CO₂ REFRIGERATION SYSTEMS FOR OFFSHORE PROCESS COOLING

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ABSTRACT

Large refrigeration systems (typically 500-5000 kWR) are commonly used on offshore platforms for preliminary processing of natural gas before it is sent ashore. Although vast quantities of flammable hydrocarbons are processed through these platforms and the safety systems required for use of hydrocarbon refrigerants would not add any incremental cost compared to non-flammable, there is a preference for safety reasons to use non-flammable refrigerants, and most systems use R-134a. Due to high corrosion and the difficult maintenance environment, leakage is high, and >100% annual loss is not uncommon.

Most natural gas contains at least a small proportion of CO₂, and in high-CO₂ fields (which can exceed 30% CO₂) refrigeration is used as part of the CO₂ removal process, so a source of CO₂ is available. Consequently, offshore gas processing is an application uniquely suited to CO₂ refrigeration systems, provided this can be done competitively compared to other refrigerants.

1. INTRODUCTION

Substantial process refrigeration systems are often used in offshore gas processing, on both fixed platforms and floating facilities. This is principally in two applications – removal of CO₂ from gas, and gas dewpoint control.

As the cheaper and higher-quality gas fields are becoming developed, the natural gas production industry is turning their attention to fields previously thought uneconomical. In many parts of the world, large gas fields exist containing substantial percentages of CO₂. For example, within the Natuna Sea is a vast gas reservoir, but much of this contains gas in the 20-60% CO₂ range. CO₂ removal generally requires refrigeration as part of the process, and it is becoming economical to do the CO₂ removal offshore, allowing use of a smaller pipeline to shore, rather than take the CO₂ ashore with the gas through a bigger pipe, and separate it onshore.

The other common offshore application is in dewpoint control. As well as methane (and CO₂) natural gas contains many other hydrocarbons, mainly in the range C₂ to C₁₀ but there can be traces over C₅₀. Gas to be sent ashore from a platform passes through undersea pipelines, often hundreds of kilometres long. During its time in what is effectively a long single-tube heat exchanger, the gas is cooled to seabed temperature and some of the heavier hydrocarbons may condense out. The resulting liquid tends to gather into liquid slugs which can cause damage to valves and other equipment at the onshore receiving terminal. Refrigeration is commonly used to cool the gas before it leaves the platform, to a temperature
below seabed temperature. The resulting condensate is separated on the platform, and the process then prevents further condensation in the pipeline.

However, there is (paradoxically) a preference to use non-flammable refrigerants on offshore platforms, so fluorocarbon refrigerants, mainly R-134a etc, are widely used. Some companies refuse to use flammable refrigerants offshore, others will accept them, but in general all want to minimise flammable inventories offshore for safety reasons. On gas platforms there is actually quite a small flammable inventory at any time – just what is in the piping and pressure vessels as gas, and a few tonnes of propane in a flooded shell and tube chiller can be the largest single hydrocarbon inventory on the platform.

Renewed interest worldwide in use of CO\(_2\) as a refrigerant may have a uniquely suitable application in offshore process refrigeration systems. Transcritical CO\(_2\) cycles are becoming viable as better compression technologies have become available, together with heat exchangers such as micro-channel types which are well suited to the properties of supercritical CO\(_2\) in refrigeration cycles.

Power is always a consideration, and power input to transcritical CO\(_2\) cycles can be higher than conventional cycles, but it is far from the only consideration. Substantial offsetting savings are available, as offshore is a harsh environment, and specialist refrigeration maintenance expertise is not readily available. Refrigerant leakage is often high – loss of 40% to 100% per year (from a charge of over 10 tonnes) is not uncommon from systems which have been operating for a few years. The cost of getting large, heavy cylinders of refrigerant out to an offshore platform is very high – the transport and handling cost may double the cost of R-134a by the time it is landed on a platform.

Virtually every gas well contains at least a few percent of CO\(_2\). Although the main CO\(_2\) stream after separation would not be refrigerant-grade, a small separation unit, with a capacity of less than 100 kg/day, is feasible at relatively low cost and could supply sufficient refrigerant-grade CO\(_2\) for makeup of leakage. CO\(_2\) refrigerant, produced on the platform, has many advantages – low or zero cost, non-flammable, non-toxic, negligible greenhouse warming potential compared to synthetic refrigerants, and huge savings in transport and handling costs.

This paper outlines the opportunities and advantages for CO\(_2\) on offshore platforms. Much has been written elsewhere about optimization of CO\(_2\) cycles, and this paper is not intended to address specific cycle development.

2. DEWPOINT CONTROL

Natural gas as it comes from the well is typically wet (containing water vapour). Seabed temperatures may be as low as -2°C at some points of the North Sea (Ravi et al. 1999) but even in tropical areas such as the Timor Sea, seabed temperature may be +10 to +15°C or lower (Dept of Environment, 2009). This means that gas must be cooled to about +5 to +10°C in order to maintain an adequate safety margin from condensation in the pipeline. However, gas temperature and evaporating temperature cannot be too low, as not only will the water in the gas freeze at 0°C, but water and liquid hydrocarbons can form solid hydrates at temperatures in the range from approximately +1 to +4°C, depending on pressure and liquid hydrocarbon composition. (Glycol or methanol may be injected into the gas upstream of the heat exchangers to suppress hydrate formation.) System evaporating temperatures for
offshore dewpoint control are typically in the range -1°C to +5°C. Duty specifications for some recent projects from the author’s experience are shown in Table 1.

<table>
<thead>
<tr>
<th>Project no.</th>
<th>Cooling duty kW</th>
<th>Evaporating Temperature, °C</th>
<th>Refrigerant specified</th>
</tr>
</thead>
<tbody>
<tr>
<td>4002</td>
<td>1750</td>
<td>-1.5</td>
<td>R-134a</td>
</tr>
<tr>
<td>6945</td>
<td>631</td>
<td>-1</td>
<td>R-134a</td>
</tr>
<tr>
<td>7231</td>
<td>3700</td>
<td>+5</td>
<td>Propane</td>
</tr>
<tr>
<td>8041</td>
<td>263</td>
<td>+4</td>
<td>R-134a</td>
</tr>
<tr>
<td>4106</td>
<td>865</td>
<td>-1.5</td>
<td>R-134a</td>
</tr>
</tbody>
</table>

Table 1 – Typical offshore dewpoint control duties

3. CO2 REMOVAL

The cooling process temperature for CO2 removal varies somewhat with the process used, but is typically in the range -10°C to -30°C. Obviously, at these temperatures formation of ice and hydrates will occur, so the gas must first be dehydrated to remove water, usually by a glycol dehydration process.

Cooling duty for CO2 removal varies greatly with gas flow and CO2 content, but is generally well over 1000 kW. Due to the cost of the CO2 removal system it is usually only employed offshore for very large gas production facilities. The CO2 removal plant is frequently so large that it completely occupies a separate platform adjacent to the gas production platform.

4. OFFSHORE ENGINEERING CHARACTERISTICS

4.1 Safety

Safety anywhere in the oil and gas industry is always a paramount concern, but offshore, where escape opportunity is more limited, safety is treated even more conservatively than onshore. The Piper Alpha disaster when 167 people died on a platform in the North Sea in 1988 is still fresh in the industry’s memory, and events such as the Montara well blowout and subsequent fire in Australia in 2009 reinforce safety issues in the industry’s mind. For this reason, many (but certainly not all) of the major oil companies favour non-flammable refrigerants.

Despite the fact that an offshore gas platform may be handling thousands or tens of thousands of tonnes per day of flammable gas, in case of emergency the flow from the field can be rapidly shut off, and actual inventory on board at any time is generally small, perhaps only a few tonnes. There is a view that if a potential hazard, such as another 3-5 tonnes of propane refrigerant, can be easily avoided by using a non-flammable substitute, then it should be done. The view on FPSOs (floating production, storage and offloading facilities) where tens of thousands of tonnes of oil are stored for regular offloading to shuttle tankers, is usually somewhat more accepting of another few tonnes of flammable refrigerant.

Consequently, R-134a is frequently specified as the refrigerant for offshore use, for safety reasons. CO2 should be equally acceptable, but is virtually unknown. There should be no concern over the relatively high operating pressure of CO2, as production gas operating pressures are frequently in the range 10-15 MPa (100-150 bar.) The hydrocarbon industry understands high pressure, and is comfortable with it.
There may be another safety benefit of CO₂, in that a large charge of refrigerant CO₂ could be used as an emergency source of inert gas for fire suppression.

4.2 Heat rejection
Despite the presence of unlimited seawater for cooling, heat rejection is frequently by means of air-cooled condensers. In tropical areas, the warm water temperatures encourage vigorous growth of marine life such as mussels and barnacles inside exchangers and piping. In any area, mobile marine creatures such as fish, squid, jellyfish and even migrating crabs can be drawn into cooling water intakes causing frequent blockages and requiring high maintenance. In tropical areas, water temperature can also be very close to air temperature, so there is often not a great thermodynamic advantage for water-cooled systems. Nevertheless, the large physical area required for air-cooled exchangers and the limited space available offshore sometimes drives the design towards more compact water-cooled systems.

A large part of the world’s offshore oil and gas production occurs in temperate to tropical zones, between the latitudes of 25°N and 25°S. This band includes the Gulf of Mexico, Nigeria, north Africa, Australia’s north-west shelf, the South China, Timor, and Natuna Seas, and the Persian Gulf. There is certainly offshore oil and gas further north and south, such as the North Sea, Russia around Sakhalin Island, and Australia’s Bass Strait, but the majority of offshore gas production is in the temperate/tropical zone. Within this zone, average air temperatures for coastal locations in the coldest month are generally above 17°C (ASHRAE, 2009) and sea surface temperatures are generally above 22°C and may be as high as 30°C.

In this temperate/tropical zone above, whether seawater-cooled or air-cooled, condensing will be above 31°C for all or most of the year, so CO₂ systems will be transcritical.

4.3 Conservatism
The hydrocarbon industry, both onshore and offshore, is extremely conservative, and with good reason. The cost of a large offshore platform can exceed US$1 billion, operating costs of hundreds of thousands of dollars per day, and lost revenues in case of downtime can be millions of dollars per day. Offshore, due to space requirements, major equipment is commonly installed as a single 1 x 100% system, with no standby. Therefore any new technology to be adopted for offshore use must be thoroughly proven and seen to be absolutely reliable. Currently, CO₂ is perceived either as an old technology that was superseded many years ago, or as something experimental being pushed by environmental fanatics.

The huge costs of downtime, plus the safety requirements when handling large quantities of high-pressure, flammable fluids, have bred a highly conservative engineering culture. For this reason, getting a transcritical CO₂ system accepted for a major refrigeration system offshore will be difficult. R-134a is seen as the proven, safe option. The offshore gas industry will need a better argument to adopt CO₂ than “saving the planet”.
4.4 Cutting-edge
Paradoxically, despite the conservatism mentioned above, the industry also is at the forefront of technology. Compact heat exchangers such as plate-fin and printed circuit types are widely used. New technologies which can demonstrate potential advantages will be thoroughly explored by the industry to establish their viability, but once established, they are usually rapidly adopted.

4.5 Space and weight
Unlike onshore applications, space and weight are at a high premium offshore. A platform or FPSO has a fixed load-carrying capacity and a fixed area, and any technology which can demonstrate space or weight savings has a substantial interest for offshore. The high density of CO$_2$ makes it well suited to microchannel exchangers, and despite the higher pressures, CO$_2$ has potential for savings in space and especially weight, compared to conventional HFC-based systems.

5. CONCLUSIONS
CO$_2$ has many characteristics that make it a uniquely attractive refrigerant for offshore process cooling in the natural gas industry. This industry is largely unaware of CO$_2$ as a potential alternative to HFCs. It is hard-headed, conservative and financially-driven, yet will readily adopt new technologies once they are reliably proven to have advantages for the industry.

The old-but-new-again technology of CO$_2$ refrigeration has great potential for offshore application, but currently lacks a sponsor to make the investment necessary to demonstrate its viability for offshore application. A concerted effort is needed to raise awareness of CO$_2$ in the oil and gas industry before it will even be considered, and then to demonstrate that it can be competitive on first cost and running cost compared to more common alternatives.

REFERENCES