SPE-193029-MS

Experimental Investigation over Effect of Geometrical Changes on Gas/ Liquid Cylindrical Cyclone GLCC Separator

Hamidreza Asaadian and Bahram Soltani Soulgani, Petroleum University of Technology; Sina Rezaei Gomari, University of Teesside; Bahador Soltani Soulgani, PetroPersian

This paper was prepared for presentation at the Abu Dhabi International Petroleum Exhibition & Conference held in Abu Dhabi, UAE, 12-15 November 2018.

Abstract

- Gas and liquid outlets length Study and its effect on Gas/liquid Cylindrical Cyclone (GLCC) separator performance.
- Gas body column length Study and its effect on GLCC separator performance.
- Inlet diameter Study and its effect on GLCC separator performance.
- Study of body column diameter and its effect on GLCC separator performance.
- Study of gas and liquid outlets diameter and its effect on GLCC separator performance.

An experimental GLCC separator was designed and built in laboratory to determine its domain. The best operational domain is where the equilibrium liquid level placed below the inlet and between 1 L/D and 3 L/D of separator column. If it pass the inlet it causes liquid carry over and if it settles below the 3 L/D it creates gas carry under in the separator. Thus the equilibrium liquid level was measured for different range of liquid and gas flowrates. In this work the gas superficial velocity was set between 0.3 and 6 meter per second and for each gas superficial velocity, liquid superficial velocity was from 0.3 to 3.3 meter per second. Moreover, different parts of test separator was changed and their effects on the separator operating domain was studied. These changes are 12.7 mm reduction in inlet diameter size, 5 mm reduction in liquid outlet diameter size, 5 mm reduction in gas outlet diameter size, 0.12 meter reduction in gas column length, 25.4 mm reduction in column diameter size and 1.4 meter increment in outlet length.

Based on this work the following results were obtained:

- Reducing the inlet diameter improves the GLCC separator performance. It allows more gas and liquid flowrates enter the separator for total separation by enhancing the centrifugal effect on liquid and gas phases.
- Reducing the liquid outlet diameter has negative effect in GLCC flowrates domain but this reduction can be used to control the equilibrium liquid level by a gate valve in liquid outlet leg.

- Reducing the gas outlet diameter has negative effect on GLCC performance. But in some situations controlling the amount of accumulated gas in GLCC can avoid liquid carry over in the system.
- Reduction in gas column length shows no effect on the separator flowrates domain.
- Increasing in length of outlet legs increases the friction force and limited the separator performance.
- Reduction in separator body diameter raises the chance of liquid carry over and gas carry under and has negative effect on flowrates domain.

These findings from GLCC performance give the main guideline to design more efficient separator design for oil and gas fields. Proper designing makes separator performance domain wider whereas it creates separators more compact which in turn minimizes the cost of construction accordingly.

Introduction

Hydrocyclones have been widely used in different industries such as petroleum, minerals and environment engineering. These kinds of separators are characterized for being compact and simple structure, low-cost and low weight to build as well as applicable in different operations (Li et al. 2011). Depending on the field and operating conditions these aforementioned properties are convincing to use a cyclone separator practically. Intention of simple structure is form the body of a cylindrical cyclone which consists of a vertical pipe with a downward inclined tangential inlet placed at mid-height and two outlet at top and bottom of the vertical pipe for outlet of the gas and the liquid streams, respectively (Gomez et al 2000, Hreiz et al. 2011). The simple schematic of a gas liquid cylindrical cyclone (GLCC) separator is illustrated in figure 1.

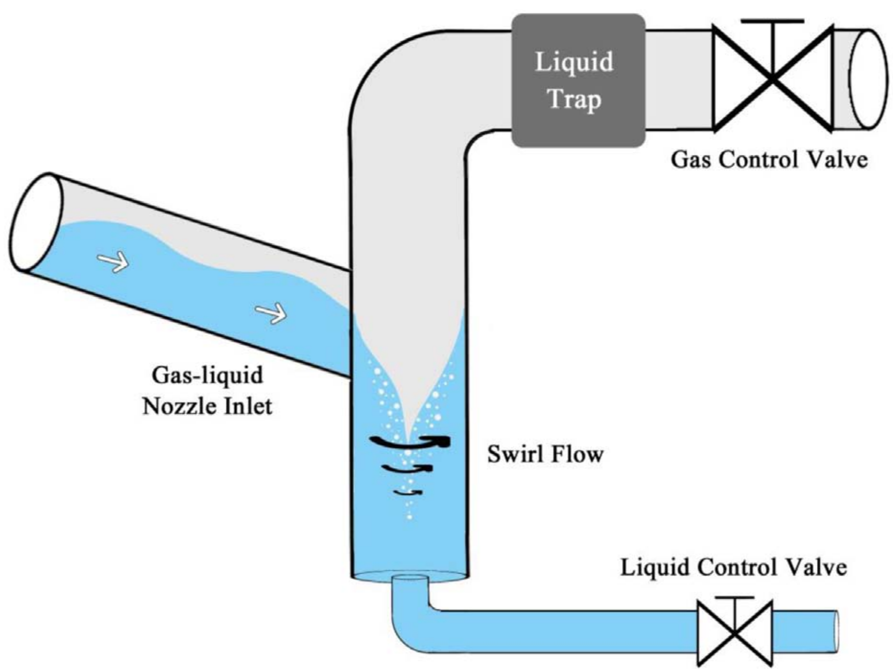

Figure 1—Simple schematic of a gas liquid cylindrical cyclone (GLCC) separator

In addition to the gravity force the main reason which distinguishes the function of cyclone separator is its centrifugal force which leads to enhance the separator efficiency compared with conventional gravity-based separators. In addition this feature reliefs the fluid maintenance in separator for long time. The downward inclined tangential inlet directs the multiphase flow stream to slide around the inner pipe wall and this movement generates centrifugal force and swirl regime nearby the nozzle inlet. Due to this force, fluid phase with high density (liquid) swirls near the wall and exits through bottom outlet but fluid phase with low density (gas) exits through top outlet by passing the central channel. Optimum design of a GLCC separator guarantees prosperous function during field production life (Arpandi et al. 1996, Hreiz et al. 2011).

In literature, the liquid carry-over and gas carry-under are indicated as two destructive phenomena which treat the GLCC function. High velocity gas stream may carry liquid droplets and bring them into gas outlet. Chirinos et al. 1999 expressed that the gas stream with superficial velocity higher than the onset of mist flow velocity (υ_{crit}) is able to cause liquid carry-over ($\upsilon_{sg}>\upsilon_{crit}$).

$$\upsilon_{crit} = 0.6818\left(6\, W_C \frac{\rho_l-\rho_g}{\rho_g^2}\right)^{0.25} \tag{1}$$

Where W_c is Weber number. The gas superficial velocity in GLCC body is also defined:

$$\upsilon_{sg} = {Q_g}\Big/{\frac{\pi}{4} d^2} \tag{2}$$

Equipping GLCC separator with a gas control valve and a liquid trap on gas leg could control the function of separator or/and avoid entering any liquid droplet into gas outlet or leg. Furthermore high liquid flowrate intensifies the swirl flow regime which could drag gas bubbles into liquid outlet. Control of liquid level by placing a control valve on liquid leg helps to solve this problem. Liquid level must be located approximately 1 to 3 L/D below the inlet otherwise the gas may blow through the liquid and causes liquid carry-over. Liquid level more than 3 L/D above the liquid outlet is assumed as safety margin for gas carry-under prevention. Additionally, the properties of swirl flow which is directly depends on gas and liquid flowrates determine this safety margin. Understanding the effect of different parts of separator and their geometries on the operational function leads to improve the separation efficiency. (Shoham et al. 1998, Movafaghian et al. 2000)

The aim of this work is to investigate the effects of different parameters on the performance of GLCC separators to reach the optimum and proper design for the oil and gas field condition.

Litretaure Review

Since 1996 till now, Tulsa University Separation Technology Project (TUSTP) team (Kouba et al. 1995, Marti et al. 1996, Arpandi et al. 1996, Shoham et al. 1998, Movafaghian et al. 2000, Gomez et al 2000) conducted the majority of researches on GLCC separators. Besides several studied have been done around the subject of GLCC separators over last two decades by other researchers. For example, Li et al. 2011 investigated U-shape transition zone and carried out numerical computation in nearby newly design column of gas-liquid cylindrical cyclone body. Hreiz et al. 2011 continued numerical investigation and tried to get better understanding about swirling flow nearby nozzle inlet. Liu et al. 2012 reported their experiments about Liquid-Liquid Cylindrical Cyclone (LLCC) separators. Also, their numerical simulation predicted values with a good agreement compare to experimental data. Later, Hreiz et al. 2014 in two separated works investigated the effect of nozzle design and swirling flow characteristic on GLCC performance. They stated that the geometry of nozzle directly influences the characteristic of swirl flow and a double inlet can fix nozzle restriction. They also concluded that multiple tangential inlets can improve separation efficiency due to creating swirl motion in cyclone body.

Van Sy 2016 determined the effect of nozzle inlet angle on GLCC function. Although it was proven 27° as the optimum nozzle angle for GLCC separator in TUSTP reports. However, Van Sy 2016 predicted the flow pattern for different angle by a numerical study. After that Ghasemi et al. 2016 tried to find optimum design for GLCC separator. They reported optimum point for liquid cary-over with varing specifics of different GLCC parts such as body diameter, inlet width and angles. Then Kristoffersen et al. 2017 worked on control systems and presented a feedbacks linearizing control to robust against variation in GLCC separators. Their control algorithm was based on feedback from liquid level and gas pressure in separator body column. Moreover Zhu et al 2018 investigated the effect of lower outlet on flow field of GLCC. They mentioned single rectangular outlet provides a steady flow and makes a huge backflow zone which help to inhance the separation efficiency. Table 1 shows the summery of recent studies about cyclone separator.

Table 1—Literature review summary

(TUSTP)	1996-2000	Present and introduce GLCC separator to industry for first time
Li et al.	2011	Investigate U-shape transition zone
Hreiz et al.	2011	Numerical investigation over swirling flow nearby nozzle inlet
Liu et al.	2012	Experiments study about Liquid-Liquid Cylindrical Cyclone (LLCC) separators
Hreiz et al.	2014	Investigate the effect of nozzle design and swirling flow characteristic on GLCC performance
Van Sy	2016	Study the effect of nozzle inlet angle on GLCC function
Ghasemi et al.	2016	Find optimum design for GLCC separator
Kristoffersen et al.	2017	Present a feedback linearizing control to robust against variation in GLCC separators
Zhu et al.	2018	Study the effect of lower outlet on Floe field of GLCC

Method

All experiments were conducted on a two phase flow set-up within the Research Center of the Ahwaz Faculty of Petroleum, Iran. The experiment set-up is shown in Figure 2. Details of the experimental facilities configuration and their functions are presented in the following section. The set-up consists of two-phase flow loop with three connected sections,

1. Metering Section and
2. Mixing Section
3. GLCC separator Test Section.

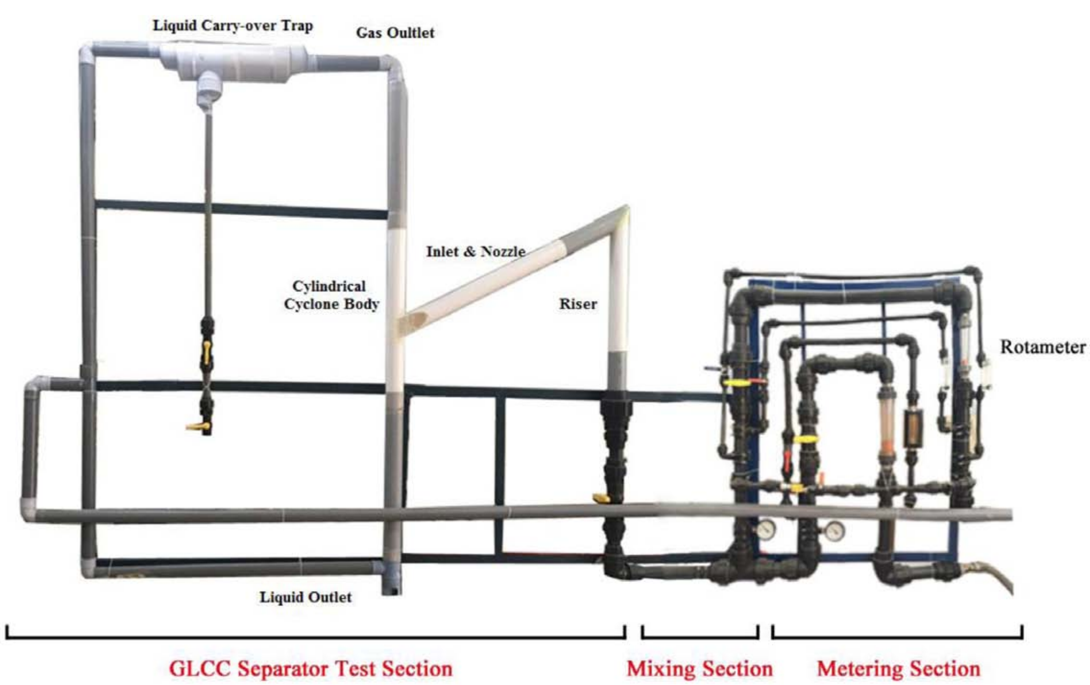

Figure 2—Experiment set-up

Metering section – The responsibility of this part of the loop was to measure and conduct each single phase stream to the mixing section. Two separated single lines was designed to provide gas and water per required phases from air compressor and centrifugal pump. The air compressor had the capacity of 250 m^3/hr at 80 psi and the liquid pump had a rate of 7.2 m^3/hr and an 80-liter storage tank. Five rotameters (two rotameters for the liquid phase stream and three rotameters for the gas phase stream) were used to measure the flowrate of each phase. The measuring system was able to measure the flowrates in range of 0.1 up to 1 m^3/hr for gas phase and 0.12 up to 1.32 m^3/hr for liquid phase. Also in every elbow and downstream of facilities a ball valve is located for safety and better control over the loop system. In addition two check valves are used after feeders to prevent backflow.

Mixing section - After the metering each single phase, the gas and liquid streams were than combined together in a mixing part to be delivered to the test GLCC separator section. A 25.4 mm diameter hose which has 45 holes with 1 mm diameter spaced equally in 3 columns over a length of 100 mm, is used as mixer. The gas was introduced to the liquid stream by the holes on the hose which was placed into the liquid pipe for better circumference mixing effect. Also a static mixer which was consisted of three spiral plate, located after this part along the two phase line to guarantee the uniformity of mixture. Then, two-phase flow regimes are created due to the flow rates of fluids in the GLCC separaror test section.

GLCC separator test section - A GLCC separator can be divided to four main part: 1.The inlet nozzle 2.The cylindrical cyclone body 3.The liquid outlet and leg 4.The gas outlet and leg which includes a liquid carry-over trap. The experimental diagram of GLCC test separator is shown in figure 3. The inlet of this test GLCC separator is a 76.2 mm diameter pipe which is connected to the main body of separator through a sector-slot/plate configuration with a nozzle area 25% of the inlet pipe cross-sectional area. 27 degree is chosen as optimum inlet degree for the most efficient flow circulation into main body.

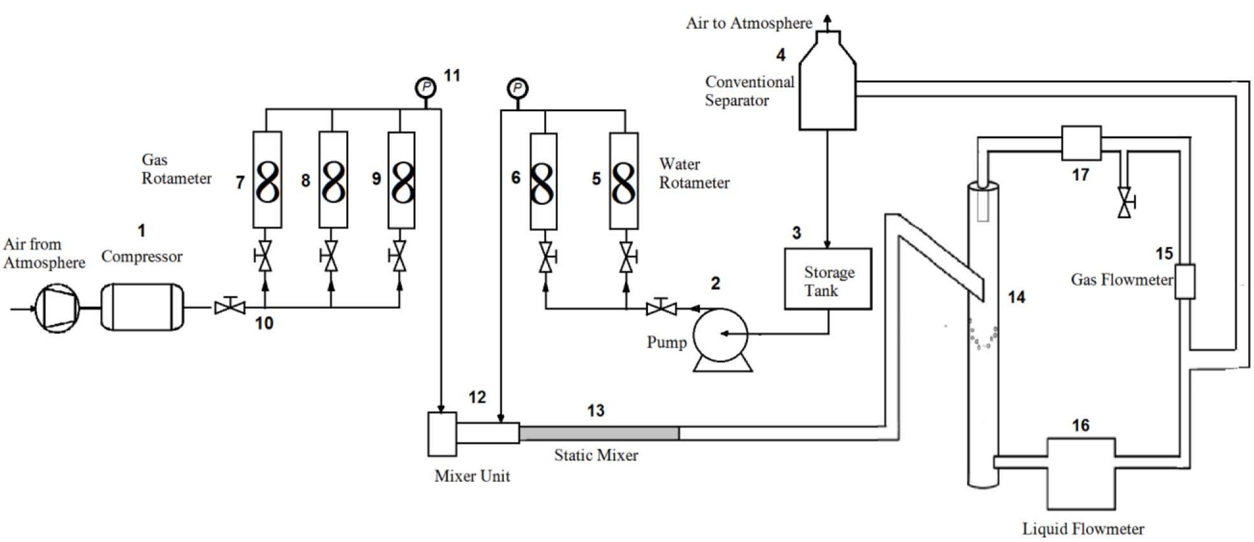

Figure 3—Experimental diagram of GLCC separator

The Cylindrical cyclone body has a height of 2.25 meter and diameter of 76.2 meter. The internal diameter of liquid and gas outlet are also 50.8 mm. The gas outlet includes a liquid carry-over trap with 152.4 mm diameter that is connected to the leg with diameter of 50.8 mm. It helps to measure the amount of liquid carry-over when the separator function is out of operational performance range. This amount of liquid remains in a pipe that was equipped with a valve just after the liquid trap. A mesh that installed at the end of the liquid trap to separate the liquid droplets from the gas stream. After the GLCC separator section, the liquid and gas transferred to a conventional separator section. In this section, the gas was vented to the atmosphere and the water was returned to the pump storage tank to complete the cycle.

As mentioned before a GLCC consists of different parts such as a two-phase inlet measurement system, a vertical column, two horizontal outlet for gas and liquid. The diameter and length of each section of GLCC system can affect the capacity and quality of separation performance of gas and liquid. Field conditions determines the operational flow domain and capacity of GLCC. Hence, the optimum and proper separator must be designed to be compatible with field conditions.

Field condition compromise wide range of parameters including flow rate of live oil and GLCC characteristics. Therefore, the study of GLCC separator in the laboratory is necessary to investigate the effect of different operating parameters on its performance. To study the denoted parameters, GLCC test loop has been built to determine the flow capacity and the range of operating condition.

The best operating range is where the equilibrium liquid level placed below the inlet and between 1 L/D and 3 L/D of separator column. If it pass the inlet it causes liquid carry over and if it settles below the 3 L/D it will create gas carry under in the separation.

Thus the equilibrium liquid level was measure for different range of liquid and gas flowrates. In this work the gas superficial velocity was set between 0.3 and 6 meter per second and for each gas superficial velocity, liquid superficial velocity was changes from 0.3 to 3.3 meter per second. After that, different parts of test separator were changed and their effect on the operating range of the separator was observed. These changes include the following: 12.7 mm reduction in size of inlet diameter, 5 mm reduction in size of the liquid outlet diameter, 5 mm reduction in size gas outlet diameter, 0.12 m reduction in gas column length, 25.4 mm reduction in column diameter size and 1.4 m increment in outlet length.

The study of these properties determines the role and importance of effective parameters in improving the performance of GLCC separator. Therefore, in order to conduct comprehensive study on the denoted parameters, new software has been developed based on the hydrodynamic model which was presented by TUSTP team, with Visual Basic program. (Kouba et al. 1995, Arpandi et al. 1996). And experimental data on the GLCC test loop were modeled with developed software.

Results

In the following, the effects of changes in different parts of GLCC separator are investigated and observation will be reviewed and discussed in detail.

Original test GLCC

In order to conduct comprehensive studies to cover a wide range of operating condition, 18 different gas and liquid flowrates are selected to examine the equilibrium liquid level of our test GLCC separator. For test that fluid inlet height to the GLCC column was 1.36, the equilibrium level must stays between 0.42 to 0.84 m of the body column.

The Liquid level was placed for some test flowrates between these operating condition domains. But for some other flowrates, liquid level was pleased within the proper range of operating domain of the GLCC.

It is clear that increasing in gas flowrate reduces the equilibrium level in body of GLCC separator. The accumulated gas in the body of GLCC push the liquid level down and may carry gas through the liquid outlet. On the other hand, increasing liquid flowrate increases the accumulated liquid volume in the GLCC body and rises the liquid level. Therefore, tolerance of liquid and gas flowrates should be balanced. For a better operating performance of GLCC separator, the changes should reduce the slope of these curves and bring them closer together each other. Understanding the effect of these changes in physic of GLCC helps us to design a proper separator according our operating field conditions. The liquid equilibrium level for original test GLCC for mentioned flowrates are illustrated in figure 4.

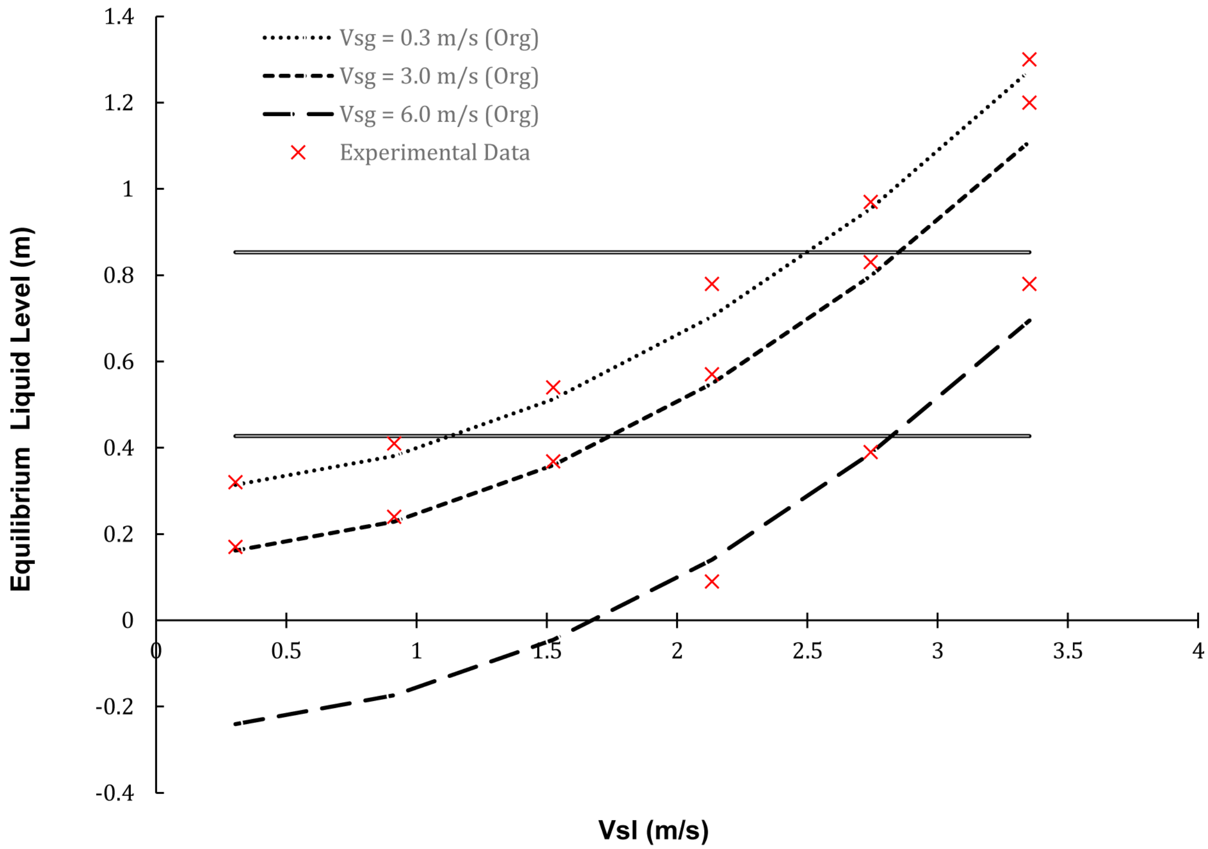

Figure 4—Equilibrium level liquid for original test GLCC

Reducing the Inlet Diameter

In this section, the effect of inlet diameter on the performance of GLCC with a decrease of 12.7 mm was investigated. Reducing the inlet diameter causes the multiphase flow stream be more effective when entering to the body of the GLCC column. Reducing the inlet diameter increases both the phase velocity and the centrifugal force. That intensifies the performance and quality of the phase separation in GLCC separator.

Figure 5 shows the effect of reducing outlet diameter. The curves become closer to each other and their slope decreased. The results of hydrodynamic model predicted accurately experimental data of this change. The enhanced effect is more obvious in high gas and liquid flowrates. Since high centrifugal force has a significant effect on those flowrates. This proves that reducing the inlet diameter in the GLCC has a positive impact on the performance and improve its domain to accept more gas and liquid flowrates.

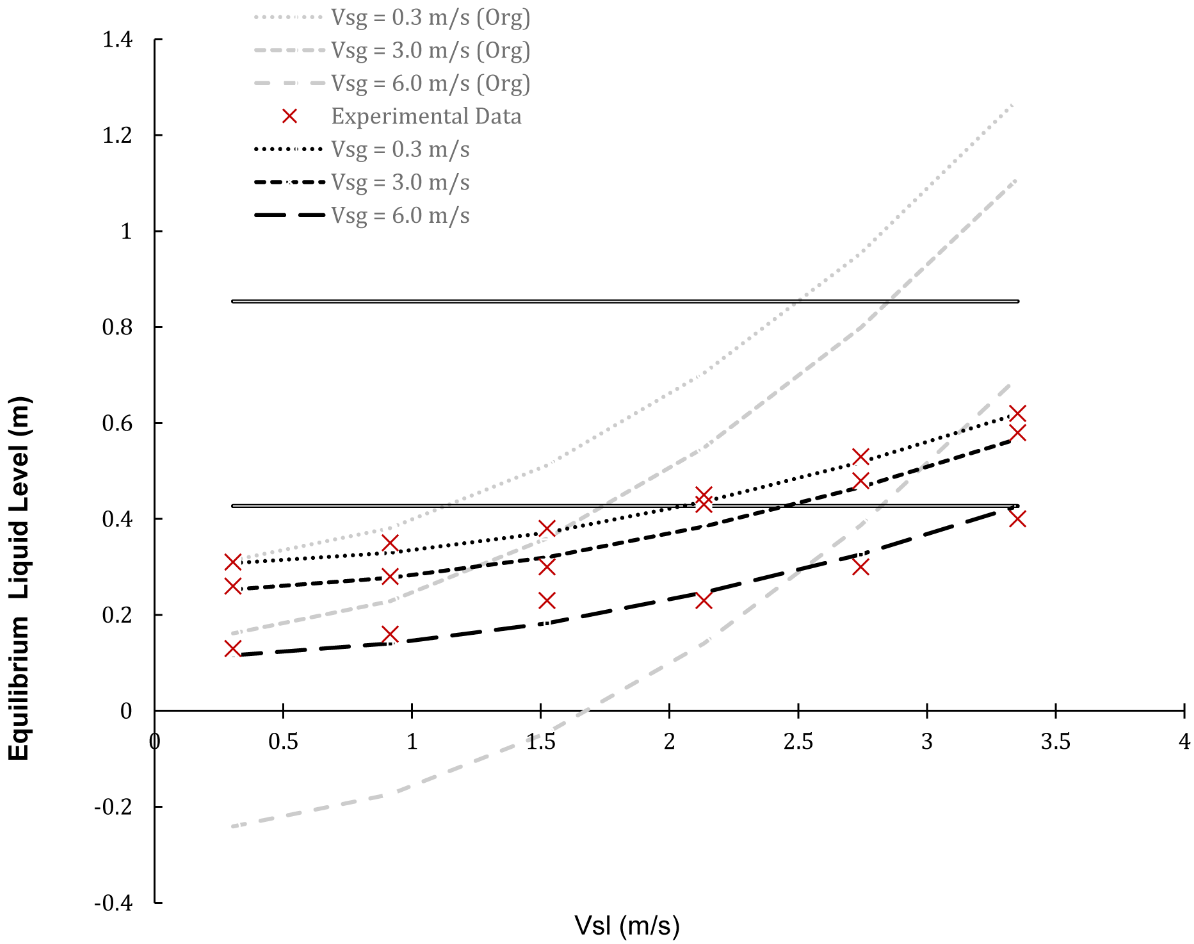

Figure 5—Equilibrium liquid level in test GLCC with 12.7 mm reduction in inlet diameter

Reducing the Liquid Outlet Diameter

As it was discussed, the accumulated liquid in the body of GLCC increases the equilibrium liquid level. Reducing the liquid outlet diameter causes the liquid volume drain slower than normal condition. The gate valve can turn this responsibility to become a simple passive control for equilibrium liquid level. But it can be effective only when gas flowrate are high. Otherwise in high liquid flowrates it can cause liquid carry over in the GLCC separator.

Figure 6 shows the modeling results of a 5 mm reduction in liquid outlet diameter. This change helps the high gas velocity curve move and placed in the acceptable liquid level domain but this fact has a negative effect on the low gas flowrates with high liquid flowrates points. In total, reducing the liquid outlet diameter reduces the performance of the GLCC separator. It can be used in special situation to control liquid level.

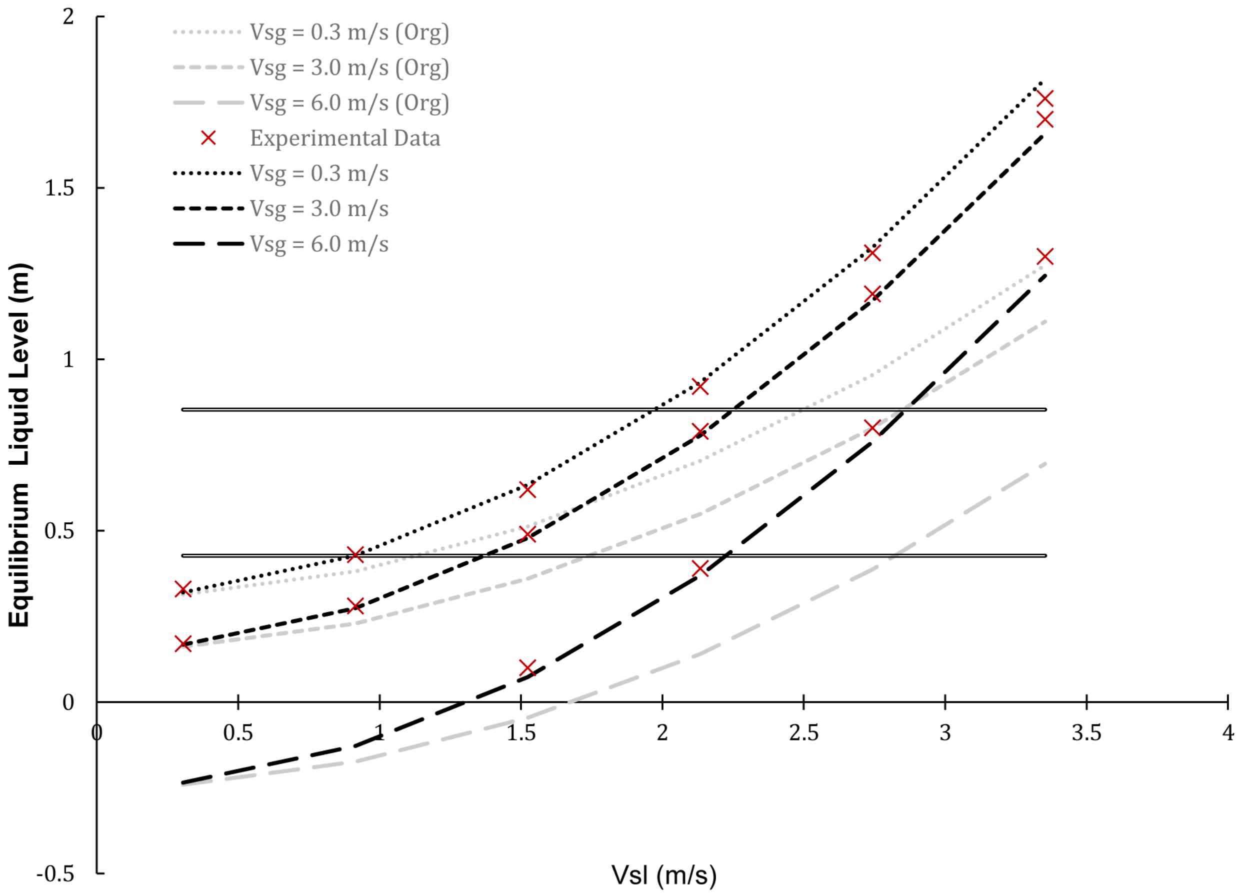

Figure 6—Equilibrium liquid level in test GLCC with 5 mm reduction in the liquid outlet diameter

Reducing the Gas Outlet Diameter

Another sensitivity to study the different parameters on the performance of GLCC was reducing the gas outlet that increases the accumulated gas volume in the GLCC body column. As mentioned before this accumulation push the liquid level down. Again a gate valve placed on the gas outlet leg can play the role of a passive control system simply. Figure 7 shows the result of experimental data and modeling for reducing gas outlet diameter. This change pushes the curves down except the low gas flowrate curve. Because in low gas flowrate there is no enough force to accumulate the gas in the separator. Of course if the gas outlet diameter is further reduced, then, it can push this curve down like other curves.

It is clear that this change make the curves further in compression with normal condition and move them below their primary place. It can be useful to control the equilibrium liquid level when the separator is dealing with high liquid flowrates.

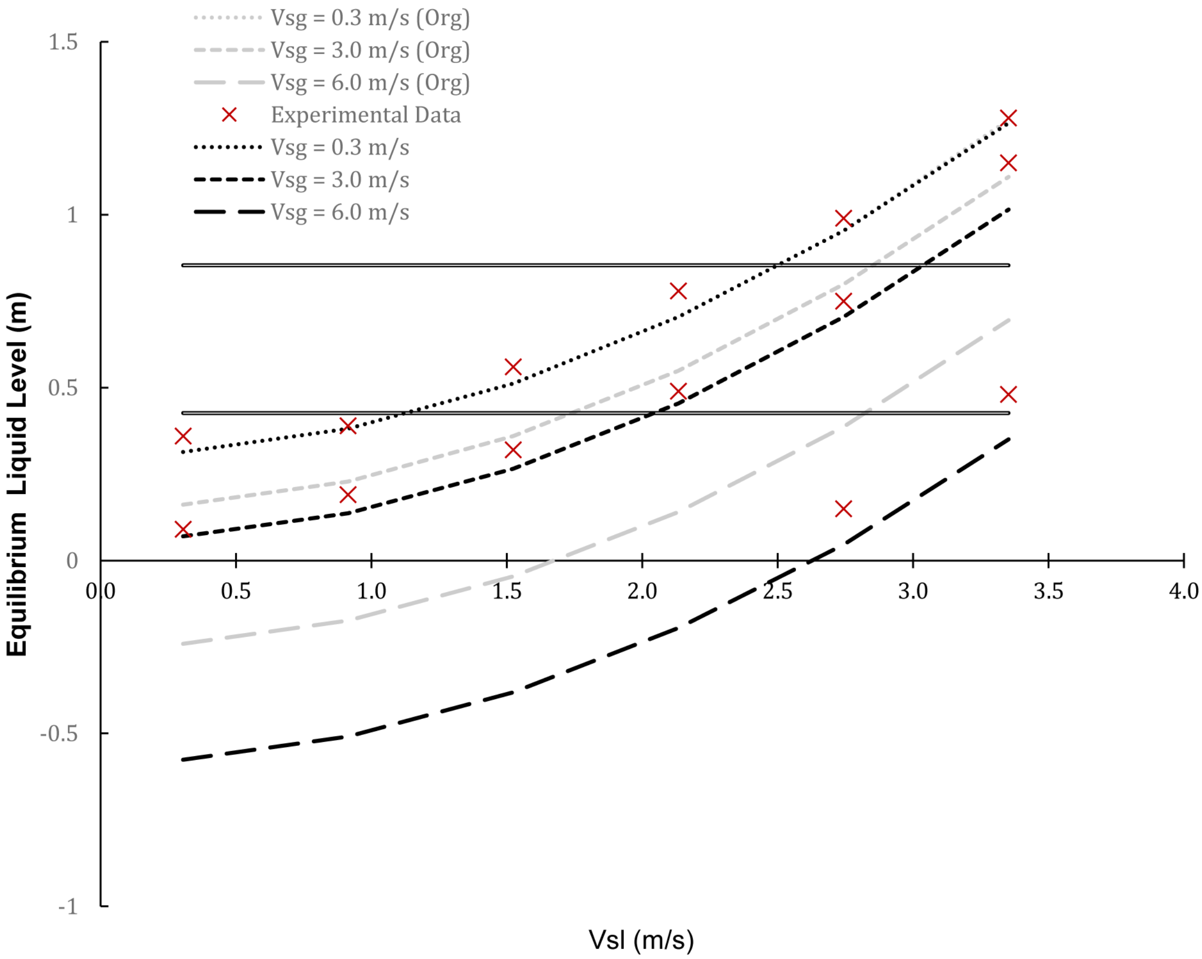

Figure 7—Equilibrium liquid level in test GLCC with 5 mm reduction in the gas outlet diameter

Reducing the Gas Column Length

The effect of reducing gas column length on the performance of GLCC was investigated. Figure 8 shows the results of experimental data on the equilibrium liquid level when the gas column length reduced to 0.12 m. However there is no appreciable change in curves and it indicates that changes in gas column have no major effect on separator performance in experiments that this paper run. In the hydrostatic model, if the distribution occurs, a drop of liquid is thrown into the gas column and gas carries it to the gas outlet. Therefore, reducing the length of the gas column increases the chance of liquid carry over. This phenomena is more difficult in high gas flowrates and when the equilibrium liquid level is close to the inlet. This is problem due to puffing up the gas into the liquid level. However compactness of a GLCC separator always is important topic but for more tolerance with field condition reducing the length of gas column is not recommended.

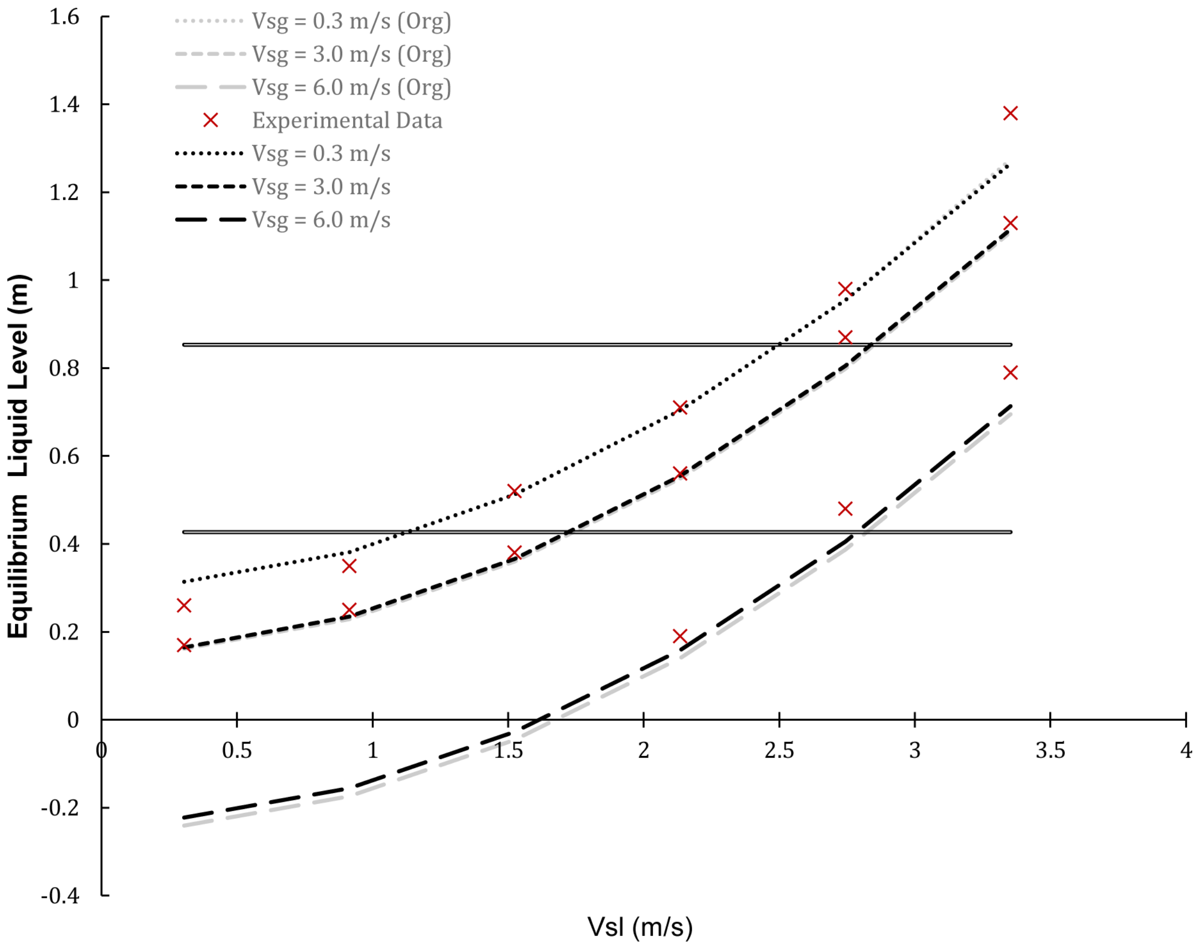

Figure 8—Equilibrium liquid level in test GLCC with 0.12 m reduction in the gas column length

Increment in Outlet Leg Length

In this section, the effect of increasing in the length of outlet leg is studied. The only thing that matters when length of horizontal outlet pipe increases is the friction force rises and resistant against the flow movement in the pipelines. So, this change absolutely has a negative impact on the physical size of the GLCC.

Modeling of experimental result is shown in figure 9. Any increasing in length of outlet leg increases the curves slope. This change in slope in low gas and liquid flowrates is not seen due to low friction in pipelines. Other interesting result is that in high gas flowrates and low liquid flowrates the gas friction has greater effect than liquid friction. That increases accumulated gas volume in GLCC body and pushes the equilibrium liquid level down. Generally, increasing in the length of outlet leg rises the equilibrium liquid level.

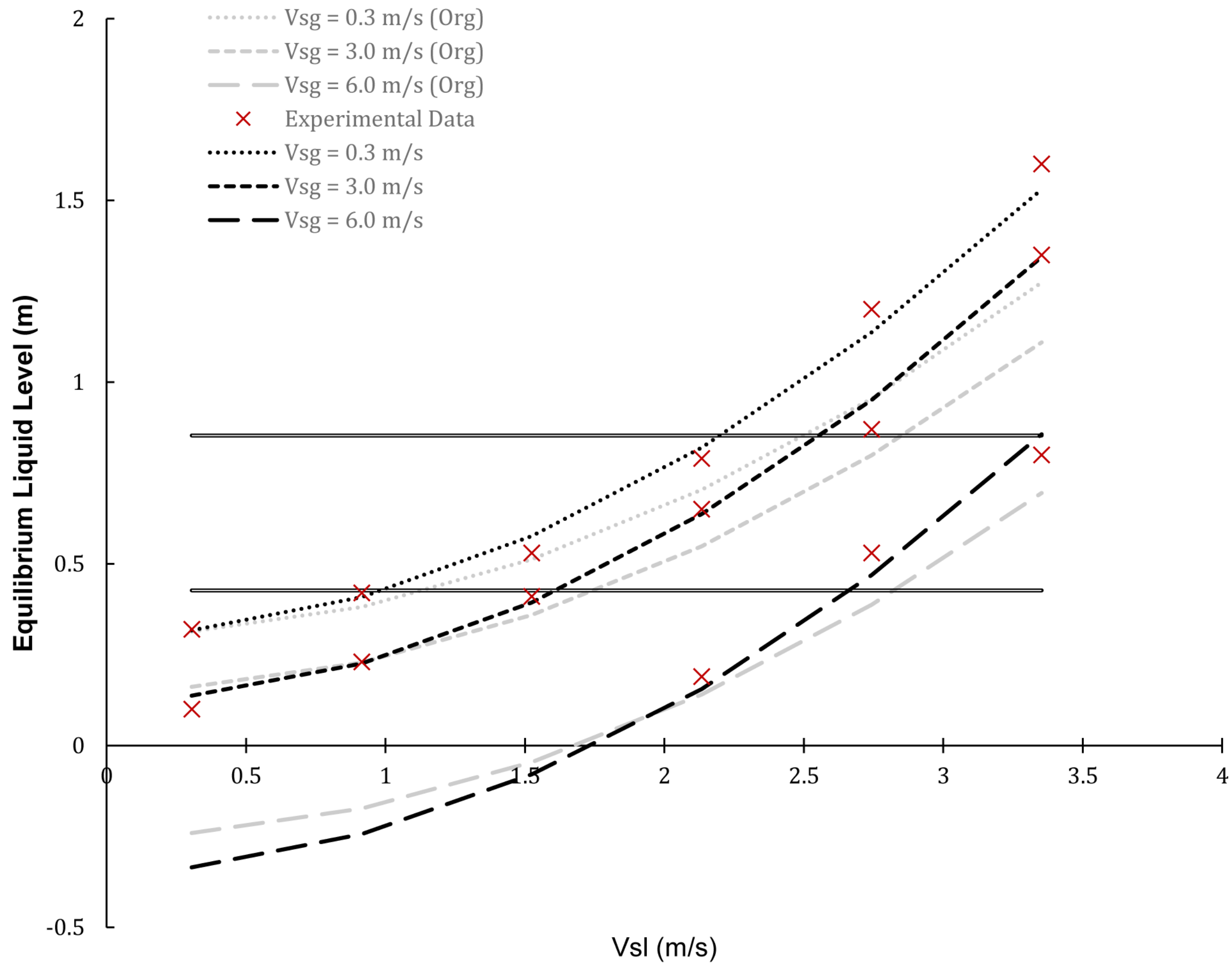

Figure 9—Equilibrium liquid level in test GLCC with 1.4 m increment in outlet leg length

Reduction in Column Diameter

It seems that reduction in column diameter has negative effect due to nature of vortex flow. A vortex is defined as a circular liquid streams with narrow gas core in center of liquid streams. In high liquid flowrates, any decreases in column diameter causes the gas core penetrates more into the liquid phase. Thus in the worst condition the gas phase can reach the liquid outlet and gas carry through occurs.

Figure 10 shows that in high gas and liquid flowrates equilibrium liquid level is raised. Totally this change in column diameter has negative effect on GLCC performance but it is not quite sure any increasing in GLCC body diameter helps its performance. The nature of vortex flow is much complex and further studies are doing through this issue.

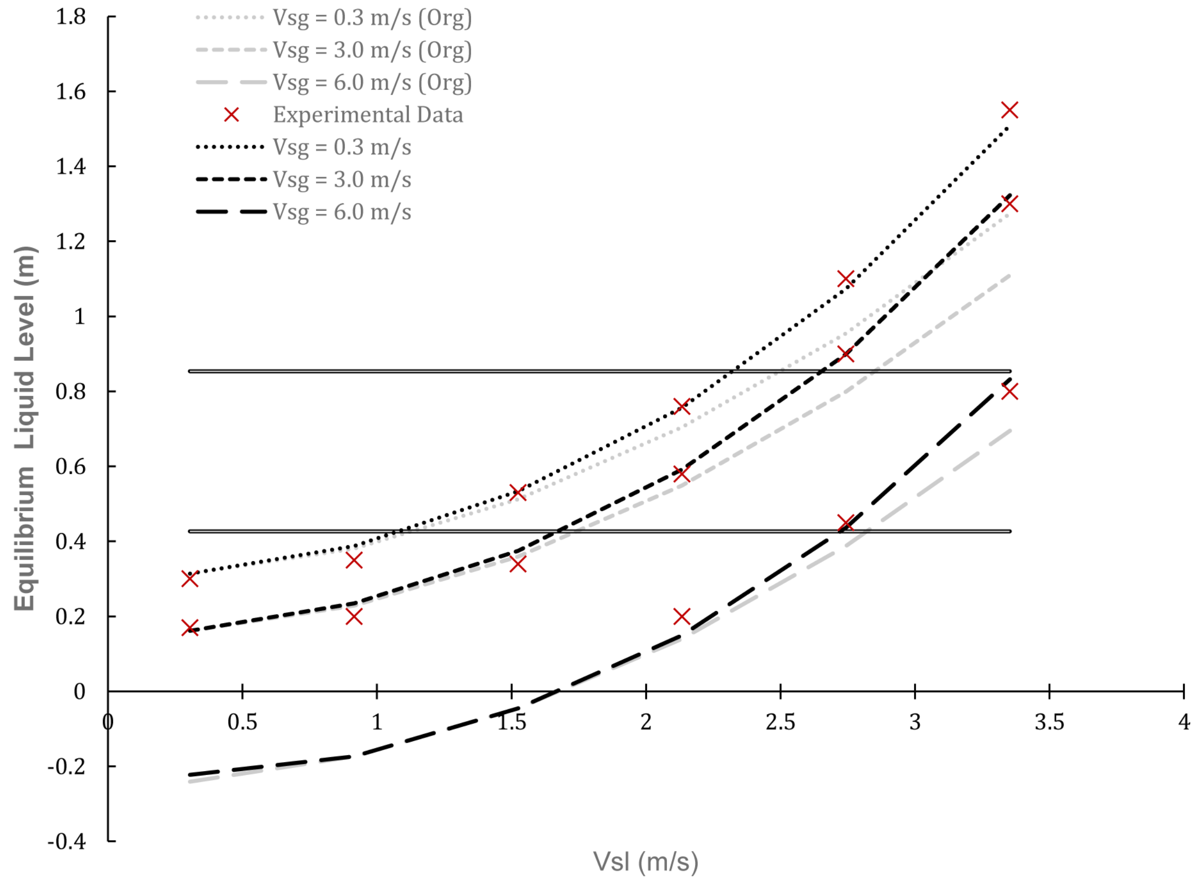

Figure 10—Equilibrium liquid level in test GLCC with 25.4 mm reduction in column diameter

Conclusion

The performance of a test GLCC was investigated by changing in different parts of a separator. Following conclusion are conducted through these changes.

- Reduction in inlet diameter helps the GLCC separator performance. It allows more gas and liquid flowrates enter the separator for total separation by improving the centrifugal effect on liquid and gas phase.
- Reduction in liquid outlet diameter has negative effect in GLCC flowrates domain but this reduction can be used to control the equilibrium liquid level by a gate valve in liquid outlet leg.
- Reducing in the gas outlet diameter has negative effect on GLCC performance. But in some situations controlling the amount of accumulated gas in GLCC can avoid liquid carry over in the system.
- Reducing the gas column length shows no effect on the separator flowrates domain.
- Increasing in length of outlet legs increases the friction force and limited the separator performance.
- Reduction in separator body diameter raises the chance of liquid carry over and gas carry under and has negative effect on flowrates domain.

References

1. O. Shoham and G. Kouba, "State of the art of gas/liquid cylindrical-cyclone compact-separator technology," *J. Pet. Technol.*, vol. **50**, no. 07, pp. 58–65, 1998.

2. I. Arpandi, A. R. Joshi, O. Shoham, S. Shirazi, and G. E. Kouba, "Hydrodynamics of two-phase flow in gas-liquid cylindrical cyclone separators," *SPE J.*, vol. **1**, no. 04, pp. 427–436, 1996.
3. S. Movafaghian, J. A. Jaua-Marturet, R. S. Mohan, O. Shoham, and G. E. Kouba, "The effects of geometry, fluid properties and pressure on the hydrodynamics of gas–liquid cylindrical cyclone separators," *Int. J. Multiph. Flow*, vol. **26**, no. 6, pp. 999–1018, 2000.
4. L. E. Gomez, R. S. Mohan, O. Shoham, and G. E. Kouba, "Enhanced mechanistic model and field-application design of gas/liquid cylindrical cyclone separators," *Spe J.*, vol. **5**, no. 02, pp. 190–198, 2000.
5. G. E. Kouba, O. Shoham, and S. Shirazi, "Design and performance of gas-liquid cylindrical cyclone separators," in Proceedings of the BHR Group 7th International Meeting on Multiphase Flow., Cannes, France, 1995, pp. 307–327.
6. S. Marti, F. Erdal, O. Shoham, S. Shirazi, and G. Kouba, "Analysis of gas carry-under in gas-liquid cylindrical cyclones," in Hydrocyclones 1996 International Meeting, St. John College, Cambridge, England, April, 1996, pp. 2–4.
7. W. A. Chirinos, L. E. Gomez, S. Wang, R. Mohan, O. Shoham, and G. Kouba, "Liquid carry-over in gas-liquid cylindrical cyclone compact separators," in SPE annual technical conference and exhibition, 1999.
8. C. LI and J. XIONG, "Numerical Computation of New Gas-liquid Cylindrical Cyclone Separator [J]," *Oil F. Equip.*, vol. **2**, p. 10, 2011.
9. R. Hreiz, C. Gentric, and N. Midoux, "Numerical investigation of swirling flow in cylindrical cyclones," *Chem. Eng. Res. Des.*, vol. **89**, no. 12, pp. 2521–2539, 2011.
10. H. Liu, J. Xu, J. Zhang, H. Sun, J. Zhang, and Y. Wu, "Oil/water separation in a liquid-liquid cylindrical cyclone," *J. Hydrodyn.*, vol. **24**, no. 1, pp. 116–123, 2012.
11. R. Hreiz, R. Lainé, J. Wu, C. Lemaitre, C. Gentric, and D. Fünfschilling, "On the effect of the nozzle design on the performances of gas–liquid cylindrical cyclone separators," *Int. J. Multiph. Flow*, vol. **58**, pp. 15–26, 2014.
12. R. Hreiz, C. Gentric, N. Midoux, R. Lainé, and D. Fünfschilling, "Hydrodynamics and velocity measurements in gas–liquid swirling flows in cylindrical cyclones," *Chem. Eng. Res. Des.*, vol. **92**, no. 11, pp. 2231–2246, 2014.
13. L. Van Sy, "Influence of inlet angle on flow pattern and performance of gas-liquid cylindrical cyclone separator," *Part. Sci. Technol.*, vol. **35**, no. 5, pp. 555–564, 2017.
14. A. Ghasemi, M. Shams, and M. M. Heyhat, "A numerical scheme for optimizing gas liquid cylindrical cyclone separator," *Proc. Inst. Mech. Eng. Part E J. Process Mech. Eng.*, vol. **231**, no. 4, pp. 836–848, 2017.
15. T. T. Kristoffersen, C. Holden, and O. Egeland, "Feedback linearizing control of a gas-liquid cylindrical cyclone," *IFAC-PapersOnLine*, vol. **50**, no. 1, pp. 13121–13128, 2017.
16. W. Zhu, L. Hu, and X. Zhang, "The effects of the lower outlet on the flow field of small gas–liquid cylindrical cyclone," *Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci.*, p. 0954406218768838, 2018.