest fluid (water) outwards. The second vortex is located in the core of the separation region (inner region), which contains the separated gas. This second vortex is a forced type and extends gradually upward above the inlet region. On the other hand, in the vicinity above the inlet, a small region, which contains a liquid film fast spinning along the pipe wall, can also be observed in Figure 2 as a tornado shape. This liquid film seems to be rotated by the gas forced vortex present in the core region. The visual analysis of the liquid carry over phenomenon has revealed that the stability of this liquid film above the inlet is very important to the efficiency of the separation. Liquid carry over was observed at the moment where the gas-core vortex gains enough energy to shear off the liquid film, and entrains the liquid in the form of droplets of different sizes. Preceding this state, at specific gas-and liquid-flow rates, a perturbation imposed on the liquid film occurred and an upward-downward oscillatory motion could be observed. When deionized water was used as working solution, the liquid film formed at the top of the inlet had a very clear layer in the vicinity of the pipe wall. The operational envelope for liquid carry-over was investigated by systematically combining liquid-and gas-flow rates until liquid carry-over was observed for defined liquid-and gas-flow rates. Figure 3 summarizes the results in a map where liquid and gas-superficial velocities are presented. For the curve designating deionized water, in the region above the curve liquid carry over was observed, while any combination of liquid and gas flow rates situated below the curve corresponds to a stable complete gas-liquid separation as previously stated. Once the operational envelope for deionized water was obtained, table salt was added gradually in the water storage tank, and mixed until completely dissolved. The analysis of the operational envelope for liquid carry-over was again performed. The results obtained for different values of the salinity S are reported in Figure 3, as comparison with the deionized water case. For each curve, in the region above the curve liquid carry-over was observed, while in the region below the separation was complete. As the salinity increases, the results show that the liquid carry-over existing region increases in the separation map. Salinity levels corresponding to artificial sea water (i.e. 35 ppK) show a very poor performance of the gas-liquid separation. This effect is mainly related to the phenomenon of gas breakage and coalescence of gas bubbles in the system. Visually it could be seen that the liquid film located above the inlet region was not clear anymore at high salinity concentrations, but was rather observed as highly rotating foaming

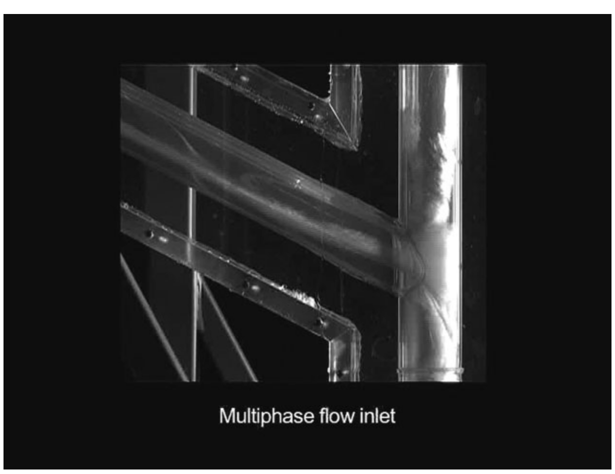

Figure 2. Flow visualization of the inlet separation region.

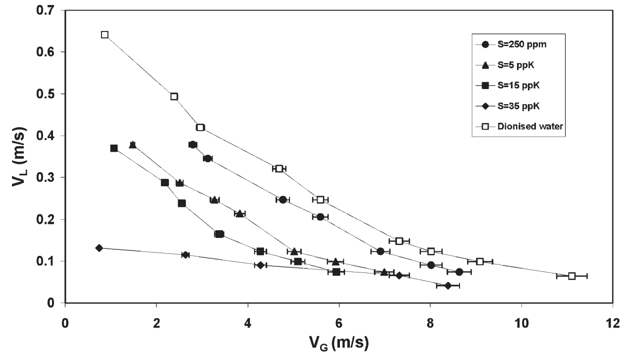

Figure 3. Operational envelope of the gas-liquid separator.

The liquid level was fixed at 500 mm below the multiphase inlet.

region. It was observed that the gas vortex could break easily this foam region, which was mainly formed by very small air bubbles trapped inside the liquid film leading to the decrease of the apparent density of the mixture. The curves in Figure 3 also show two kinds of behaviors. For high gas-flow rates and low liquid contents it seemed that the difference in regions of liquid carry-over was relatively small. As the gas-flow rates decreased and the liquid-flow rates increased, the difference between the curves when the salinity increased became more pronounced. This result can be explained by the fact that for high liquid-flow rates and high salinity, the gas breakage phenomenon was predominant, and a substantial amount of the gas was broken into small bubbles in the liquid film and not coalescing. The efficiency of separation is affected in these flow regimes for higher salinity values. On the other hand, flow visualization has shown that due to the gas breakage in the presence of high-concentrations of salt, the gas carry-under phenomenon was strongly present in all cases. A gas-liquid mixture could be seen in the liquid exit leg. The air bubbles were so small and their density distribution was so large in a cross section that visually it was difficult to distinguish single bubbles.

Conclusions

The effects of salinity on the performance of a gas-liquid cylindrical cyclone have been experimentally studied. It has been shown that the presence of high-concentrations of sodium ions affects significantly the performance of the separator. This effect is mainly due to the gas-bubbles breakage mechanism in the presence of high ion concentration, which prevents small bubbles from coalescing. A hypothesis on a possible mechanism can be described by the entrapment of gas bubbles in the liquid film, resulting in the change of the apparent density of the liquid charged with a higher amount of gas. The liquid film being lighter might then be easily sheared off by the gas-core vortex entraining the liquid in form of droplets, and provokes early liquid carry over compared to low-concentration ion-water systems. Gas breakage also affected the performance of the separator with the presence of substantial amount of gas carry-under.

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Notation

S = salinity concentration, ppm
V_G = gas-superficial velocity, m/s
V_L = liquid-superficial velocity, m/s

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