3D Modeling and Simulation of Subsea Separation System for Offshore Field Development

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Abstract

Offshore technologies that help to separate oil, gas and water cost-effectively and efficiently have been the focus of the petroleum industry. Subsea processing has become a promising alternative for fields located in difficult settings due to flow assurance problems encountered by surface facilities. This paper seeks to model and construct a 3D subsea separation system coupled to a developed simulator software called Separator Processor (Se-Pro) to simulate and monitor the subsea fluid processing system. The developed computer application is used as a human-machine interface (HMI) to optimally control flow valves automatically or manually for the separated distribution of the fluids into various network facilities. The system may also maintain the safe operation of the processing facilities when unacceptable conditions occur by sounding an alarm to the operator. The subsea processing system on the seabed process segregates fluids into various pipelines for effective flow assurance problems minimization and the produced water is re-injected to improve the reservoir pressure decline. The Se-Pro simulator explores the use of process instrumentation and control principles to monitor a horizontal separator that separates oil, gas, water, and sand slurry. The results show a final rendered work of a subsea processing and production simulator that can work in both automatic and manual modes by adjusting flow control valves and level setpoints of the fluids during processing.

Keywords: Subsea Processing Simulator, Subsea Production System, Flow Assurance, Horizontal Separator, Human Machine Interface.

1 Introduction

In the oil and gas industry, new offshore fields are being developed that use cutting-edge technologies to extract hydrocarbons from deep oceans, where subsea boosting is required to transport the hydrocarbons from the seabed to surface facilities for further processing (Burger *et al*., 2010; Ronald, 2002).

With developments in subsea technologies (Leffler et al., 2011), it is crucial to consider which option is suitable to help operators produce more hydrocarbons cost-effectively and boost productivity (Hong *et al*., 2018; Brantson *et al*., 2022). In recent times, subsea separation is a modern strategy for recovering hydrocarbons from reservoirs with low temperatures and high pressures, where there is a considerable risk of hydrate formation and corrosion, which could damage pipes and disrupt multiphase fluid flow assurance.

Flow assurance is currently a major issue for surface production facilities in deepwater operations (Bai and Bai, 2019). Disposing and handling of excess produced water and sand (Bouquier *et al*., 2007), slows oil production and decreases pipeline network efficiency, as well as affecting multiphase flow assurance, particularly for topside process equipment. Due to the multiple consequences of the multiphase fluid combination, the topside process equipment may be able to handle some flow restrictions for the primary separator, which may not be able to handle an increase in produced water and released overboard, potentially causing environmental damage (Igwe, 2013).

The development of a subsea separation system at the subsea level might potentially handle an increase in generated water and permit it for reinjection by using pumps to enhance reservoir pressure thereby boosting hydrocarbon productivity (Guo *et al*., 2007). A three-dimensional model and Human Machine Interface (HMI) are commonly regarded in the petroleum industry as excellent techniques for visualizing a conceptual framework of how a system must function and deliver outcomes. The creation of a model is a quick and easy way to analyze a problem and assist in the resolution of facility-related difficulties in a 3D environment. An HMI can help people learn more by allowing them to operate and communicate with machines more effectively.

However, one of the challenges for most oil and gas field projects lies in the inability to reproduce and establish a more consistent 3D design guidance to obtain an accurate fore-idea of how subsea separation systems are to be installed and arranged. In order to curb this issue, designing 3D models of subsea separation systems will assist to generate accurate representations of the systems. Further, having a 3D model of a facility provides an easy source of accurate information. It also allows for the evaluation of the potential of 3D model design of subsea processing systems to fuel a successful oil and gas project (Shimamura, 2002).

Therefore, this paper seeks to model and construct a 3D subsea separation system coupled to a developed simulator software called Separator Processor (Se-Pro) to simulate and monitor the subsea fluid processing system. The developed computer application is used as a human-machine interface (HMI) to optimally control flow valves automatically or manually for the separated distribution of the fluids into various network facilities.

This paper is structured into the following sections. Section 2 dwells on the method used to design the subsea separation system simulator. Section 3 states the results obtained from the design as well as the discussion of the results. Section 4 summarizes the major conclusion obtained from the study.

2 Subsea Processing System Design Methodology

2.1 Materials Used

Blender is a free and open-source 3D computer graphics software (Israel, 2020) used for model construction in this study.

2.2 Methods Used

The following procedure illustrates a step-by-step approach used to obtain 3D models from the software for the subsea processing system designs. By default, Blender shows a splash screen when the application opens as shown in the screenshot in Fig. 1.

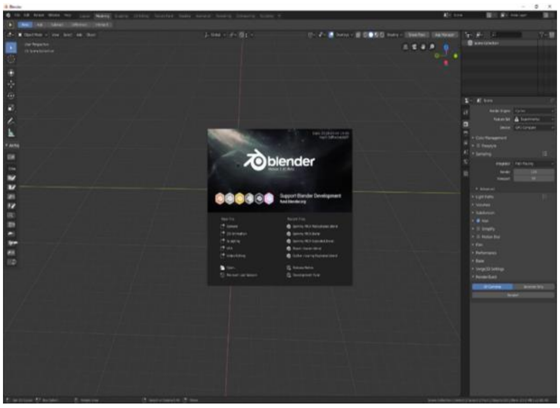


Fig. 1 Blender's Default Launch Interface

2.2.1 Modelling the Separator

i. At the first launch of the blender software, a default cube, camera and light source were displayed on the scene, to model the separator. The default cube was deleted by pressing X;

ii. A UV sphere was added to the scene world by pressing shift + A, then a mesh was selected on the pop-up menu, with the sphere in the scene, the number 3 was hit to enter the front view of the scene world;

iii. While the UV was selected, the R key was pressed while typing the number 90 to rotate the sphere 90 degrees on its axis;

iv. The tab key was pressed while the sphere was selected to enter into the edit mode, and the top half of the sphere was selected by pressing B on the keyboard. The selected top half was then deleted by pressing X;

v. Furthermore, half of the remaining sphere was selected and pulled on the y-axis. With the side selected, the scale was applied to it to shape it into the separator. To fill the top portion of the separator shaped object, the top vertices were selected by pressing the F key to fill it; and

vi. After the separator design was obtained, the other components like the pipeline, x-mas tree, manifold, water injection pump, jumper, flowlines, etc were designed. All operations performed so far to this point were done in Blender's layout and modelling workspaces with python programming codes. Figs. 2 and Fig 3 below show the image sequence of the workflow from Blender and the final untextured image model of the subsea separator.

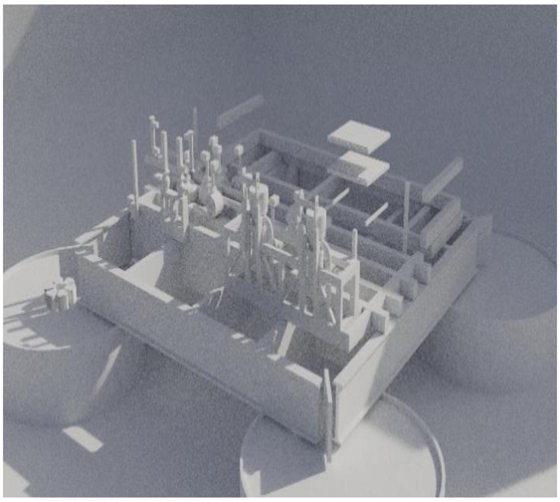


Fig. 2 Initial design of the subsea separator

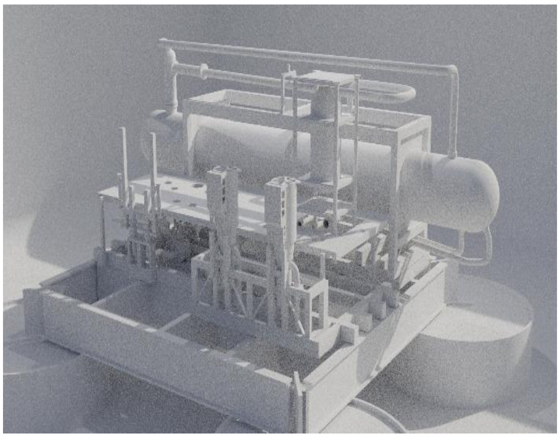


Fig. 3 Final design of the subsea separator.

After the modelling was completed entirely and all the necessary components of the subsea processing systems were installed, materials (colour) were assigned to them to make them look comparable to what they certainly look like in real-world applications.

The simulation application Se-Pro was created primarily to monitor the process control of the horizontal separator at subsea and to inform operators via the HMI to make necessary adjustments when the system is in closed-loop manual control and to automatically modify the system when the system is in closed-loop automatic control mode.

2.2.2 Application Development (Se-Pro*)*

The application development process included the creation of flow charts and the design of the software's graphical user interface (GUI) (Fig. 4). The flow chart for Se-Pro is shown in Fig. 5.

The application's GUI was created using the Windows Form Application user interface and the C# programming language (around 1850 lines of code were written for the primary application interface while 25 lines of code were written for the secondary application interface).

The user interface is divided into two sections: user control and simulation. Windows Form Controls were used to create the user control portion, which included buttons, radio buttons, and text boxes, while progress bars, track bars, and radio buttons were used to create the simulation part. Other controls were used in the GUI design, such as labels, picture boxes, group boxes, tab control, and a timer tool. The GUI also has user controls that accept inputs or actions from users to function as shown in Fig.4 below.

2.2.3 Software Application Testing and Debugging

The testing process was done in two phases. The first phase of testing was carried out throughout the coding stage of the application. It involved debugging which is a process to detect errors in the codes written to run the application and hence, correct them. The second phase of testing was carried out finally to ensure that the application runs effectively and functions properly. To determine graphically the logical steps involved in the development of the Se-Pro application, a standard flowchart was designed using a standard logic flowchart symbol as shown in Fig. 5.

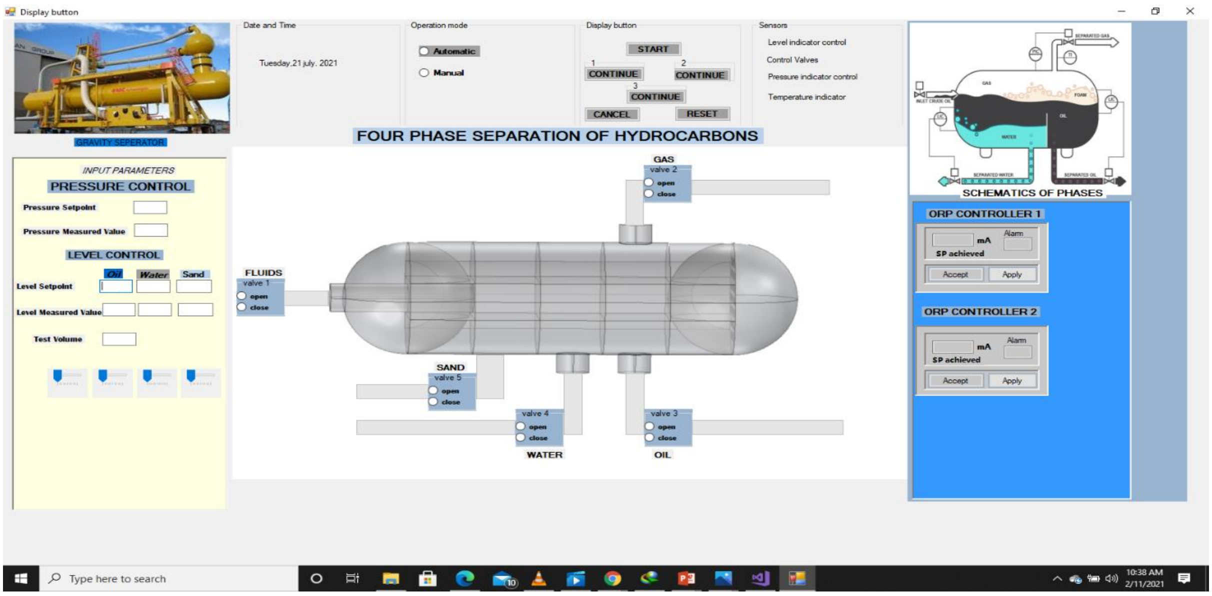
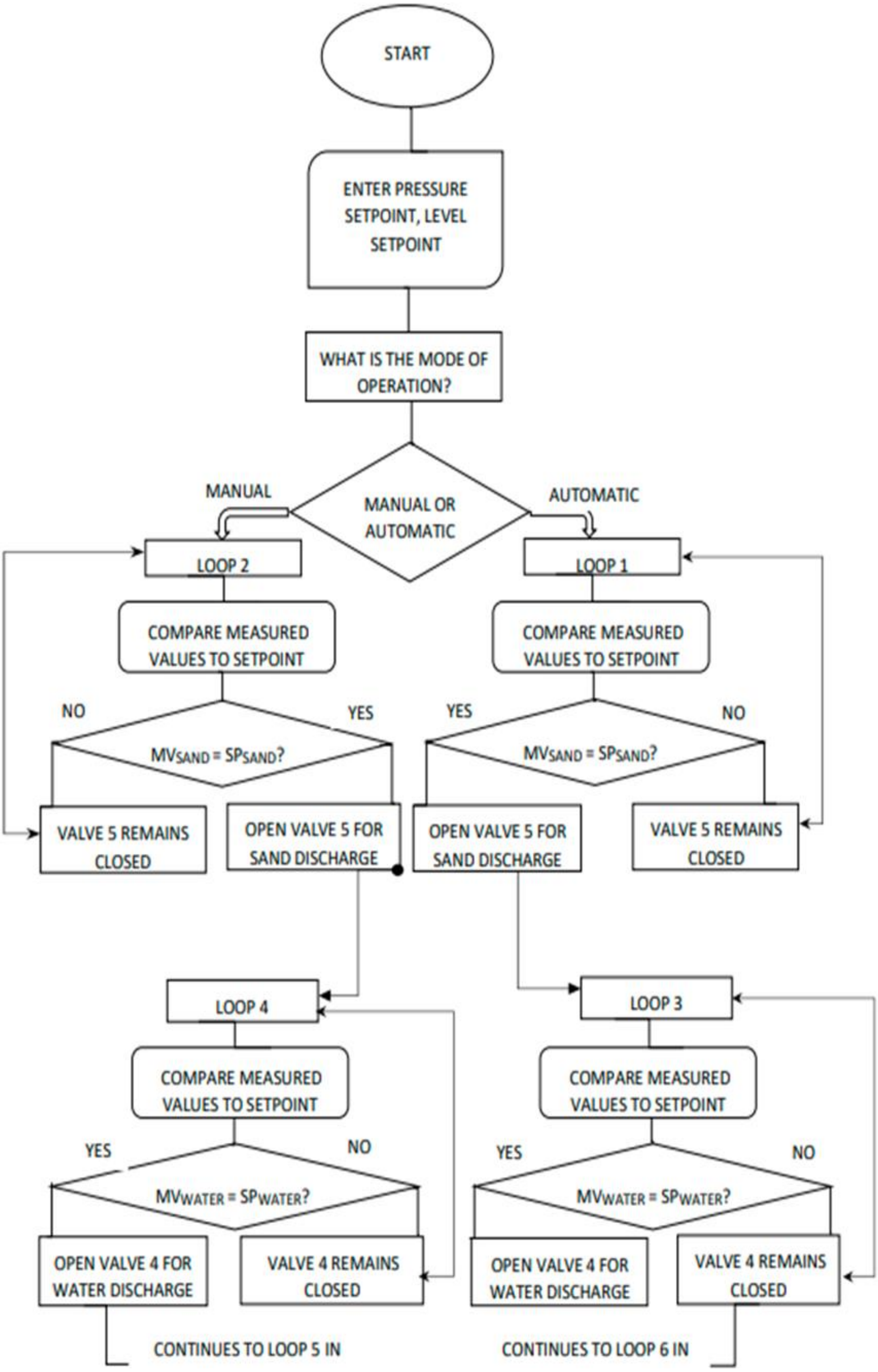


Fig. 4 Initial GUI Interface of Se-Pro


START
ENTER PRESSURE SETPOINT, LEVEL SETPOINT
WHAT IS THE MODE OF OPERATION?
MANUAL
MANUAL OR AUTOMATIC
AUTOMATIC
LOOP 2
LOOP 1
COMPARE MEASURED VALUES TO SETPOINT
COMPARE MEASURED VALUES TO SETPOINT
NO
YES
YES
NO
MVSAND = SPSAND?
MVSAND = SPSAND?
VALVE 5 REMAINS CLOSED
OPEN VALVE 5 FOR SAND DISCHARGE
OPEN VALVE 5 FOR SAND DISCHARGE
VALVE 5 REMAINS CLOSED
LOOP 4
LOOP 3
COMPARE MEASURED VALUES TO SETPOINT
COMPARE MEASURED VALUES TO SETPOINT
YES
NO
YES
NO
MVWATER = SPWATER?
MVWATER = SPWATER?
OPEN VALVE 4 FOR WATER DISCHARGE
VALVE 4 REMAINS CLOSED
OPEN VALVE 4 FOR WATER DISCHARGE
VALVE 4 REMAINS CLOSED
CONTINUES TO LOOP 5 IN
CONTINUES TO LOOP 6 IN

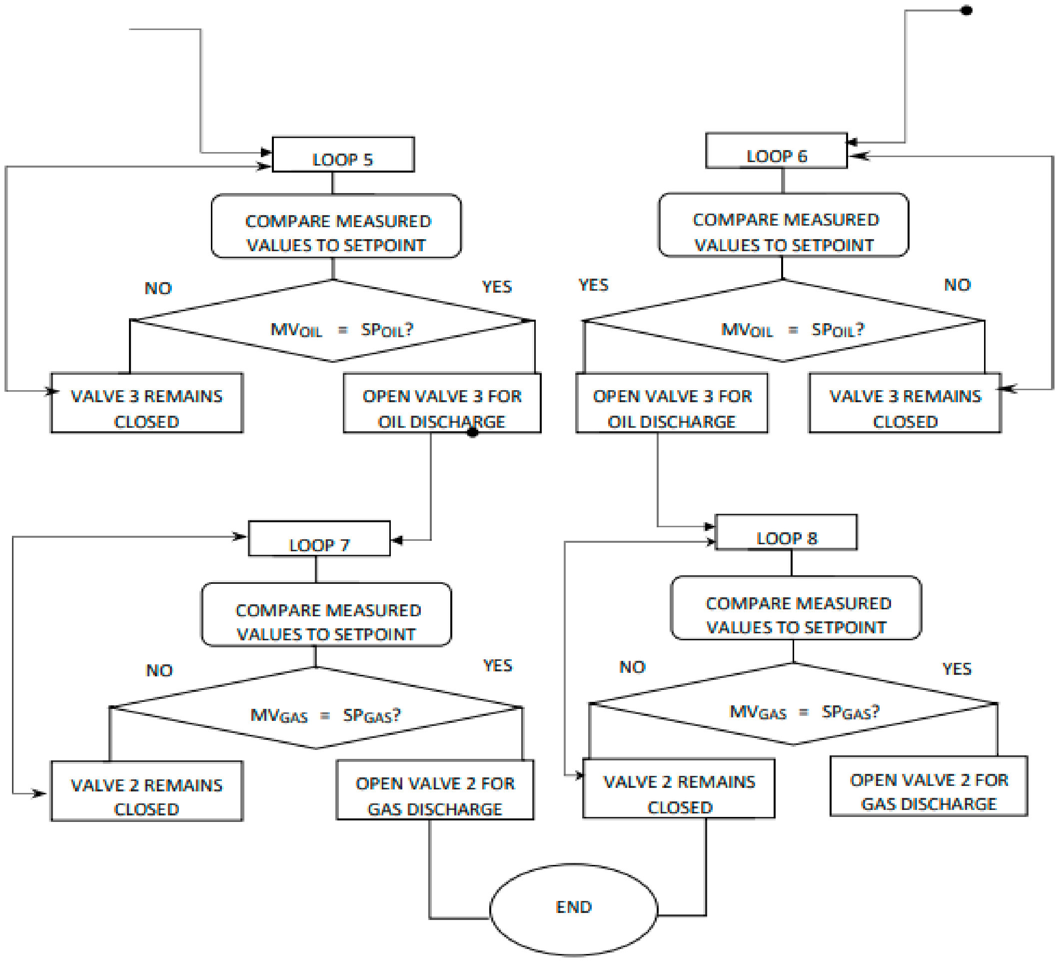


Fig. 5 Logical Flow Chart of Se-Pro Operation

The equation (1) (Fosu et al., 2020) used in the program for the conversion of the measured signal (in milliampere) of the level transmitter to a measured level setpoint value is expressed as:

$$MV = \left[\left(\frac{MS - LRV_s}{Span_s}\right) \times (Span_m)\right] + LRV_m \quad (1)$$

Where; MV stands for the Measured Value.

MS stands for the Measured Signal.

LRV_s stands for the Lower Range Value of Transmitter Signal

$Span_s$ stands for the Signal Span of the Transmitter

$Span_m$ stands for the Span of Measurement

LRV_m stands for the Lower Range Value of Measurement

3 Results and Discussion

The produced results after the study are a three-dimensional model of a subsea processing system and show a simulation of oil, water, gas and sand from the reservoir into the various subsea structures. Also, a user-friendly interactive simulator called Se-Pro was developed to monitor the process control of a four-fluid processing phase in a horizontal separator in both automatic and manual modes.

3.1 Operation of Se-Pro

Se-Pro is a simulation application, developed mainly to monitor the process control of a four-fluid processing phase in a horizontal separator and control the parameters (pressures and level setpoints) involved in the process. Se-Pro operates in both manual and automatic modes. It was developed by modifying and simulating the process and instrumentation diagram (P & ID) in Fig. 4 The application compares the measured values and level setpoints of oil, gas, water and sand that flows into the separator and also allow the operator to manually or automatically control the valves for the fluids to be discharged

3.2 Automatic Mode

In the automatic mode, the measured values of the pressure and level of the fluids are constantly compared to the setpoints. The simulator automatically opens the first valve (Fig. 6) for the fluids to enter the separator and process it in various stages. The level measured values (high and low) of the fluids are constantly compared to the level setpoint of the fluids (Table 1) as the separation phase begins. Once the separation is done (Fig. 7), the valves are automatically opened by the system to allow the fluids to flow. This ensures that the optimum levels are achieved for the fluids to be discharged via adjusting the valves. The opening of the discharge valves allows the fluids to flow into various channels for further processing after separation when the setpoints are achieved.

Table 1 Hypothetical Data for Validation (Automatic Mode)

Parameters	**Values**
Pressure Setpoint	98 psi
Pressure Measured Value	55 psi
Level Setpoint High (Oil)	95 cm
Level Setpoint High (Water)	96 cm
Level Setpoint High (Sand)	45 cm
Level Setpoint Low (Oil)	10 cm
Level Setpoint Low (Water)	12 cm
Level Setpoint Low (Sand)	8 cm

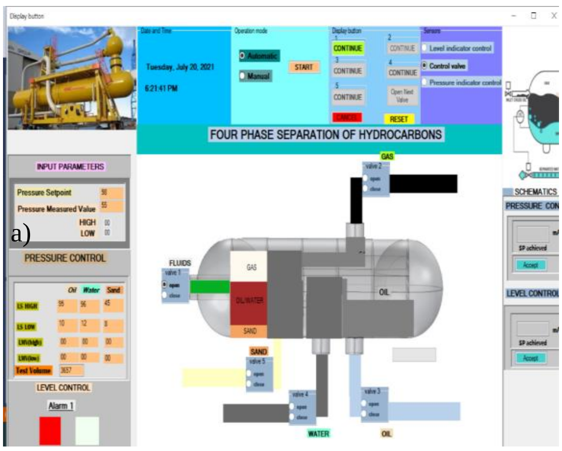


Fig. 6 Initial Stage of Separation

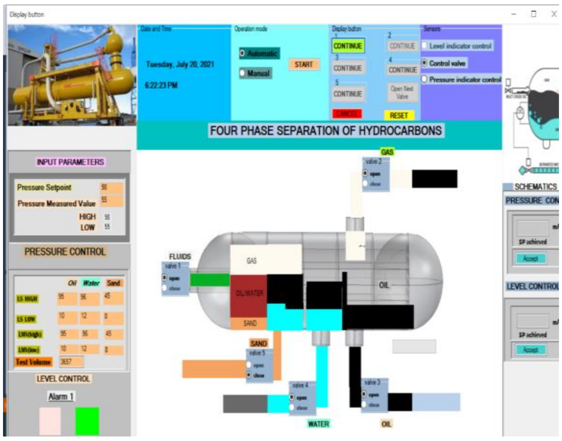


Fig. 7 Final Separation Condition

3.3 Manual Mode

In the manual mode, the measured values of the pressure and level of the fluids are constantly compared to the setpoints (Table 2). The opening of the first valve (Fig. 8) is done manually for the fluids to enter into the separator and process it in various stages. The respective Level Indicating Controller (LIC) and Pressure Indicating Controller (PIC) trigger an alarm if the setpoint is not achieved. The controller's action alerts an operator to take action by adjusting the valve that must be opened to allow the required number of fluids to flow out to achieve the setpoint as illustrated in Figs. 8 and 9. Fig. 8 has a message box that alerts the operator that the first stage of separation is completed and can continue with the separation process till the final stage of separation is done as shown in Fig. 9. The level measured values (high and low) of the fluids are constantly compared to the level setpoint of the fluids as the separation phase begins (Table 2). Once set points are achieved, the system allows the operator to manually open the discharge valves to allow fluids in each compartment to flow from one separation stage to another as illustrated in Figs 8 and 9. The opening of the discharge valves allows the fluids to flow into various channels for further processing after separation when the setpoints are achieved.

Table 2 Hypothetical Data Used for Validation (Manual Mode)

Parameters	**Values**
Pressure Setpoint	120 psi
Pressure Measured Value	55 cm
Level Setpoint High (Oil)	65 cm

Level Setpoint High (Water)	55 cm
Level Setpoint High (Sand)	45 cm
Level Setpoint Low (Oil)	8 cm
Level Setpoint Low (Water)	8 cm
Level Setpoint Low (Sand)	8 cm

3.3 Manual Mode

This section shows a simulation of the subsea structures, from the reservoir to the pipeline, X-mas tree, manifold, subsea separator, and injection well. The movement of oil, water and gas was represented by individual colour codes. The colour green represents oil, blue represents water, and red represents gas. All the structures were designed to meet specifications (Maldonado et al., 2006) as shown in Fig. 10, and with a rendered image of the subsea structures. Finally, this study's video and programming codes can also be accessed at https://github.com/kelvinZoe/4phasesaperator.

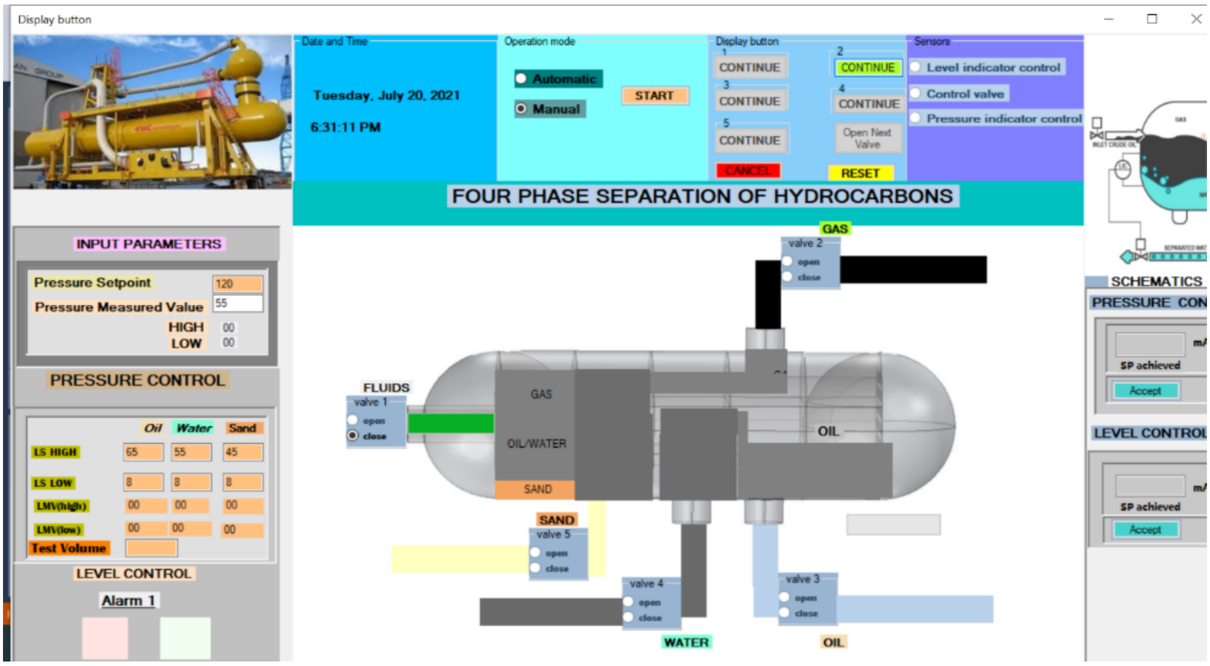


Fig. 8 Manual Mode Result

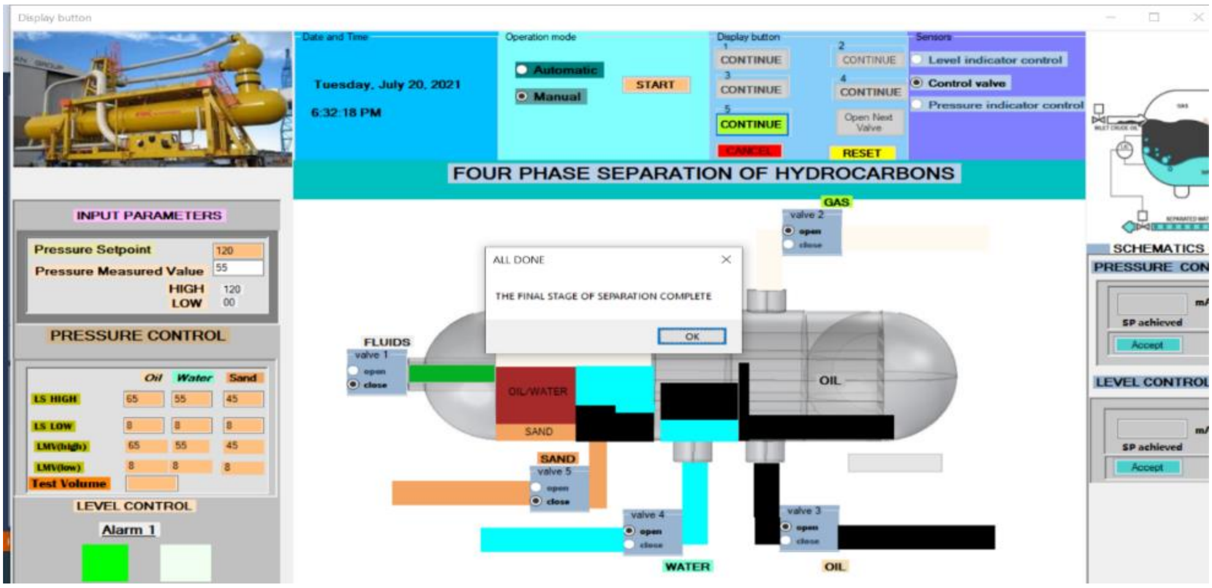


Fig. 9 Manual Mode Results

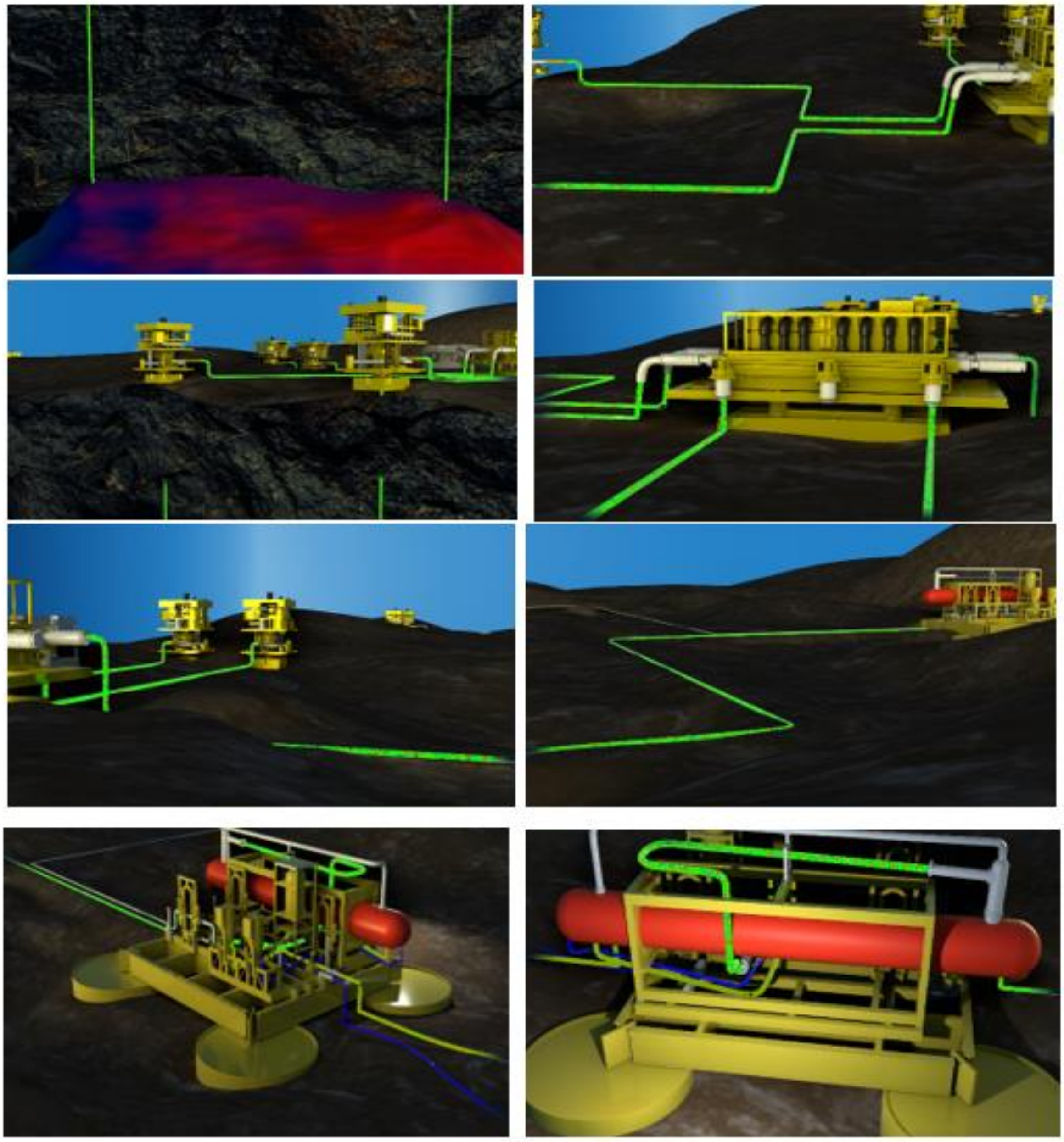


Fig. 10 Rendered Image of Subsea Structures

4 Conclusions

Conclusions drawn from the study include:

i. A well-detailed 3D model of the subsea processing was designed.

ii. The simulation of four fluid phases of oil, gas, water and sand slurry was performed in a horizontal separator on the seabed.

iii. An interactive simulator was designed using C# programming language to monitor the instrumentation and process control of the horizontal separator on the topography of the seabed.

iv. Also, this study minimizes flow assurance problems to improve production by installing a subsea separator that allows gas, water and oil phases to be separated. Also, an integrated sand handling system of the separator at the subsea ensures proper sand management.

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