

Lessons learned from the use of a reciprocating compressor for CO₂ injection

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Abstract:

In response to reduce the emission of carbon dioxide (CO₂) to the atmosphere a promising solution is underground storage, for instance in depleted gas reservoirs. This topic is growing in interest and already a few pilot CO₂ sequestration sites exists, among with the Dutch platform K12-B which is operated by Gaz de France (GDF) Suez E&P. The production gas contains a high percentage of CO₂ which normally was vented to the atmosphere. Since 2004 the platform is extended by a reciprocating compressor facility developed and supplied by ConPackSys to re-inject the CO₂ into the field again, at a dept of approximately 3800 m. During the design and operation some specific challenges were being faced, like material selection, cooling, and lubrication. This paper describes the lessons learned from several years of operation of this compressor.

1 Introduction

Injection or reinjection of carbon dioxide in almost depleted oil and gas reservoirs is regarded as a most promising intermediate solution towards sustainable energy systems in the long term. CO₂ capture, transport, and storage (CCS) (Figure 1) is therefore growing in interest. During the Kyoto convention in Japan in 1997 binding commitments has been set to reduce the CO₂-emissions worldwide. These commitments have been made by 34 countries including the Netherlands. GDF Suez E&P, operator of the Dutch offshore gas field K12-B, supports the idea of (re-)injection of the CO₂ into depleted gas fields to reduce CO₂-emissions. Together with the Dutch Government, GDF Suez E&P started a project with K12-B as a demonstration site to investigate the feasibility of CO₂ injection and permanent storage in the natural gas field.

Many research programs are running worldwide to investigate CCS possibilities. Several research or demonstration sites exist or are being developed. The current progress is to make first steps to small commercial CCS applications. A final target is to have a fully operational transport network and large scale CO₂ injection.

Gas field K12-B is located in the Dutch shelf in the North Sea, some 150 km northwest of Amsterdam. Since 1987 this platform is producing natural gas, which has a relatively high content of CO₂ (13%). The CO₂ is separated from the production stream prior to the onshore gas transport. Until 2004 this CO₂ was vented into the atmosphere. Now it is injected into the field again, at a dept of approximately 3800 m. The project comprises two phases, in the first phase the CO₂ is injected into a fully depleted compartment, in the second phase the CO₂ is injected into the production field from which it originated. This field is nearly depleted and CO₂ injection could possible preserve the production.

For this application, a four stage horizontal reciprocating compressor (355 kW) was selected by ConPackSys. During the design and operation of the compressor system some specific challenges were being faced. This paper describes the lessons learned from six years of operation of this compressor facility.

First, important facts of the K12-B field are given. Subsequently section 3 discusses details of the reciprocating compressor and design issues of CO₂ compression. Then, the operational behavior is assessed on operational experience. The last two sections discusses the impact of CO₂ on enhanced gas recovery for the K12-B field and what is expected to change if CO₂ sequestration will be implemented at larger scale.

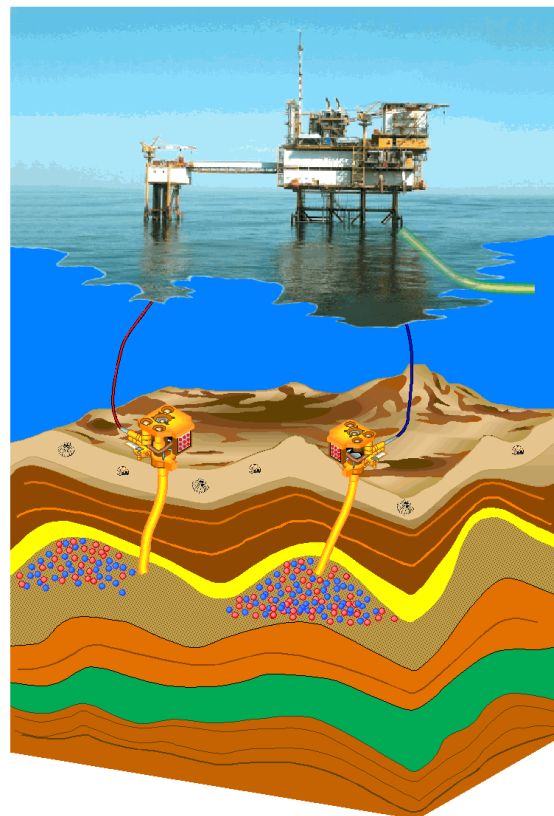


Figure 1: Schematic drawing Carbon Capture and Storage (CCS)

2 Platform K12-B

K12-B (Figure 2 and 3) is a gas production platform with a capacity of about 5.4 mio Nm³ gas/day¹. It consists of a main platform and a small drilling platform. On this drilling platform the CO₂ injection compressor is placed. The production gas then is transferred via a small pipe bridge to the main, production platform. Here the natural gas treatment takes place, consisting of a CO₂ separation column which uses an amine process to separate the CO₂ from the production gas. This process separates CO₂ with an efficiency² of 95%, leading to a production gas containing a reduced percentage CO₂ of 2%.



Figure 2: K12-B platform



Figure 3: main platform K12-B

The K12-B field consists of several compartments³ (Figure 4). The northern compartment is depleted. One well is located in this compartment and during the first phase this well is used as injector for CO₂. The pressure in the compartment is low, just about 30 Bara. In total approximately 9000 ton CO₂ is injected. In 2005 the second phase started. The CO₂ is injected into a nearly depleted reservoir compartment (compartment 3). This compartment contains three wells, two are still producing (K12-B1 and K12-B5) and the third is used now as injector (K12-B6). The pressure in this field is higher, about 50 Bara. The CO₂ injection is still continuing up to today.

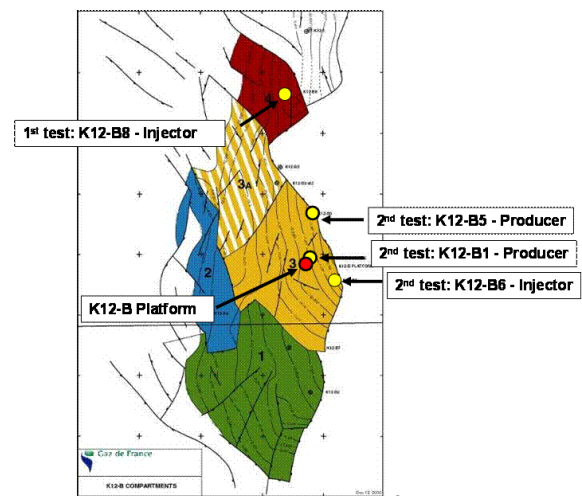


Figure 4: Structure map of K12-B reservoir

CO₂ re-injection at K12-B is subjected to several research programs, such as MONK, CATO, CASTOR and CO₂GEONET. These are mainly focused upon the behavior of CO₂ injection⁴.

3 Compressor Design challenges

For the CO₂ injection project, the CO₂ separation installation is extended with a compressor unit. The used compressor for K12-B is a four stage horizontal reciprocating compressor; Ariel JGR/4 (see Figure 5). This compressor consists of a four crank frame with a stroke of 108 mm, and is equipped with a cylinder - and packing lubrication system. The compressor is driven by a variable speed electric drive with a maximum speed of 985 rpm, which corresponds to a maximal piston speed of 3.5 m/sec. This electric motor has a maximum shaft power of 355 kW.

On the drilling platform only a small footprint is available and due to lifting limitations of the crane the compressor should be light. The total skid dimensions are 5m x 5m x 3.5 m (length x width x height). Due to limited offshore construction time it was decided to make a complete make-up of the

compressor system onshore. Therefore no offshore welding is required and the only offshore activities were installation, assembly and wiring. This resulted to a fast start-up of 5 weeks from unloading. (Figure 6)

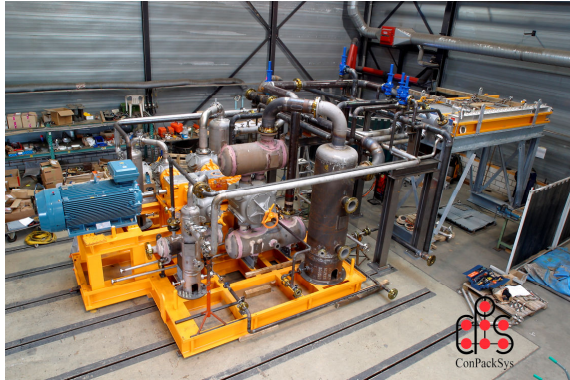


Figure 5: Ariel JGR/4 compressor



Figure 6: Compressor ready to transfer to K12-B platform

For CO₂ compression unit at K12-B the main process requirements are:

- Fluid conveyed is 100% wet CO₂
- Suction pressure is atmospheric at 40°C
- Discharge pressure ranges between 30 up to 90 Bara, temperature is 65 °C.
- The flow rate is averaged 30,000 Nm³/day CO₂ (about 55 ton CO₂ per day).

3.1 CO₂ Compression

The CO₂ properties are important for the design of the compressor. This section deals with some specific CO₂ properties which have to be taken into account.

Carbon dioxide has somewhat lower specific heat ratio ($k = c_p/c_v$) ($k = 1.28 [-]$ for CO₂ at 40 °C and atmospheric pressure (inlet condition)) compared to other gasses like air ($k=1.41$) or hydrogen ($k = 1.40$), resulting in a lower temperature change on adiabatic compression. However, operating nearer to the critical point (31.1 °C, 73.9 Bar), the physical properties of CO₂ change. At higher pressures the specific heat for CO₂ increases to $k = 1.67 [-]$ (at 65 °C and 53 Bar (discharge conditions)). To retain good efficiency each discharge stage is air cooled to approximately 50 °C. The wet CO₂ contained approximately 7% water, which condensates in the intercoolers. Separators are placed after each cooler to catch the liquid water. (Figure 7)

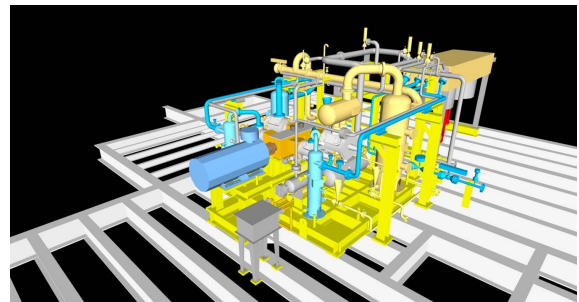


Figure 7: Design phase reciprocating compressor including separators.

A property of CO₂ is that together with water the fluid becomes very corrosive. This is important when selecting the materials. ConPackSys carried out a material selection study. As a result of this duplex stainless steel is chosen as material of construction for a part of the process piping and -equipment. Another possibility is 316 alloys, which also have a good corrosion resistance. However this material can be affected by salts and is therefore less suitable. Special attention is given to the material of the valves, which also are dealing with corrosion and should resist impulse forces.

Another aspect which was considered is the poor lubrication property of CO₂, first due to the low viscosity of the gas (8.3e-6 m²/s compared to 15.7e-6 m²/s for air, at 27°C and atmospheric pressure) and second due to CO₂ gas at high pressure and temperatures have high absorption properties. The lubricant oil is dissolved. Higher levels of cylinder - and packing lubrication are therefore required than for regular gas applications.

It is known that carbon dioxide may permeate to some elastomeric materials in seals and hose connection⁵. To prevent leakage attention has been paid to types of seals.

3.2 Pulsation study

A pulsation study is performed by TNO conform the API 618. CO₂ is a heavy gas and consequently the velocity of sound is lower than for example a methane duty. At 50 Bar and a temperature of 63 °C the velocity of sound is 253 m/sec. As a result the wavelengths are generally smaller to conventional gas applications and in this small, compact pipe layout resonances can excited more easily. The CO₂ compressor is delivered with dampers between the stages and these appeared sufficient to reduce the pulsations to a safe level.

A special layout in acoustic viewpoint is the twofold function of the scrubber as liquid separator and as acoustical damper. To reduce weight and space the inlet scrubber is used as damper for the pressure pulsations. The pressure pulsations did not influence the separation function.

3.3 Safety consideration

The compressor system is classified conform the ATEX. This classification is chosen due to it's location in a flammable environment on the platform. For the compressor the Equipment group II, category 3, atmosphere G is used, for the area the category zone 2, gas group IIA, temperature class T3.

CO₂ gas in elevated concentration causes asphyxiation. However, since the CO₂ separation column is already present at the platform, no additional or new hazards are identified. The monitoring at the K12-B platform is identical to the methane line. The compressor and tie-ins are provided with regular instrumentation and controllers to measure the temperature, pressure, vibrations and flow. What's more, carbon dioxide is denser than air and the gas will sink below the high-built platform. To measure possible elevated concentrations on the platform a portable CO₂ instrumentation is present.

4 Operational experiences

The compressor is operational since 2004. It was designed for a test pilot with an estimated lifetime of half a year, however the platform is still operating today. The compressor will be reviewed according to the availability, material selection (corrosion effects), and pulsations and vibrations.

The compressor is continuously in operation. In the beginning some problems were encountered with the suction separators. The combination of water, oil and CO₂ resulted in an emulsion. This emulsion

caused plugging of the separator drain lines. A solution was found in adding a chemical addition to the oil, as a result the liquid to be drained was less viscous and the separators could be easily drained. Since then the compressor is operating continuously.

During the first phase the CO₂ was being injected in a depleted gas field. The pressure was low and the temperature of the gas was about 60 °C at the discharge side. At these conditions the CO₂ is gaseous and no abnormal behaviour was noticed. (Figure 8⁶). Possible downtime was rather on injection level than due to failure of the compressor².

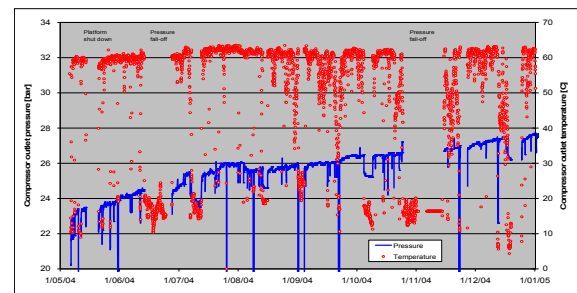


Figure 8: Operational data (pressure and temperature) compressor of first period (2004)

In the second phase the CO₂ is being injected in the almost depleted but still operational compartment. The pressure is higher at averaged 53 Bara and the temperature is averaged 65 degrees Celsius. Also in the second phase the compressor operated as expected. Except for the regular maintenance periods, no downtime due tot the compressor is recorded.

Duplex stainless steel appeared a valid choice for a part of the process gas containing piping and equipment. The vessels and piping will be checked on corrosion each 4 years and the wall thickness is measured. Up until now no problems were encountered. Also in the rest of the pipelines and equipment on the K12-B platform no extensive corrosion is found after 30 years of operation. The injection riser holds a different story. In the injection riser three times a measurement device has been put through to study corrosion effects. Some corrosion has been found but no correlation could be made between the three measurements. Also a video recorder has been put through. Some filth and rubbish has been found at the walls. Hence corrosion could become an issue, on the moment research is going on. Further corrosion measurements on the platform have not been performed.

No elevated pulsations or vibration levels are observed. Also around the scrubber manifold,

which functions as well as damper, no significant deviations are observed.

5 Enhanced gas recovery

The gas field was almost depleted and CO₂ was regarded as an option to save the field by increasing the field pressure. During the first phase the field started temporarily to produce again, which was surprising. The pressure in the field increased as expected and predicted by the simulations. Presumably the CO₂ injection blow away the stone-dust which had collected around the riser and made room for the natural gas to flow.

In the second phase the enhanced gas recovery was marginal. Unlike oil recovery fields the CO₂ does not change the viscosity of the gas, gas is only recovered by bringing the compartment up to pressure. The used riser for injection was originally a production riser. It is located at the middle of the field at a relative high geometrical location. To use CO₂ as a propellant it would be more convenient to inject the CO₂ at the boundaries or corner of the compartment and at a lower geometrical dept since the CO₂ gas is denser than the methane. In principal, if you raise the pressure of the field the production increased⁷.

A negative influence occurs when the carbon dioxide mixes with the production gas. In the northern compartment (first phase) the original concentration was 13% of CO₂, after the injection the percentage raised up to 20%. In the second phase it took some time for the CO₂ to mix with the methane and to travel to the nearest production riser. The CO₂ fraction increased from 13% to 25%. GDF estimates the total enhanced production of about 1 to 2%².

Overall it is difficult to predict the enhanced gas recovery. It is unknown what will have happen if no gas was injected. Research is still going on.

6 Up-Scaling

K12-B is a demonstration site and the amount of injected CO₂ occurs on a relative small scale and in gaseous phase. For commercial applications liquefied or high dense carbon dioxide is more evident as the mass flow increases, compressibility decreases and the pressure drop reduces. For such systems the compression is provided by 5 to 10 stages compressors with final cooling. In some cases a multi-stage compressor in combination of a pump could be used for improved energy consumption.

The current challenge is to scale up CO₂ injection rates to commercial applications. For K12-B a 355 kW compressor is used. Reciprocating compressors are flexible, have a good cost/benefit ratio and have a wide experience range, which make them suitable for demonstration sites. Reciprocating compressors can be increased up to a flow of 300 ton CO₂ per day, based upon an atmospheric suction and 50 Bara discharge, and are therefore applicable for the first, small commercial scales. For larger scales, up to 3,000 to even 25,000 ton CO₂ per day, centrifugal compressors will be applicable.

Regarding the pipeline system, transporting CO₂ in a liquid phase gives some challenges concerning pressurizing the flow (additional boosters will probably be required). Multiphase flow has to be prevented in the pipe lines. In the injection riser an unstable flow might be expected as the pressure declines and the temperature rises along the tube and multiphase flow is likely to occur.

5 Conclusion

K12-B is a Dutch gas platform in the North Sea, operated by GDF Suez E&P. Since 2004 the produced CO₂ has been re-injected into the reservoir. For this application a four stage horizontal reciprocating compressor is used.

During the design phase of the CO₂ compressor some attention is being paid to the properties of CO₂. In combination with water CO₂ very corrosive and a material selection study will be required. In our case duplex stainless steel appeared a valid choice for the part of the gas containing equipment and piping. Furthermore, oil solves easily in CO₂ at high pressures and temperatures. As a result the cylinder and packing lubrication levels need to be increased. Moreover, water, oil and CO₂ forms an emulsion which causes plugged separator drain lines. Adding an additive to the oil can solve this problem. Fourth, attention need to be paid for sealing and packaging selection as CO₂ may permeate through some elastomeric materials. Fifth, CO₂ is a heavy gas with relative short wavelengths, for compact systems this may result to resonances in the pipe layout. Finally, CO₂ is not flammable but can cause asphyxiation at elevated concentrations. At K12-B equal safety consideration are taken as methane.

After six year of operation the CO₂ reciprocating compressor at K12-B platform gives no operational problems. Even in the second phase at K12-B, where a higher discharge pressure was required, the compressor worked as expected. The main lesson learned is that reciprocating compressors can very

well be used for CO₂ injection, however specific technical design issues have to be considered.

The pressure inside the field increased after starting the CO₂ injection and theoretically the production of methane is enhanced, however mixing of the injected CO₂ and the methane influence negatively the production. Research is still going on.

K12-B is a demonstration site with a relative small injection rate. The current development is to make first steps to a commercial plant. For these bigger scales the CO₂ will not be transported as a gas but a liquid form is more evident. This will give to some new challenges.

6 Acknowledgements

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