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Dynamic Simulation and Control Structures of Feed Conditioning System for CO_2 Capture

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Supersonic Gas Separation technology for CO_2-NG separation is based on the phase change of the gas mixture component. Simulation technique is typically used to design the SGS separator geometry to optimize the separation efficiency. This approach is economically feasible if compared to experimental method, which requires the manufacturing of SGS technology for testing purpose. However, 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 for SGS technology. 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. The result shows that overall plant energy and sustainability can be improved using the dynamic analysis of plant control structure system.

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, training operators as well as sensitivity studies of process disturbance during operation (Seborg et al., 2010). For new technologies, prior to being applied at actual field, dynamic simulation of the plant is crucial to investigate and assess the variations of feed and process conditions as these will impact its performance and functionality. Even though the SGS technology has been developed since 1989, the application is more on dehydration and hydrocarbon dew pointing (Haghighi et al., 2015). For CO_2 separation, although the concept has been proven 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 (Samawe et al., 2014).

Twister, a proprietary-owned SGS technology developed by Twister BV, works such that 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 (Schinkelshoek and Epsom, 2008). For modelling of SGS, most of the data available in literature is on numerical modelling, typically computational fluids dynamic modelling of the supersonic separator. A supersonic separator has been developed to study the swirling effects on the separator performance for natural gas separation (Wen et al., 2011). A Fluent CFD software was employed in the numerical study and the experimental result was compared against the CFD simulation which shows good agreement. Prast et al. (2006) from Twister BV produced a paper on CFD model of the Twister device, which incorporates nucleation and droplet growth using the Ansys CFX software. It was found that the CFD model gave good indication in predicting the physical behaviour 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 will affect the performance of this process,

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reduce the separation efficiency of SGS technology and resulting in higher CO_2 content in sales gas which is undesired. Based on the dynamic simulation analysis, 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. A study on a biogas plant has utilized Aspen HYSYS to study the effects of operational disturbances on the system which leads to establishment of safe operating limit for the plant (Salm et al., 2017). Depending on process demand of a plant, different criteria is used to evaluate the control structures developed, namely structural simplicity, performance indices and ease of realization (Di Capaci and Scali, 2017).

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:

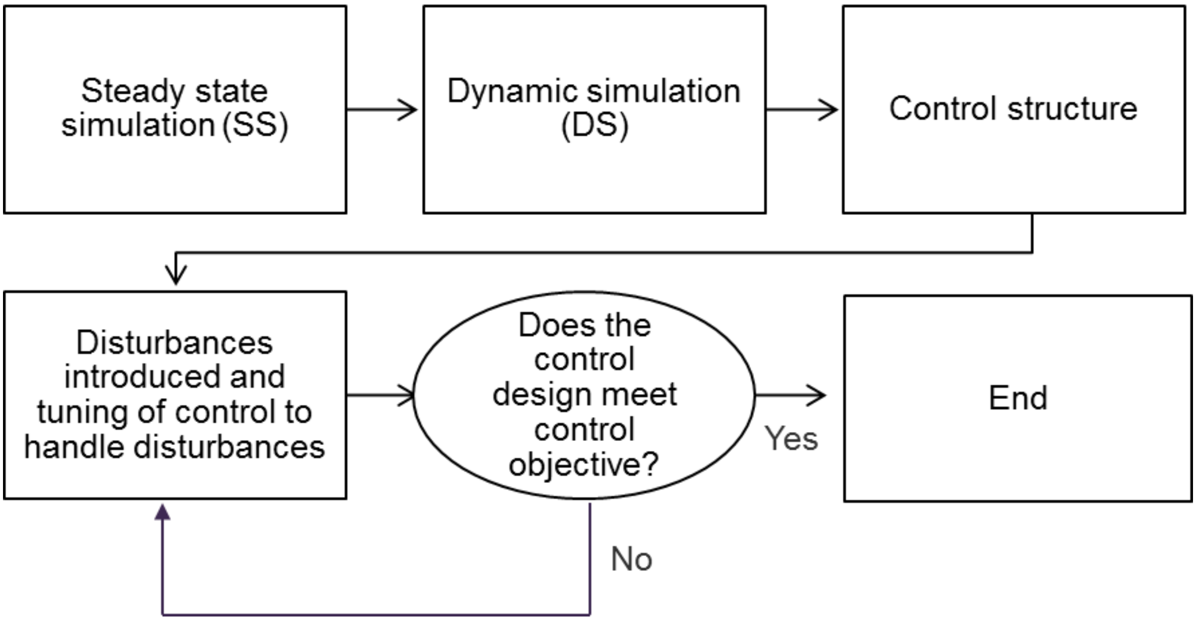

Figure 1: Flow chart of research work

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, as per illustrated in Figure 1, the control strategies are developed and tuned based on their response towards disturbances introduced and finalized. Process simulator software Aspen HYSYS V.8 was utilized for rigorous steady-state and dynamic simulation of the feed conditioning process.

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 is listed in Table 1.

Table 1 : Feed gas conditions

Parameters	Values
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

For this study, there are two control structures developed as shown in Figure 2 and 3:

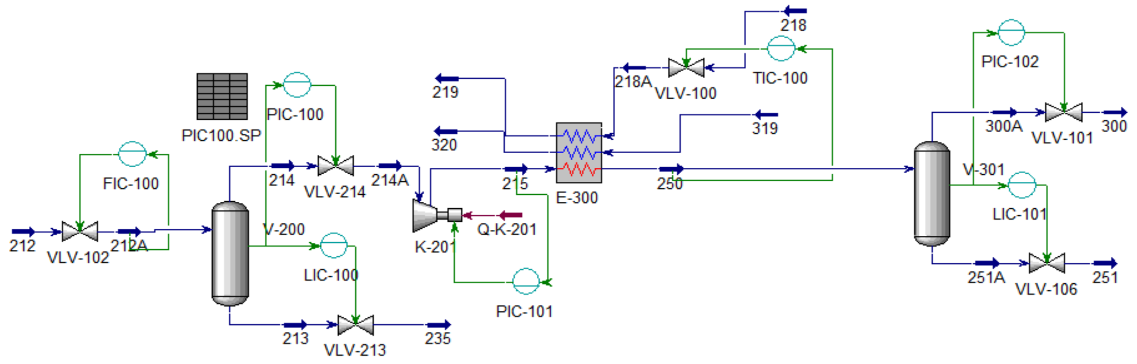

Figure 2: Control Structure 1 (CS1) of feed conditioning plant for CO_2 removal

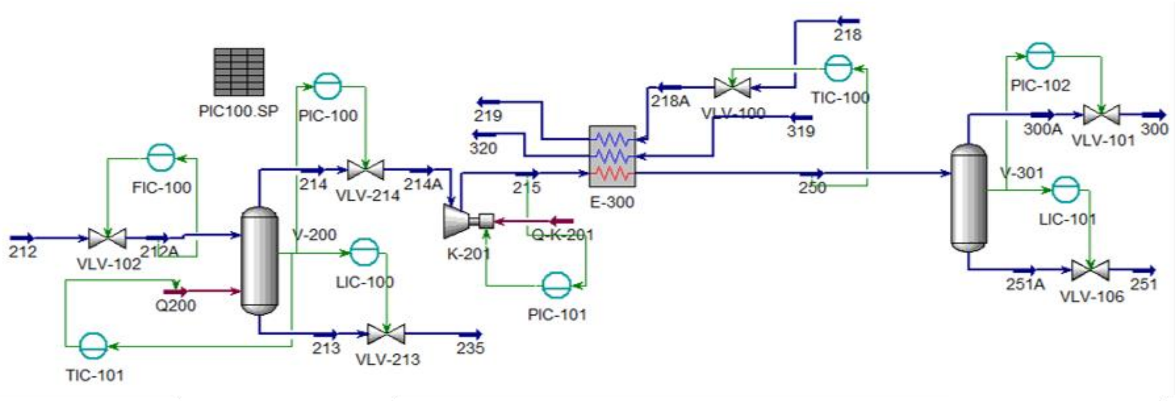

Figure 3: Control Structure 2 (CS2) of feed conditioning plant for CO_2 removal

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 mol % and +1 mol %; and to maintain operating pressure and temperature of stream 300 within the tolerance limit of ±1 %. 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. This selection is based on the fact that 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. The control structures are designed to cater for disturbances in terms of variation in feed pressure, temperature and CO_2 composition (stream 212). Feedback controllers are deployed in these schemes instead of feedforward controllers due to its simplicity in design and capability to take corrective action as soon as the deviation occurs; regardless of the source and type of disturbance (Seborg et al., 2010). As shown in Figure 2 and 3, 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. The difference between these two control structures is that for CS2, the first flash separator is further equipped with heat supply system that can be adjusted to raise the temperature to the desired temperature when there is lower temperature condition at stream 212 (in case of low temperature disturbance).

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 temperature and CO_2 composition of SGS technology inlet, stream 300 are the selected parameters which need to be observed. As for pressure of stream 300, the pressure controller PIC-102 has deployed to maintain the pressure hence it will stay unaffected by the disturbances.

3.1 Disturbance in feed gas pressure

The feed gas is varied from +15 % to -15 % of its original operating pressure. The red dotted lines in the figures indicate the control objective range for respective process parameters. Dynamic responses are shown in Figure 4 and 5.

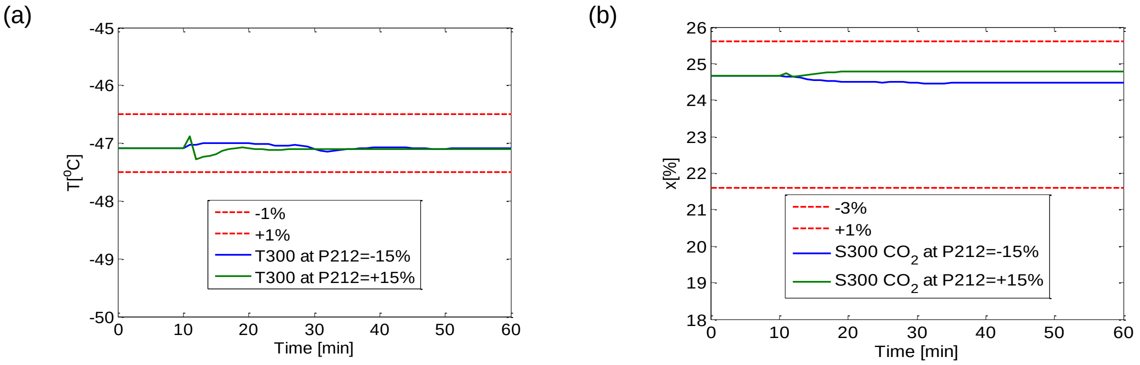

Figure 4: Response of stream 300 to +/-15% pressure disturbances in feed stream for CS1 against (a) Temperature; (b) CO_2 composition

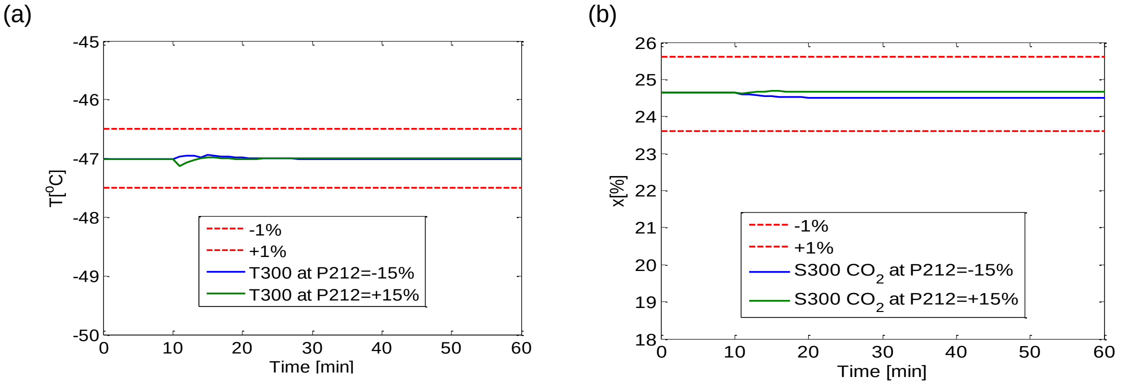

Figure 5: Response of stream 300 to +/-15% pressure disturbances in feed stream for CS2 against (a) Temperature; (b) CO_2 composition

Based on the response of stream 300 in Figure 4 and 5, 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 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. There is very little difference between both control structures but it is observed that CS2 response for temperature reached steady state faster than CS1.

3.2 Disturbance of feed gas temperature

The feed gas is varied from +15% to -15% of its original operating condition. Dynamic responses of controlled variables are illustrated in Figure 6 and 7. For CS1, it is observed in Figure 6 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 CO_2 content in stream 300 at only 19 % compared to original condition, 25 %.

However, for CS2, as observed in Figure 7 the low temperature offset of stream 212 was satisfactorily handled by the heat supply system at V-200; hence resulting in CO_2 composition of stream 300 unaffected by the disturbance, as seen in Figure 7(b). It is shown that CS2 is more capable of handling the low temperature offset and maintain the CO_2 composition parameter of stream 300 within tolerance limit compared to CS1. However, this comes at the price of additional heating duty to be able to raise the temperature back to desired condition.

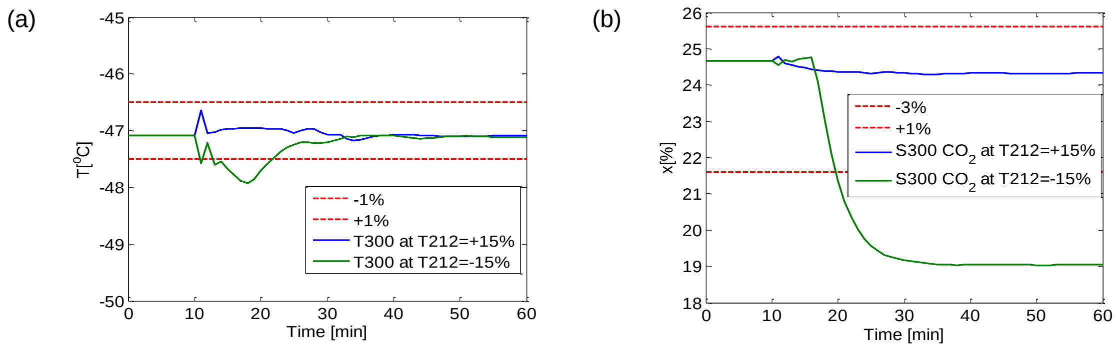

Figure 6: Response of stream 300 to +/-15% temperature disturbances in feed stream for CS1 against (a) Temperature; (b) CO_2 composition

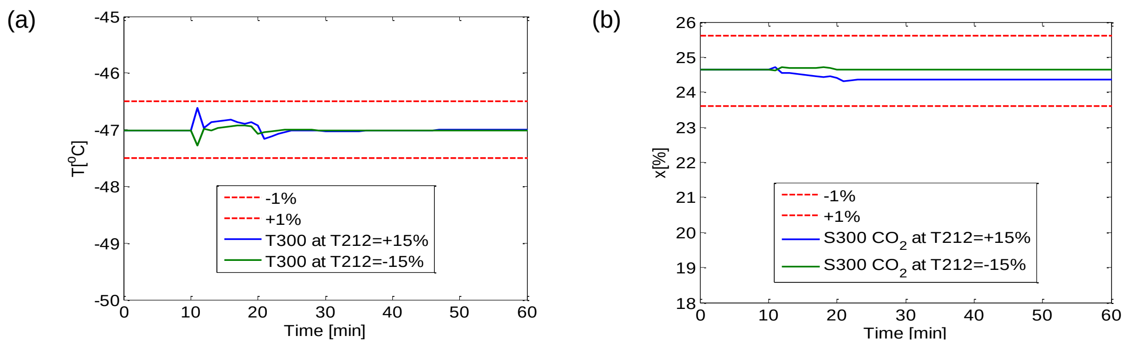

Figure 7: Response of stream 300 to +/-15% temperature disturbances in feed stream for CS2 against (a) Temperature; (b) CO_2 composition

3.3 Disturbance of feed gas CO_2 composition

The feed gas is varied from +5 mol % to -5 mol % of its original CO_2 composition. Dynamic responses of controlled variables are illustrated in Figure 8 and 9.

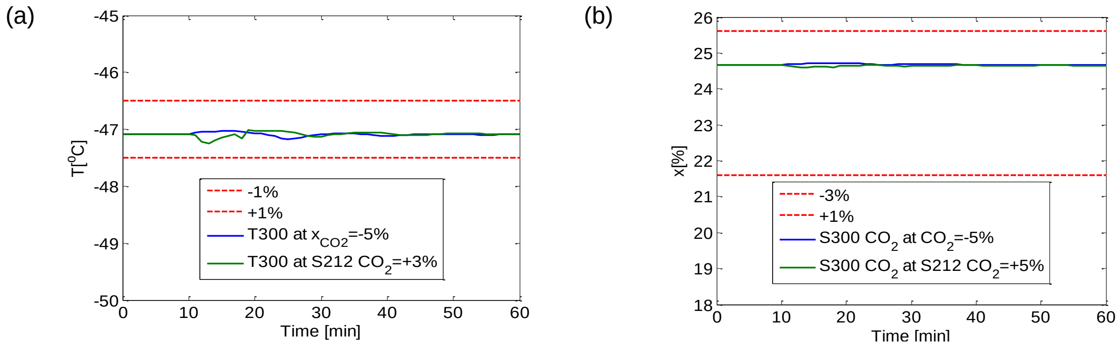

Figure 8: Response of stream 300 to +/-5 mol % feed CO_2 composition disturbances in feed stream 212 for CS1 against (a) Temperature, (b) CO2 composition

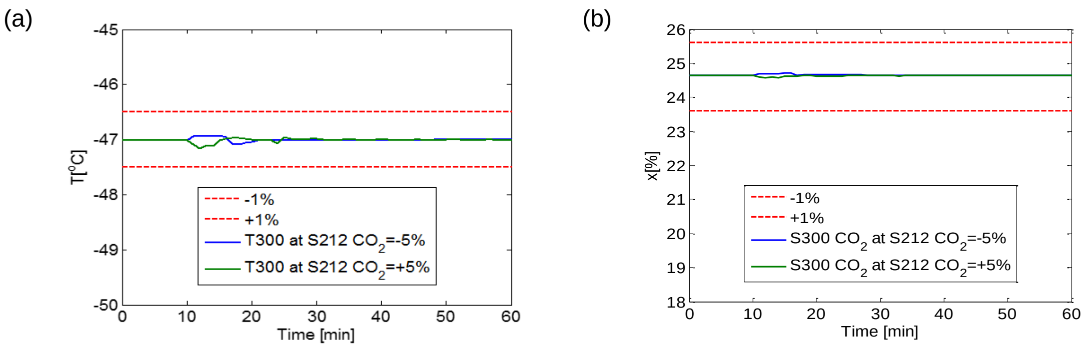

Figure 9: Response of stream 300 to +/-5 mol % feed CO_2 composition disturbance in feed stream 212 for CS2 against (a) Temperature, (b) CO_2 composition

It is observed in Figure 8 and 9 that variations in feed CO_2 composition have very minimal impact to the system for both control structures, as the temperature and CO_2 composition parameters are hardly perturbed by the changes.

4. Conclusion

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 behaviors of the plant. 2 control structures, CS1 and CS2 are developed and the results after disturbances were introduced to the feed are compared. The results indicated that the proposed control structure CS1 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. While for CS2, all control objectives are met but at the expense of additional heating duty to bring back the temperature to its original condition. 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 preferably at lower duty requirement or no duty at all so as to maintain a good economic case of the plant.

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