A STUDY OF IN-LINE TYPE SUBSEA SEPARATOR FOR MULTIPHASE FLOW OF OIL AND GAS WELLS

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ABSTRACT

The implementation of subsea separation and liquid boosting is becoming a common development scheme for the exploration of deep water fields. Subsea separation is an attractive and economic solution to develop deep offshore fields producing fluid without hydrate or wax. The subsea separation system should be reliable to ensure successful operation in a wide range of 3-phase flow regime, without the need for developments. A subsea separator can avoid or simplifying costly surface platforms of floating vessels, as well as being an efficient tool to enhance hydrocarbon production. One solution of interest is the separation and re-injection of water at the seabed to avoid bringing the water up to the surface facility. In this study, multiphase flow characteristics inside in-line type subsea separation systems are investigated for the design of a subsea separation system. The separation efficiency of the subsea separator is determined through experiments that are the liquid-gas phased separation. Also internal swirl element (ISE) modelling of the separator was optimized. The analysis results were utilized to improve the reliability and efficiency of the subsea separation system.

Keywords: in-line type separator, multiphase flow simulation, numerical analysis.

1 INTRODUCTION

Subsea production systems are wells located on the sea floor, as opposed to the surface. Subsea systems are typically used at depths of 500 meters or more and do not have the ability to drill, only to extract and transport. Some wells have a pure gas production, which can be taken directly for gas treatment and compression. More often, the well produces a combination of gas, oil and water, with various contaminants that must be separated and processed. The production separators come in many forms and designs with the classic variant being the gravity separator, but the recent trend is in-line type separator [1].

In recent years, it has been a trend to move several production facilities such as separator that were processed at sea to subsea (Fig. 1). Subsea separator is essential equipment for offshore plant it performs the oil and gas separation process from crude oil in the subsea. Also, it can costly avoid or simplify surface platforms of floating vessels, as well as being an efficient tool to enhance hydrocarbon production. Generally subsea separation system is divided into gravity type and in-line type depends on water depth. In the case of deep sea more than 1,000 m depth due to manufacturing cost and safety problem, the development of separator in compact in-line type have been required [2]. Dirkzwager [3] designed an in-line liquid-liquid separator. Subsequently, single-phase experiments were carried out for this separator [4]. Also, Slot et al. [5] discussed the flow patterns observed in the newly designed separator for both single-phase water and two-phase oil-water flows. And Kim et al. [6], multiphase flow characteristics inside in-line type subsea separator are investigated for the design of compact in-line type subsea separation system.

In this study, numerical analysis research was conducted to analyze multi-phase flow characteristics inside in-line type subsea separation system. Especially, it is focused on 2-phase separation of gas-liquid mixtures in separation system. Also internal swirl element

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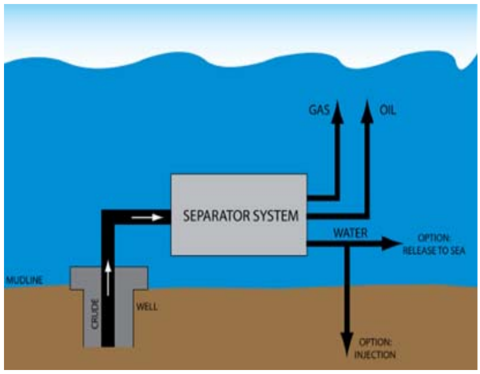


Figure 1: Schematic diagram of subsea separation system.

(ISE) modelling was optimized for separation efficiency and gas to oil ratio. And the result of this study will be utilized to improve reliability and efficiency of gas-liquid separation system.

2 FINITE ELEMENT ANALYSIS OF FIRST SEPARATOR

2.1 Modelling

Fig. 2 is ISE modelling for numerical analysis. The ISE modelling was designed by referring to the previous study [7], [8]. The dimension of the ISE outer diameter is 100 mm and another dimension is recorded in Fig. 2. The pipe length is 2 m and pipe diameter is 100 mm, the ISE is fixed in the pipe. The three cases are compared different vane length and tail length. The basic shape (Case 1) is based to optimize the shape of the ISE for multi-phase separation, the Cases 1–3 are classified by vane length, Case 4–6 are classified by tail length.

2.2 Boundary condition

The physical property of the working fluid and the boundary conditions are summarized in Table 1. The volume ratio of the crude oil and natural gas mixture flowing from inlet was assumed to be 80% of oil and 20% of gas, the oil was set to the continuous phase and the gas was set to the dispersed phase. The inlet flow rate was set to 7 m/s and the outlet was set at atmospheric pressure. For CFD analysis, Eulerian model was applied due to multi-phase fluid analysis. The analysis solver used commercial CFD code ANSYS Fluent 18 version, it was analyzed as single-type separation model.

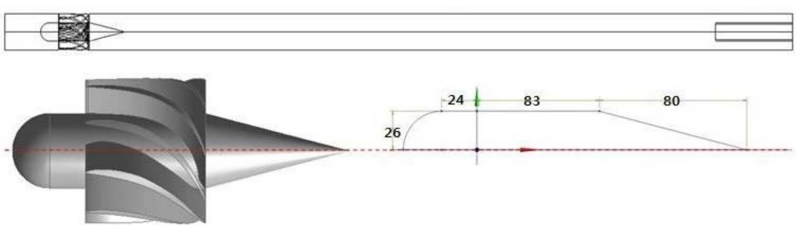


Figure 2: Initial ISE (internal swirl element) modelling.

Table 1: Boundary condition of first separator.

Condition		Value
Mixture	Liquid (water)	80%
	Gas (air)	20%
Inlet (velocity)		7 m/s
Outlet (pressure)		Atmospheric

2.3 Analysis results

As a result of numerical analysis, all cases were separated water and air due to the high speed swirl flow by the ISE. Also, due to the different densities, the natural gas was collected at the center of the pipe and crude oil was rotated and moved on the outer wall of the pipe.

Fig. 3 is vane length optimization analysis result of water volume fraction contour image. The liquid volume was well maintained along the wall surface to the outlet. All cases have a high ratio of gas at the center of the pipe, it has oil going to the edge. Also, 1.5D has best separation and the separation efficiency. So, the basic model should be increased by 1.5 times the vane length.

As the Fig. 4 is tail length optimization analysis result of water volume fraction contour image. Each case has a vortex, caused by tail length. The vortex is affected directly on the separation efficiency. As tail length getting smaller, vortex is reduced and the flow is much stabled.

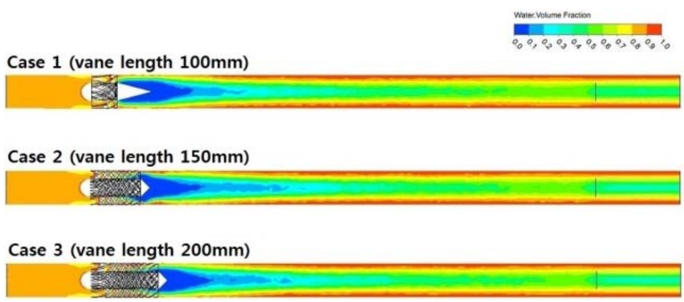


Figure 3: Analysis result of water volume fraction for compare vane length.

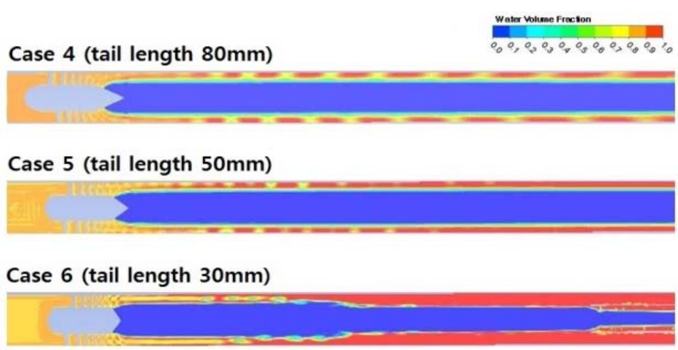


Figure 4: Analysis result of water volume fraction for compare tail length.

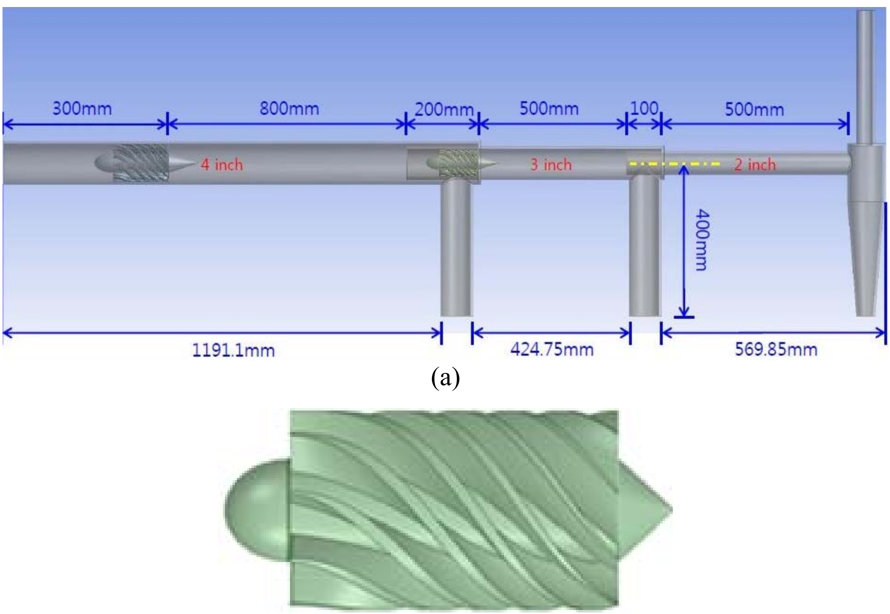
For qualitative assessment, separator calculated separation efficiency. In the result, maximum separation efficiency of Case 1 is 82%, Case 2 is 87% and Case 3 is 93%. The best model is the Case 3, it has about 90% of average separation efficiency. Therefore, the optimal design of ISE vane length is 1.5D and tail length is 3 cm.

3 FINITE ELEMENT ANALYSIS OF SECOND SEPARATOR

3.1 Modelling

Fig. 5 is optimized ISE modelling for numerical analysis: (a) is separator 3D modelling; and (b) is ISE 3D modelling image. The ISE modelling was optimized by referring to the previous study. The dimension of the ISE outer diameter is 100 mm and another dimension is recorded in Fig. 5(a). The pipe length is 2.5 m and pipe diameter is 4–2 inch, the ISE is fixed in the pipe. The three cases are compared different mass flow.

Table 2 showed the boundary condition of the second separator. The optimized ISE is used twice in the second separator, and each case of mass flow and inlet mixture velocity is analyzed to compare with experiment result.



(a)

(b)

Figure 5: Optimized design. (a) Separator modelling; and (b) ISE modelling.

Table 2: Boundary condition of separator.

Condition		Value	
Mixture	Liquid (water)	80%	90%
	Gas (air)	20%	10%
Inlet (velocity)		4–6 m/s	
Outlet (pressure)		Atmospheric	

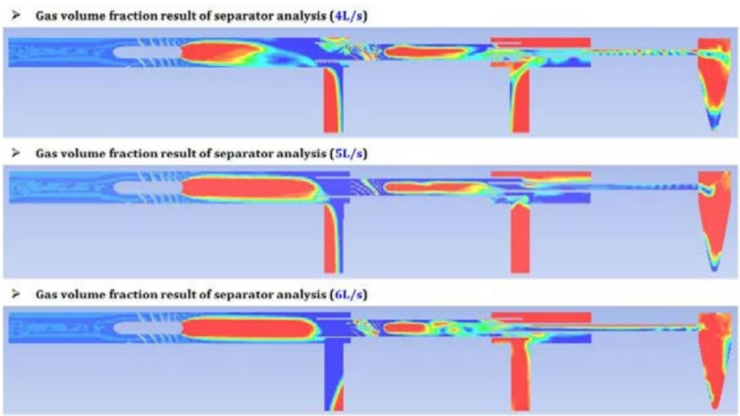
3.2 Boundary condition

The physical property of the working fluid and the boundary conditions are summarized in Table 2. The volume ratio of the crude oil and natural gas mixture flowing from inlet was assumed to be 80% of oil and 20% of gas, the oil was set to the continuous phase and the gas was set to the dispersed phase. The inlet flow rate was set to 4–6 m/s and the outlet was set at atmospheric pressure. For CFD analysis, Eulerian model was applied due to multi-phase fluid analysis. The analysis solver used commercial CFD code ANSYS Fluent 18 version, it was analyzed as double-type separation model.

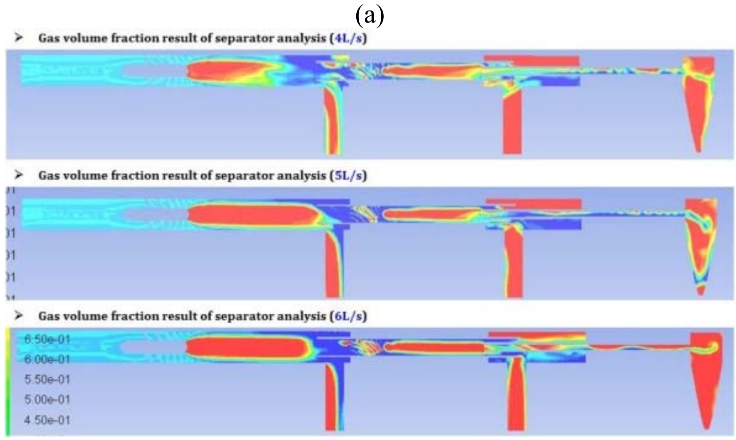
3.3 Analysis results

As a result of numerical analysis, the all cases are separated water and air due to the high speed swirl flow by the ISE. Also, due to the different densities, the natural gas was collected at the center of the pipe and crude oil was rotated and moved on the outer wall of the pipe.

Fig. 6(a) is a water volume fraction of 9:1 ratio and Fig. 6(b) is 8:2 ratio, both of them, the liquid volumes are well maintained along the wall surface to the second separator. All cases have a high ratio of gas at the center of the pipe, it is going to the edge.



(a)



(b)

Figure 6: Analysis result of water volume fraction. (a) 9:1 ratio; and (b) 8:2 ratio.

Fig. 7 is a comparison graph of 9:1 and 8:2 ratio analysis results. It showed the separation efficiency of each outlet. As the result of first outlet, separation efficiency of 8:2 ratio is less than 9:1 ratio. The result of second outlet, highest separation efficiency is 6 L/s model.

4 EXPERIMENT OF SECOND SEPARATOR

4.1 Modelling

Fig. 8 is experiment equipment of in-line type subsea separator. It sets up the same condition with numerical analysis for comparison with the result. The pipe length is 2.5 m and pipe diameter is 4–2 inch, the ISE is fixed in the pipe. The multi-phase liquid is separated by first ISE and the separated liquid flows through the pick-up tube. The remaining multi-phase liquid is separated by second ISE, all of separated liquid is gathered in each box. When the experiment is finished, then each liquid is gathering in the last box.

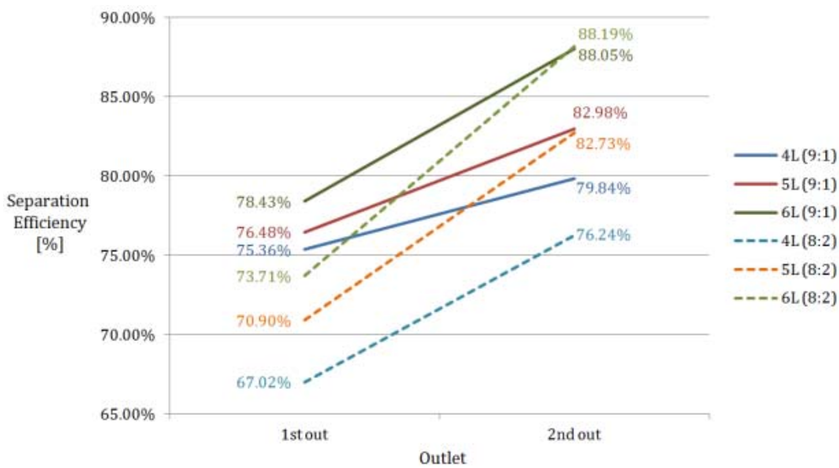


Figure 7: Comparison of 9:1 and 8:2 ratio analysis result.

Figure 8: Experiment equipment of in-line type subsea separator.

4.2 Boundary condition

The physical property of the working fluid and the boundary conditions are summarized in Table 2. The volume ratio of the crude oil and natural gas mixture flowing from inlet was assumed to be 8:2 or 9:1 oil to gas ratio, the oil was set to the continuous phase and the gas was set to the dispersed phase. The inlet flow rate was set to 4–16 m/s and the outlet was set at atmospheric pressure.

4.3 Compare with analysis results

Fig. 9 is experiment result. As the result, all cases are separated water and air due to the high speed swirl flow by the ISE. Also, due to the different densities, the natural gas was collected at the center of the pipe and crude oil was rotated and moved on the outer wall of the pipe.

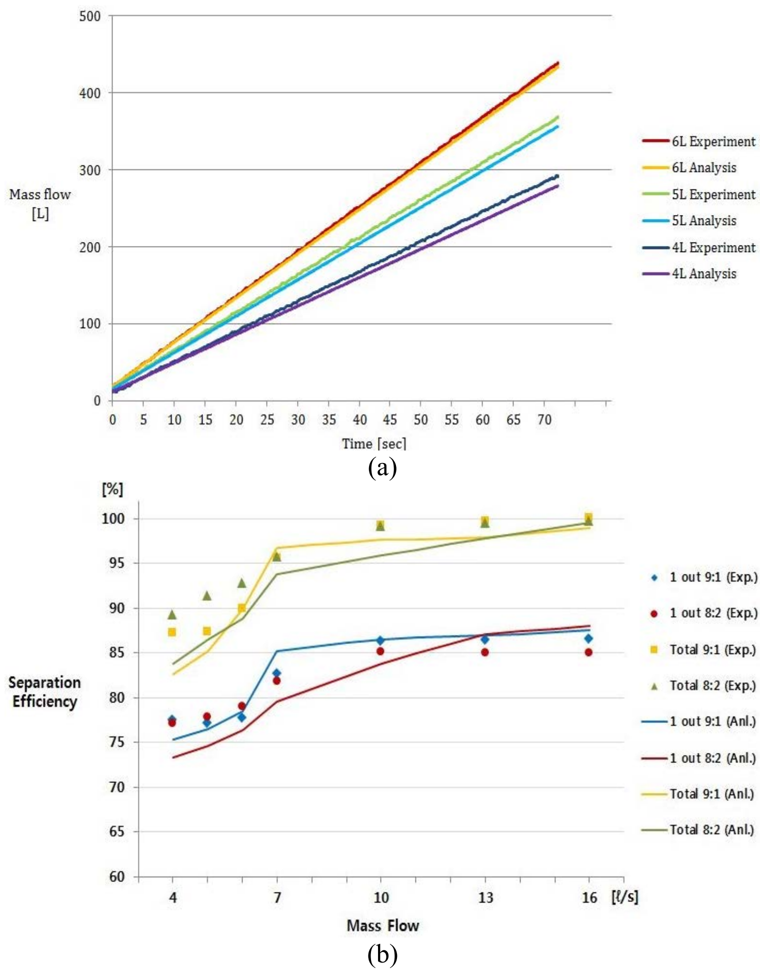


Figure 9: Experiment result of in-line type subsea separator. (a) Mass flow result; and (b) Separation efficiency result.

5 CONCLUSIONS

In this study, the ISE of the in-line type subsea separator was analyzed for shape optimization and through numerical studies on the multi-phase flow were as follows.

The ISE was designed to development of in-line type subsea separator for separating multi-phase fluid. In the analysis result, each case has different vane length and tail length for a comparison. And Case 6 is the optimal design by separation efficiency. This result will use to manufacturing experiment device based on the current optimal model. And the result of this study will be utilized to improve reliability and efficiency of the separation system.

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