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Dynamic simulation and control of feed conditioning system for CO_2 capture

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Abstract. There are several CO_2 removal technologies currently applied in the commercial and production scale. One of the potential technologies currently being evaluated for offshore CO_2 separation is Centrifugal Fluid Separation technology, specifically Supersonic Gas Separation (SGS). It is potentially better than the conventional solutions such as membrane in terms of CAPEX, hydrocarbon losses, footprint, tonnage and power requirement. However, the stringent requirement of cryogenic temperature and high pressure of its feed requires a robust feed conditioning process plant. There are limited studies on the simulation and control design which are crucial to test the stability and dynamic responses of the feed conditioning plant. This paper investigates the optimal regulatory plant-wide control strategy for the feed conditioning plant subjected by various disturbances in temperature, pressure and feed CO_2 composition.

1. Introduction

The importance of developing a reliable simulation model of technologies has long been recognized by the industry in order to assess the process dynamics, evaluate and optimize equipment design, controllability and operating procedures during design phase, training operators before actual operation as well as sensitivity studies of process disturbance during operation [1]. For a relatively new technology such as SGS technology in CO_2 removal application, prior to being applied at actual field, dynamic simulation of the plant is crucial in order to investigate and assess the variations of feed and process conditions i.e. temperature, pressure and gas compositions as these will impact the CO_2 separation performance inside the separator. Even though the technology has been developed since 1989, the application is more on dehydration and hydrocarbon dew pointing [2]. For CO_2 separation from natural gas, although the proof of concept of this technology has been successfully validated, there is still a lot of development work to be done particularly prior to the field application as there are a lot of uncertainties of feed conditions to be tackled [3].

Supersonic Gas Separation technology for CO_2-NG separation is based on the phase change of the gas mixture component. For Twister, a proprietary-owned SGS technology developed by Twister BV, the CO_2 is condensed by the instantaneous change of the temperature attributed to the expansion of the supersonic flow induced by the Laval nozzle design [4]. For modelling of SGS technology including Twister, most of the data available in literature is on numerical modelling, typically computational fluids dynamic modelling of the supersonic separator. Wen, Cao, Yang and Zhang [5] has developed a supersonic separator to study the swirling effects on the separator performance for natural gas separation. The basis used for the model are continuity equation, momentum equation and energy equation. Fluent CFD software was employed in the numerical study and the experimental result was compared against the CFD simulation which showed good agreement. Prast, Lammers and Betting [6] from Twister BV produced a paper on CFD model of the Twister device, which incorporates nucleation and droplet growth using the Ansys CFX software. The first results of the simulation were compared against experimental values for both component recoveries and wall pressures. It was found that the CFD model gave good indication in predicting the physical behavior of the separator.

While most of the studies done on the SGS technology revolves around the design parameters, there is minimal studies with regards to its feasibility and controllability, particularly for the feed conditioning in CO_2 separation from natural gas.

Dynamic simulation study is essential to evaluate the flexibility of the feed conditioning plant and generate the data required for supersonic separator operating envelope – namely temperature, pressure, gas composition and flow rate. The fluctuations in these key operating parameters, particularly temperature and CO_2 composition will affect the performance of this process, e.g., the changes in these two conditions may reduce the separation efficiency of SGS technology, resulting in higher CO_2 content in sales gas which is undesired. Based on the dynamic simulation and the variations of the feed study results, a process control design would help in achieving the tight control of the supersonic separator's inlet parameters and maintain the stability of the process.

Hence, the main aim of this paper is to develop a dynamic simulation and control strategy of the feed conditioning plant of SGS technology for CO_2 separation plant. The control strategy is designed to meet the specified operating parameters of SGS technology inlet under various disturbances.

2. Methodology

The research methodology employed for this project is summarized in the following flow chart:

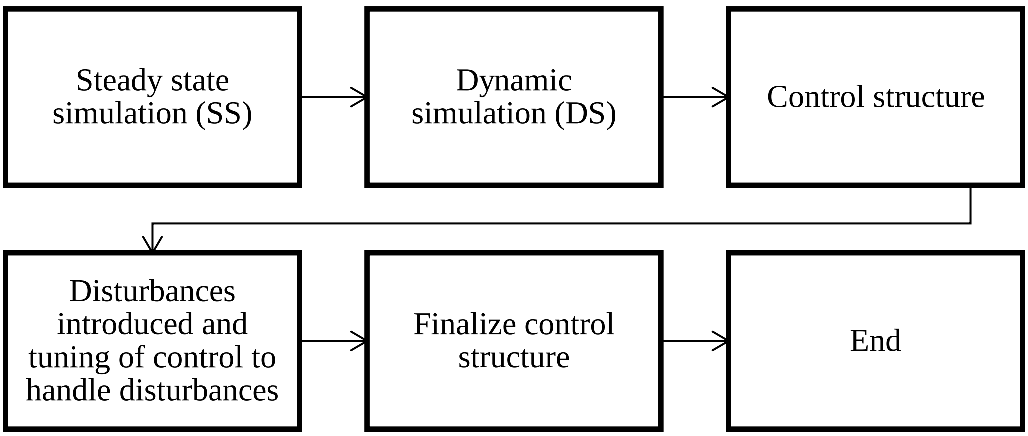

Figure 1. Flow chart of research work

In whole, the research process involves steady state simulation, dynamic simulation and process control design and testing of the feed conditioning plant of CO_2 separation process using supersonic separator. The optimum process parameters of the supersonic separator is identified based on existing data and the dynamic simulation and process control design are conducted based on the steady state simulation work. In this study, process simulator software Aspen HYSYS V.8 was utilized for rigorous steady-state and dynamic simulation of the feed conditioning process. Peng-Robinson equation of state was used to calculate the thermodynamic properties.

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2.1. Feed conditioning plant process descriptions
In the process scheme, the feed (stream 212), a cold stream at cryogenic temperature which consists of 35% CO_2 (mixed gas) goes to the first separator prior to going through the compressor and cold box to knock off most liquid from the stream. This liquid stream is being routed to CO_2 liquid reinjection as it contains high CO_2 content. After the first separator, the feed gas is compressed up to approximately 77 bar and is cooled down to cryogenic temperature, -50°C via a coldbox which uses several process streams (stream 319 and 218) as part of heat integration. The cold feed is fed to the second separator, V-301 to remove remaining liquid phase prior to being fed to SGS technology unit (after stream 300). The mole fraction and other process parameters of feed gas 212 are listed in table 1.

Table 1. Feed gas conditions.

Parameters	Value
Mole fraction of CO_2	0.34
Pressure (bar)	21.30
Temperature (°C)	-56.60
Flow rate (tonne/hr)	773.60

As the steady-state simulation was set up first, some standard modifications are required in order to transition the scheme into dynamic simulation model in Aspen HYSYS.

2.2. Control structure
The feed conditioning plant considered in this study is shown in figure 2:

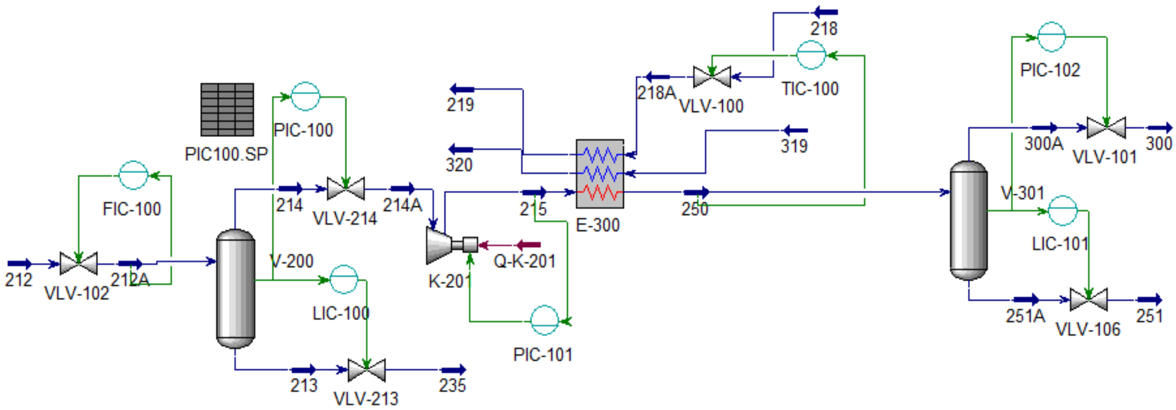

Figure 2. The schematic flow diagram of feed conditioning process of SGS technology for CO2 removal.

As shown in figure 2, there are two liquid levels which need to be controlled to maintain the system, namely the liquid level of first separator, V-200 and second separator, V-301. The main control objectives of this plant are to maintain the CO_2 content of inlet stream to SGS technology i.e. stream 300 within the tolerance limit which is -3 mole% and +1 mole%; and to maintain operating pressure and temperature of stream 300 within the tolerance limit of ±1%. Based on most of the studies conducted on numerical modelling of SGS, the main processes involved in the SGS separator are expansion, condensation of droplets and cyclonic separation of gas and liquid which need a certain design condition i.e. the inlet stream to be at high pressure to ensure sufficient pressure drop and very low temperature due to the phase envelope of CO_2. These parameters are the key process variables to ensure the SGS technology separation efficiency and to meet the CO_2 spec for sales gas.

Based on these explanations, the selected controlled variables (CV) for this system are: CO_2 composition, pressure and temperature of stream 300. Based on earlier explanation, due to the phase envelope, the increase or decrease of these 3 critical process parameters would influence the quality of the product stream of SGS technology. This control structure is designed to cater for disturbances in terms of variation in feed pressure, temperature and CO2 composition (stream 212). As shown in figure 2, there are 7 control valves in the system that can be used as manipulated variables (MV) for this process, including the 2 liquid level controllers while the flow controller FIC-100 is the throughput manipulator. The pressure and temperature of stream 300 are controlled by PIC-101 and TIC-100, while the throughput controller FIC-100 is used to control/manipulate the flow rate in response to disturbances.

3. Simulation results

This section will discuss on the dynamic responses of the plant when disturbances occur at the feed conditioning plant inlet to investigate the dynamic response. The main disturbances are feed gas (stream 212) pressure, temperature and CO_2 composition. The operating pressure, temperature and CO_2 composition of SGS technology inlet, stream 300 are three important parameters which need to be observed when the disturbances are introduced to the system.

3.1 Disturbance of feed gas pressure

The feed gas is varied from +15% to -15% of its original operating pressure, i.e. increase and decrease 15% of 21.3 bar respectively. The red dotted lines in the figures indicate the control objective range for respective process parameters. Dynamic responses of controlled variables after the increase and decrease of feed gas temperature are illustrated in figure 3 below:

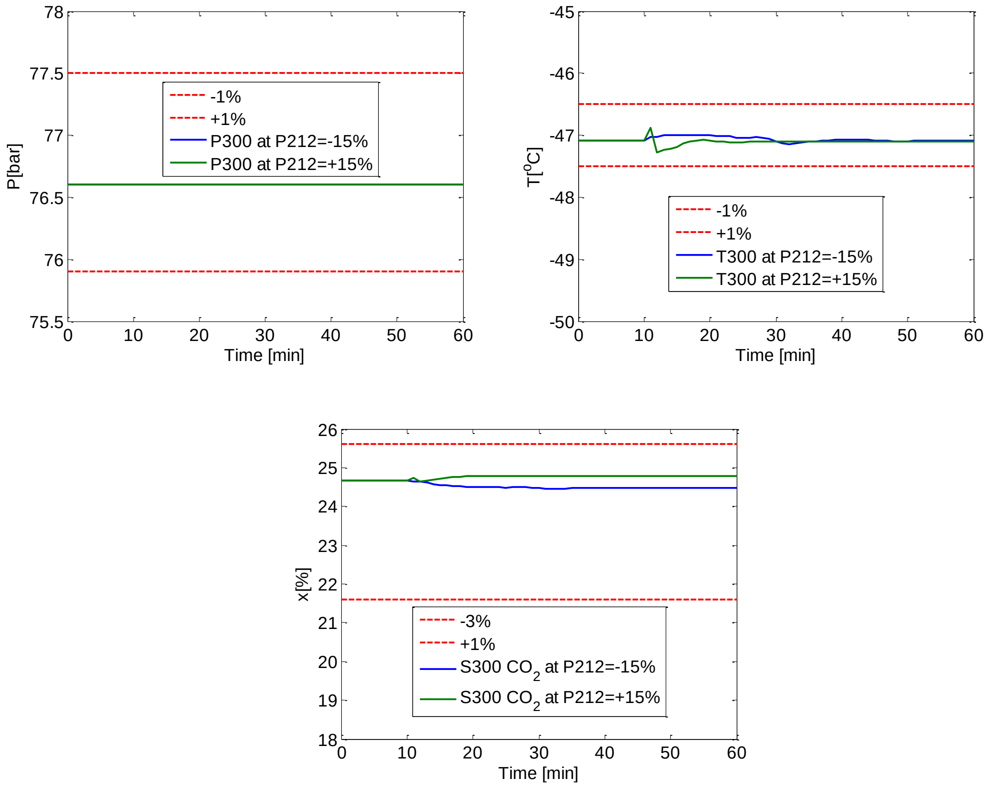

Figure 3. Response of stream 300 to +/-15% pressure disturbances in feed stream 212.

Based on the result, pressure, temperature and CO_2 composition of stream 300 are well within the desired range when disturbance in pressure of feed gas was introduced. The responses are fast, stable

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and without large overshoot. The controlled variables are minimally affected and can go back to stable state in a short time (short settling time). The control strategy works efficiently in ensuring all the three key variables are well-maintained near or at their desired set-point values.

3.2 Disturbance of feed gas temperature

The feed gas is varied from +15% to -15% of its original operating condition, i.e. increase and decrease 15% of -56.6°C respectively. Dynamic responses of controlled variables after the increase and decrease of feed gas temperature are illustrated in figure 4 below:

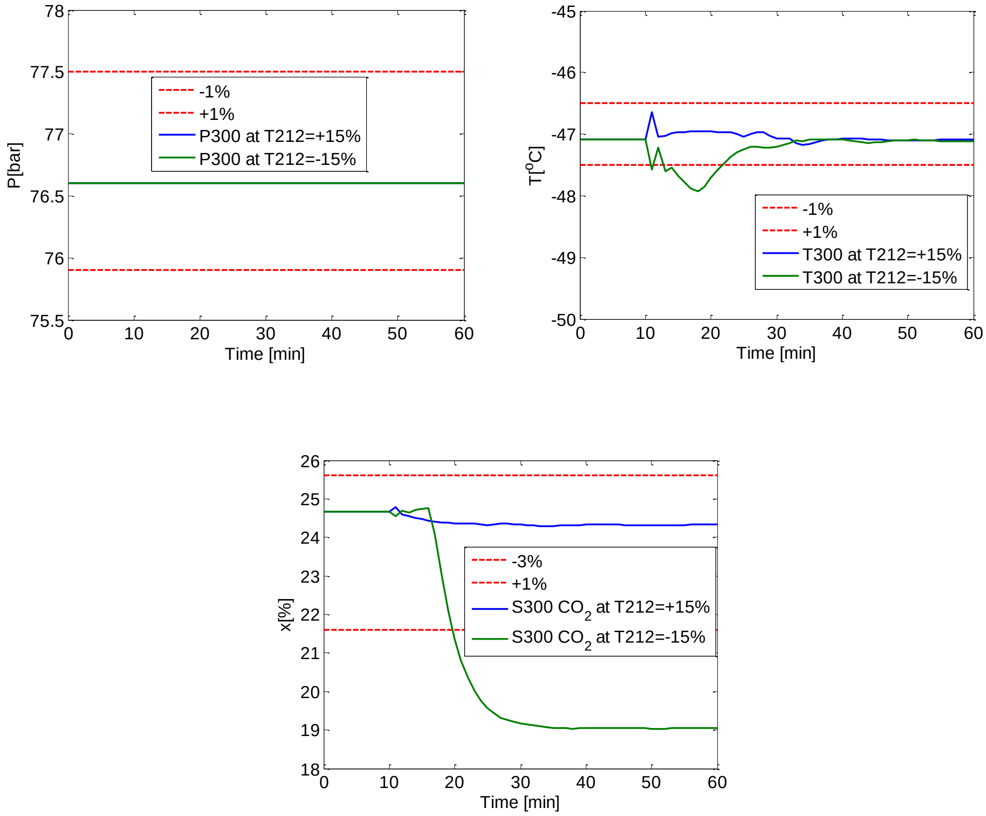

Figure 4. Response of stream 300 to +/-15% temperature disturbances in feed stream 212.

It is observed that pressure and temperature of stream 300 are satisfactorily maintained near the desired steady-state values after some initial transients, however when temperature of feed gas drops too low i.e. at -15% from original condition, CO_2 composition of stream 300 is largely affected. It is due to the lower temperature where more CO_2 condense in liquid form at the first separator hence less CO_2 were left in gas phase, resulting in the lower CO2 content in stream 300 at only 19% compared to original condition, 25%.

However, if the feed temperature drops to only -9.5% the control strategy is able to retain the CO_2 composition within the desired range of -3 mole% and +1 mole% as shown in figure 5 below:

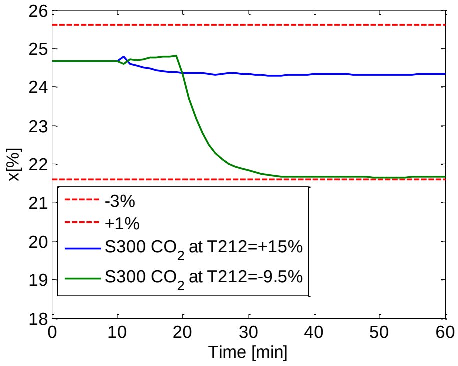

Figure 5. CO_2 composition response of stream 300 to +15% and -9.5% temperature disturbances in feed stream 212.

3.3 Disturbance of feed gas CO_2 composition

The feed gas is varied from +5 mole% to -5 mole% of its original CO_2 composition, i.e. increase and decrease 5 mole% of 0.34 respectively. Dynamic responses of controlled variables after the increase and decrease of feed gas CO_2 composition are illustrated in figure 6 below:

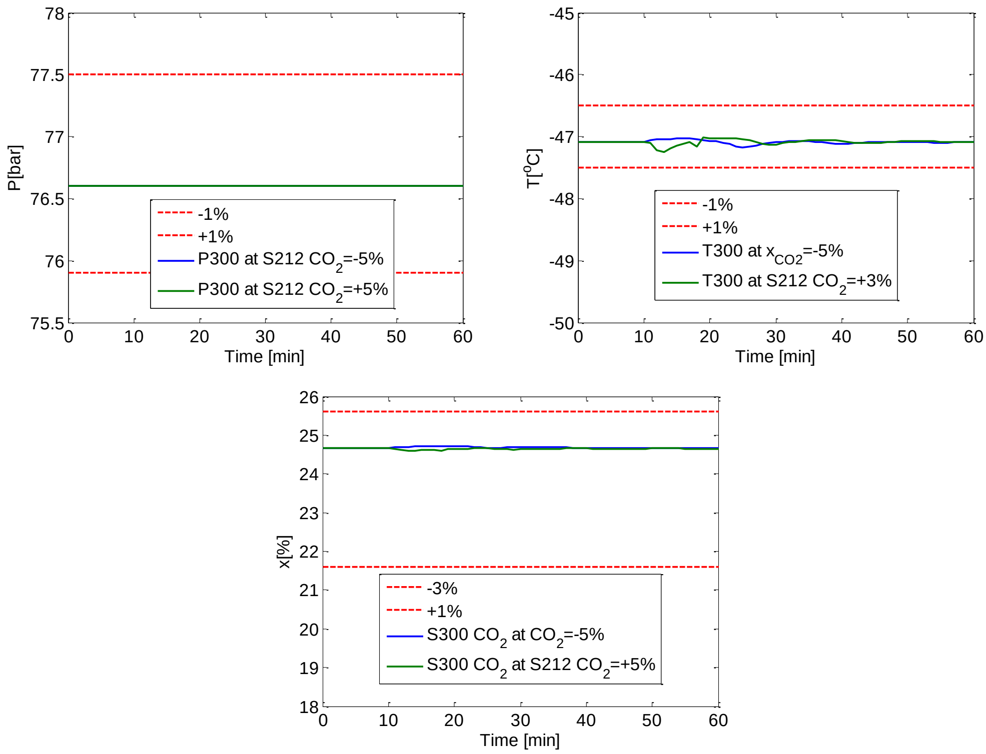

Figure 6. Response of stream 300 to +/-5 mole% feed CO_2 composition disturbances in feed stream 212.

It is observed that variations in feed CO_2 composition have very minimal impact to the system, as all three key variables are hardly perturbed by the changes.

4. Conclusions

In this study, a dynamic simulation and control of feed conditioning process of SGS technology for CO_2 removal was developed to investigate the dynamic behaviours of the plant. The results indicated that the proposed control structure could satisfy the control objectives except for -15% disturbance in feed temperature from its original condition, which results in CO_2 content of stream 300 to be lower than specification. Hence, for future work, the control structure should be improved to address lower temperature disturbances and bring the CO_2 content in the inlet stream to SGS technology to the specified range.

5. References

[1] Seborg D E, Mellichamp D A, Edgar T F and Doyle F J 2010 Process Dynamics and Control
[2] Haghighi M, Hawboldt K A and Abedinzadegan Abdi M 2015 Supersonic gas separators: Review of latest developments *J. Nat. Gas Sci. Eng.* **27** pp 109–21
[3] Samawe R A, Rostani K, Jalil A M, Esa M and Othman N 2014 Concept proofing of supersonic nozzle separator for CO2 separation from natural gas using a flow loop *Offshore Technol. Conf. Asia* Malaysia, pp 2373–76
[4] Schinkelshoek P and Epsom H D 2008 Supersonic gas conditioning - Commercialisation of twister technology *GPA Annu. Conv. Proc.* USA, pp 739–45
[5] Wen C, Cao X, Yang Y and Zhang J 2011 Swirling effects on the performance of supersonic separators for natural gas separation *Chem. Eng. Technol.* **34** pp 1575–80
[6] Prast B, Lammers B and Betting M 2006 CFD for Supersonic Gas Processing *5th Int. Conf. CFD Process Ind.* Australia, pp 1–6