The 2015 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM15)
Incheon, Korea, August 25-29, 2015

Design and Dynamic Simulation of a CO_2 Injection System for CO_2 Enhanced Oil Recovery

Felicia Salim[1)], Minji Lee[2)], Won-Sik Kim[3)], Jaihyo Lee[4)] and *In-Won Kim[5)]

[1), 2), 5)] *Department of Chemical Engineering, Konkuk University, Seoul 143-701, Korea*
[4)] *Department of Mechanical Engineering, Konkuk University, Seoul 143-701, Korea*
[3)] *Kwangshin Machine Industry company, Gyeongnam 637-924, Korea*
[5)] inwon@konkuk.ac.kr

ABSTRACT

The increase on energy demand has encouraged scientists and engineers to explore various ways to fulfill the constant need. Enhanced oil recovery (EOR) is an effort to recover remaining oils in the old or less-productive reservoir. One of the most well-known techniques is CO_2 injection in which CO_2 is injected into the reservoir to recover remaining oil. Injection system with reciprocating compressor is created for the CO_2 EOR process. In this study, a design of CO_2 injection system for CO_2 EOR has been created and evaluated by process simulator. A flow controller is created in a dynamic simulation scenario where the CO_2 supply is reduced. Simulation of CO_2 EOR injection system proven to be helpful in understanding the behavior of the process and avoiding unnecessary costs in the pilot project.

1. INTRODUCTION

Modern technology made it possible for engineers to study the behavior of a process by simulating it in a process simulator. It requires less time and cost than manipulating the process in a real plant. Process simulator is a tool which relies on the solver algorithm that sees a process as a set of equations which needs to be solved. In this study, Aspen HYSYS is used as the process simulator. Aspen HYSYS is a block-oriented program where users feed the necessary parameters and build the model using predesigned unit blocks by the program. The simulation program has built-in tools for equipment sizing and dynamic initialization and runs both steady-state and dynamic simulations.

Due to the decrement of oil production, various methods have been attempted to boost the oil recovery. Enhanced oil recovery (EOR) is a follow up to primary and secondary oil recovery attempt which involves injection of chemicals into the reservoir. One of the most popular EOR methods is CO_2 injection in which the pressurized CO_2 is injected to drive the crude oil to the production well. Injecting CO_2 into the earth crust also offer another rather beneficial result called carbon sequestration, a technique that is believed to be helpful to reduce greenhouse gas residing in the atmosphere.

To inject carbon dioxide into the reservoir, there are several number of compressor types that is suitable for the job. It is important that the injected carbon dioxide is kept at a dense phase to make sure the oil displacement at optimal condition. The primary requirement of any compressor selection is that the compressor must meet the operating conditions required by the system in which it is installed. Types of compressors can be observed in Fig. 1.

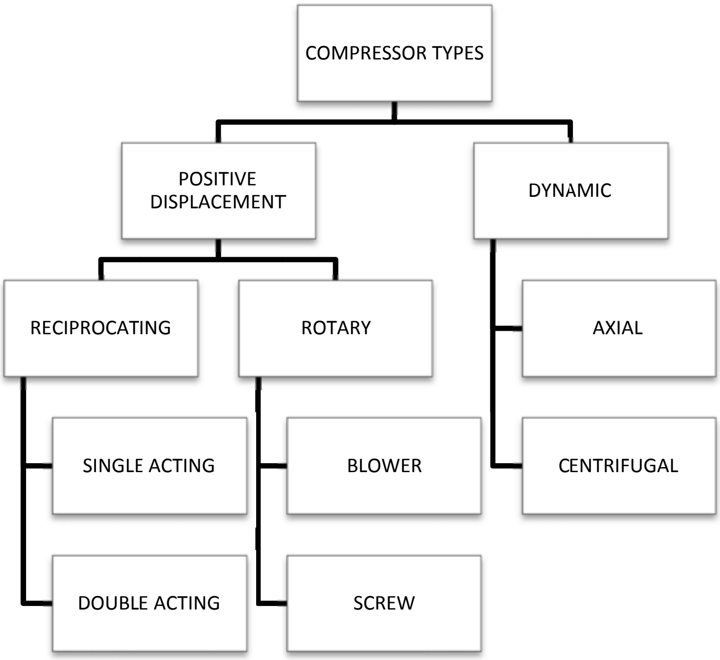

Fig. 1 Type of compressors (Giampaolo, 2010; with changes)

2. CO_2 EOR INJECTION SYSTEM

Enhanced oil recovery (EOR) is an effort to recover remaining oils in the old or less-productive reservoir by injection of gases or chemicals and/or thermal energy into the reservoir (Sheng, 2011). It is also known as tertiary production which follows the primary and secondary production phase of crude oil. Primary production refers to first phase of oil production from newfound oil field where oil and gas are produced by the pent-up energy of the fluid in the reservoir. As the fluid pressure of the reservoir subsides, the secondary production phase usually started by injecting water into the reservoir to re-pressurize the formation. While primary and secondary production phase are considered to be a conventional oil production practices, tertiary production is an enhanced oil recovery practice in which chemicals, gases or other injectants involved.

One of the most well-known EOR techniques is CO_2 injection. In this method, CO_2 is injected into the reservoir at certain pressure to push the oil out to the surface. Injected CO_2 then reacts with the oil by changing its properties, causing it to flow more freely within the reservoir by swelling and make it lighter. The mixture of CO_2 and crude oil that comes out from the reservoir then separated in surface separation facility for reinjection. As the natural resource of CO_2 is limited, captured CO_2 emissions from industrial operations can be utilized in the process. This process bolsters the opportunity of carbon sequestration implementation, which is very beneficial to reduce carbon footprint produced by industrial activities, add another appealing point for CO_2 EOR method. In this study, the injection system for CO_2 EOR utilizes a double acting reciprocating compressor with air cooler as inter and after cooler.

Vaporizer: In early stage of injection process, the CO_2 feed are heated to 10^{o}C temperature to its gaseous phase by an evaporator before it goes to the buffer tank and then the compressor. Vaporizer used in this project is a vertical long tube evaporator with the feed rate separately controlled. Fin tube length of the vaporizer is 8 m and diameter of the fin tube is 0.175 m.

Reciprocating Compressor: In order to inject CO_2 into the reservoir, a double-acting reciprocating compressor is used to pressurize the gas. A reciprocating compressor or piston compressor is a positive-displacement compressor that uses pistons driven by a crankshaft to deliver gases at higher pressure. Reciprocating compressor has a lower range of capacity and speed compared to axial and centrifugal compressor. It is typically used where high compression ratios are required per stage without high flow rates and the process fluid is relatively dry. Reciprocating compressors can accommodate a large range of single stage compression ratios, from 1.1 to 3 being normal. Reciprocating compressors have a relatively low flow capability compared to what is normally needed for large mainlines, which is suitable for a pilot project which need lower capacity.

Air Cooler: Injected gas experiences a rise in temperature and pressure when it goes through compression process in the reciprocating compressor. To lower the temperature of the injected gas, it is passed to inter and after cooler. In this project air cooled heat exchanger with induced draft, countercurrent to crossflow type is used to cool down the compressor outlet temperature. Induced draft air cooled heat exchanger are chosen as it provides more even airflow distribution and thus guarantee a more reliable and predictable heat transfer. Air cooled heat exchangers (ACHEs) or “fin-fans” is a commonly used type of inter and after cooler for reciprocating compressors. They are simpler, less costly to operate and unlike water coolers, possess no risk of corrosion or process fluid contamination.

Injection system of CO_2 EOR is a vital point of the CO_2 EOR process. It is important to reach a required injection pressure to make sure the sweeping of remaining oil in the reservoir occur smoothly. A CO_2 EOR project is planned to be applied on a reservoir with approximately 1000 m depth. It is known from preliminary studies that the injection pressure required is 150 bar. Supplies of CO_2 scheduled to be delivered daily via land transportation in an ISO Tank. The inlet of reciprocating compressor is set at 19.5 bar. While the system temperature need to be maintained not to surpass 150^{o}C because of material limitation.

The goal of the project is to inject as much as 2 tons of CO_2 per day into the reservoir for CO_2 EOR with the Huff-and-Puff method. It is highly crucial for the injection system to prevail throughout the project to guarantee the success of this project. The suction and discharge condition of the compressor is listed in Table 1. However, to create the process, it is necessary to take few adjustments and assumptions for unknown or undecided factors. In this simulation especially, the clearance volume percentage is being modified to match the piston speed to the compressor specification (1480 rpm). Also, without using default value of adiabatic and polytrophic efficiency, the system was set to match both the outlet pressure and temperature. As consequence of these action, the brake horsepower (BHP) calculated by the simulator has shown a fairly great difference with the given specification.

Table 1 Suction and discharge conditions of the reciprocating compressor

SUCTION CONDITIONS		
Stage	1st	2nd
Pressure (bar)	20.51	54.18
Temperature (^{o}C)	10	48
DISCHARGE CONDITIONS		
Stage	1st	2nd
Pressure (bar)	54.53	151.1
Temperature (^{o}C)	48	138

3. PROCESS SIMULATION

Creating a process model in process simulator helps engineers studying the process performance easily. It has been used to design, develop, analyze and optimize technical processes. System behaviors can be observed way before the project take place and saves a lot of unnecessary costs from experimental works. However, one should not rely solely on results from simulation model without validating and/or calibrating the simulation model first.

Unlike centrifugal compressors, reciprocating compressors cannot self-regulate their capacity against a given discharge pressure. In fact, it keeps compressing without limitation unless the range of work is specified, and that capacity will be a unique quantity at any point in time. In most instances, a reciprocating compressor needs to be unloaded by a bypass line for startup. Otherwise, the driver’s required torque will shoot up to 350% of normal torque. Based on said reasons, a solid bypass system is essential for the process. In this simulation, a recycle ratio of 9:1 is first simulated in a steady-state environment to get a picture of how the process will work.

To help us in verifying process simulation that have been created, the result of manual calculation and simulation results are compared to specifications provided by compressor manufacturer. Process simulation on Aspen HYSYS and manual calculation show some differences in results. Cylinder clearance and volumetric efficiency is a parameter that is highly related and depends on the design aspect of the compressor. Volumetric efficiency is especially very hard to pinpoint even through real experiment. Specification defined the volumetric efficiency in average to be 63.93%

while simulation results are 54.83% and 48.75% for the first and second stage of compression. Results of the simulation show a clearance value of 40.95% and 72.05% respectively for first and second compression stage while the specification given ranged at 18–22%. The process simulator is most likely unable to reflect said values of the compressor.

The simulation model has been validated and considered to be appropriate (with some limitation), thus a deeper look on the process can now be done. Dynamic simulation in process simulator is capable of projecting the process model in time-dependent environment. Dynamic simulation can be seen as an extension of steady-state simulation where it does not only perform a mass and energy balance but incorporate time-dependence via derivative terms.

In this study, the dynamic simulation is done in attempt to examine the control system of the recycle line. The recycle line transports a part of injection fluids back to the feed inlet to maintain and build the pressure of the overall injection system. The recycled flow re-entered the system together with the fresh feed before the vaporizer. In the steady-state simulation, the overall system is displayed as to be running with 9:1 recycle ratio. The simulation model for dynamic simulation is provided in Fig. 2. A flow controller is attached to recycle valve VLV-102 to regulate the return flow.

Installed flow controller needs a tuning like any other controller. Using rules suggested by Aspen HYSYS to start tuning, the least aggressive parameters were chosen (lowest value for KC and τ_D and the highest for τ_I) (AspenTech, 2008). While paying attention on the suggested controller parameters, a PI controller with Kc and Ti value of 0.1 and 1 was created.

A simulation scenario, in which the feed flow experiences a disturbance, is designed to observe the system response to this situation. This situation is simulated by reducing inflow of the CO_2 by reducing the valve opening to 20% after running the simulation normally for 30 minutes and then changing it back to 50% after 60 minutes. As can be observed in Fig. 3 the system maintained to endure the disturbance and the recycle system managed to keep the flow in the system. Meanwhile, the compressor performance during this event is recorded and displayed in Fig. 4 and Fig. 5.

With the chosen PI setting, the flow controller FIC-101 could handle the disturbance introduced to the system. It gave a fast response to the change and managed to maintain the operation point. The shortage in feed supply affected the compressor performance but did not cause a huge margin in performance. The process was able to be keeping running without major problem throughout the feed flow fluctuation.

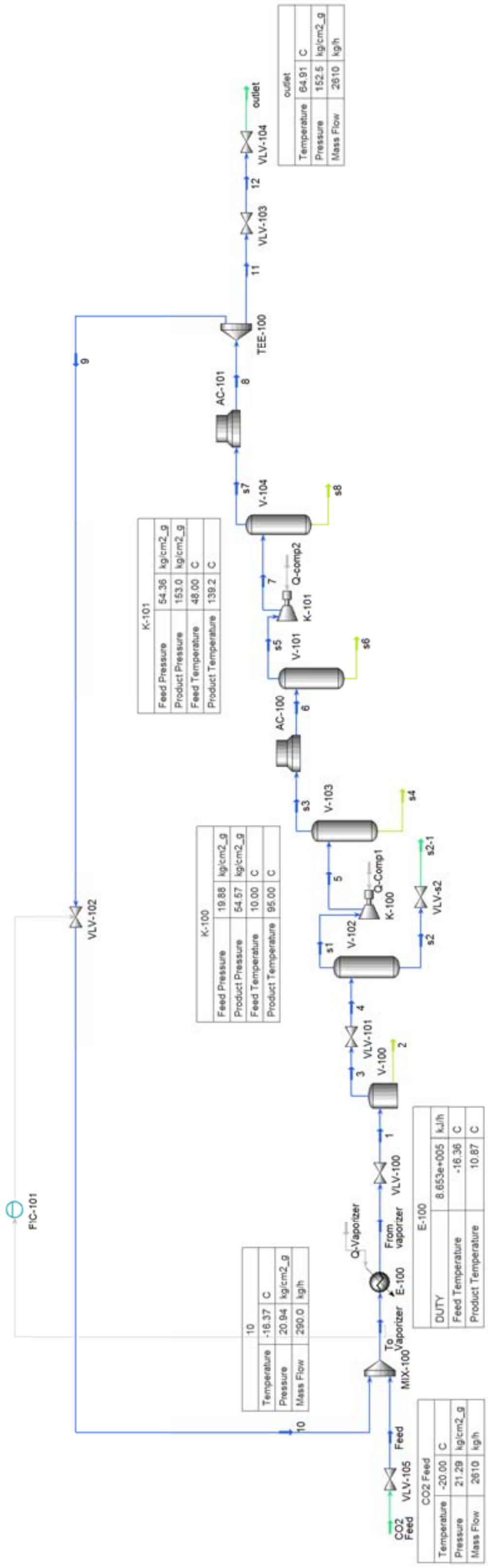

Fig. 2 Simplified system process flow diagram

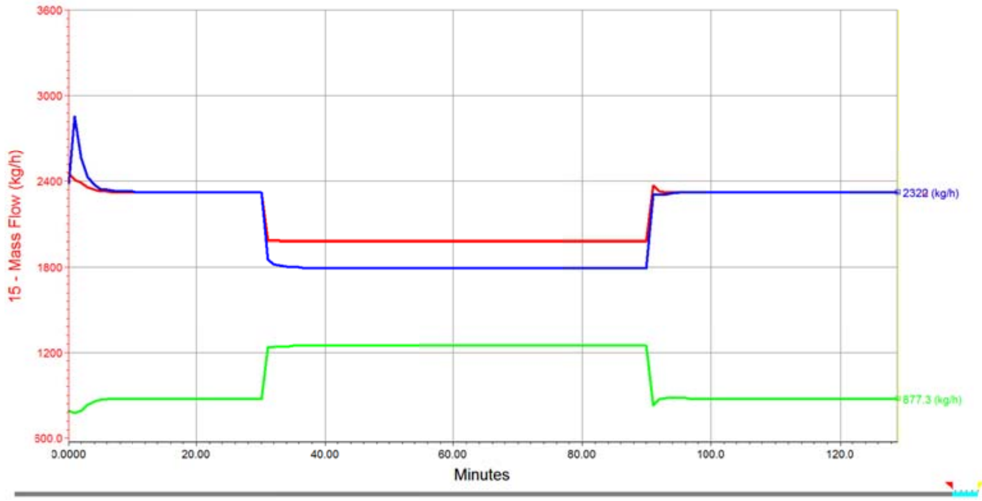

Fig. 3 Mass flow fluctuation during simulation scenario

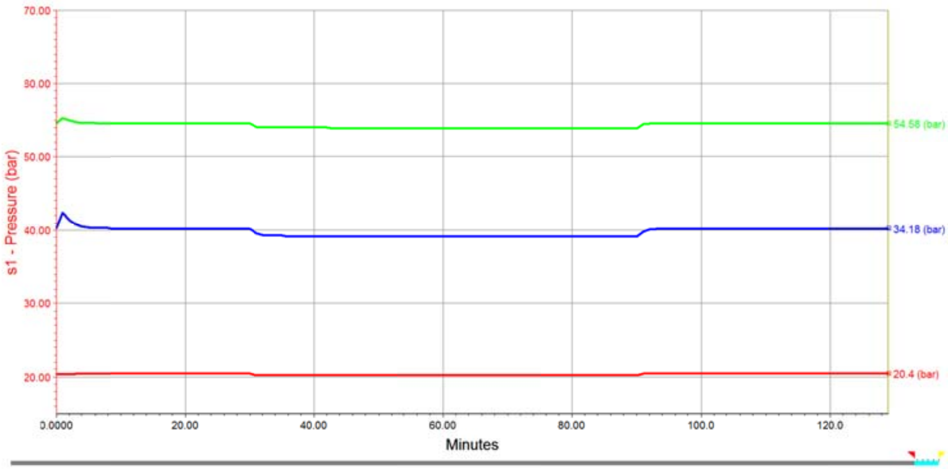

Fig. 4 First stage compression performance during simulation scenario

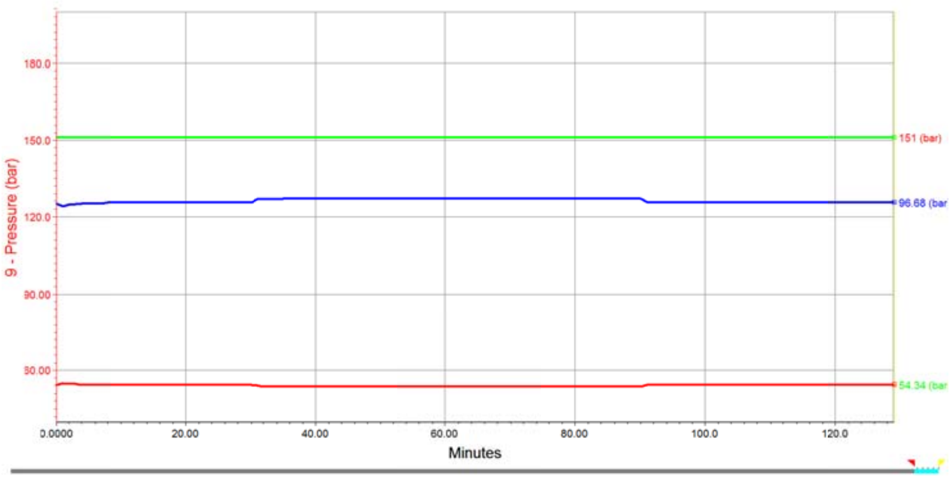

Fig. 5 Second stage compression performance during simulation scenario

4. CONCLUSIONS

From the results of the study, conclusions that can be drawn are:

1. A design of CO_2 injection system for CO_2 EOR has been created and evaluated by process simulator.
2. A PI flow controller is created and proved to be working efficiently in a dynamic simulation scenario where the CO_2 supply is reduced.
3. Simulation of CO_2 EOR injection system proven to be helpful in understanding the behavior of the process and avoiding unnecessary costs in the pilot project.

REFERENCES

Aspen HYSYS Operations Guide Version Number: 7.0. AspenTech, 2008. (www.aspentech.com)

Giampaolo, T. (2010). *Compressor Handbook: Principles and Practice*. Lilburn, GA: The Fairmont Press.

Sheng, J. (2011). *Modern Chemical Enhanced Oil Recovery: Theory and Practice*. Burlington, USA: Gulf Professional Pub.