THE KVAERNER MEMBRANE CONTACTOR: LESSONS FROM A CASE STUDY IN HOW TO REDUCE CAPTURE COSTS

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ABSTRACT

As the field of carbon sequestration and management matures, it will become increasingly important to bring new technology to the marketplace. In this paper, we review one such successful effort, development of the Kvaerner membrane contactor, in order to learn lessons about what is required to commercialize technology. We identify seven ingredients for success.

INTRODUCTION

A major barrier to the implementation of carbon management and sequestration strategies is the significant cost associated with the separation and capture of CO_2 from flue gas. While there are many proposals on how to address this challenge, most ideas are never developed, let alone implemented. In this paper, through the use of a case study, we look at how ideas are generated and what it takes to put them into practice. The case study presented here is the development of the Kvaerner Membrane Contactor (Falk-Pedersen *et al.*, 2000). For the purposes of this paper, we will focus on natural gas combustion. However, the technology can also be applied to coal-fired combustion processes.

The standard process to separate and capture CO_2 from turbine exhaust gases is using an amine process. In an absorber, the exhaust gas is bubbled through the amine solution, which preferentially absorbs the CO_2. The amine solution is then heated and almost pure CO_2 is driven off in the stripper. The amine solution is then cooled and recycled to the absorber. This process is commercial, but has several drawbacks in the application to CO_2 sequestration. The process is very energy-intensive and too expensive for most applications today (Herzog, 1999; David and Herzog, 2000). In addition, the size and weight of the equipment is quite large. While this does not pose a problem for many sites, it does pose major problems for offshore applications.

Many approaches have been suggested to address the barriers to CO_2 sequestration posed by separation and capture. One path suggests improved solvents to replace today's amine solutions. Another suggests combustion of the fossil fuels in oxygen, rather than air, thereby drastically changing the exhaust gas composition to simplify the separation process. Yet another approach suggests steam reforming the natural gas, followed by the water-gas shift and CO_2 separation from the high pressure synthesis gas, leaving mostly hydrogen to go through the gas turbine. Given all these options, it is very instructive to understand why Kvaerner chose to develop the membrane contactor.

DEVELOPMENT OF THE MEMBRANE CONTACTOR

Phase 1 – Problem Definition

In 1991, the Norwegian government instituted a carbon tax in the North Sea of approximately 50 US dollars per tonne of CO_2 emitted to the atmosphere. A major source of these emissions was the exhaust gas from the gas turbines that powered these offshore operations. Since the CO_2 tax on these emissions accounted for about 20% of the operating cost on a platform, there was a great incentive to reduce them.

Motivated in part by this carbon tax, Kvaerner held some initial discussions in 1992 with several Norwegian oil companies concerning the reduction of CO_2 emissions from oil and gas operations in the North Sea. The initial scope was quite broad, covering improved efficiency, new power generation schemes (e.g., oxygen turbines), as well as removing CO_2 from flue gases of conventional gas turbines.

After some initial scoping studies, it was determined that pursuing a strategy of using a chemical (e.g., amine) scrubbing process to capture CO_2 from the turbine exhaust was the most promising. Note that it was at this very early stage of the project that the exhaust gas scrubbing path was chosen over oxygen combustion or steam reforming the natural gas. The commercial amine process was not well suited for offshore operations, primarily due to the significant weight and size of the process equipment. To adapt the amine process for offshore use, Kvaerner formed a Joint Industrial Project (JIP) with several oil companies and the Norwegian government to undertake the major R&D effort that was required to get these features down.

Phase 2 – Solution Definition

The R&D program focused on largest components in the process, namely the waste heat recovery unit, the absorber, and the stripper. Also, the recycling of exhaust gas to increase the CO_2 partial pressure was investigated (this work actually began in Phase I). The result of this later study was that a recycle up to 40% of the exhaust gas shows promise in theory, but it means that the gas turbines must be modified. Gas turbine modifications were beyond the scope of this project, so the final design had no exhaust gas recycle.

Work on the waste heat recovery unit was done in conjunction with SINTEF (see http://www.sintef.no) in Norway. The goal was to come up with a compact design for offshore applications. Eventually, Kvaerner decided not to continue working on this unit because it was not in their main business stream. Instead, they allowed ABB to lead this effort. The end result is that ABB now offers a commercial version of this compact waste heat recovery unit (Pål Kloster, 1998), with the first unit just being put into operation by Norsk Hydro (Oseberg field in the North Sea).

One approach in addressing the issues associated with the absorber and stripper was to investigate alternate packings. However, the constraints were fairly stringent. A certain amount of area was required for mass transfer and velocities were limited due to entrainment considerations. One packing that did show promise was Higee (vapor/liquid contacting in high acceleration fields within rotating packing).

Another approach identified by Kvaerner for improved absorbers and strippers was the membrane contactor (see Fig. 1). Here, membranes are used to increase mass transfer areas in a given volume and to avoid some of the problems associated with vapor/liquid contacting. The membrane itself does not perform the separation, that job is still done by the amine (see Fig. 2). Others had tried using membrane separators in past, but they were not a commercial success. Nonetheless, an R&D effort was started, with work conducted at TNO in the Netherlands. A large number of membrane types were tested, but the amines destroyed some and wetted others (causing blockage). Only one type of membrane worked, PTFE (Pdytetrafluoroethylene).

Based on the above research, engineering studies were conducted. It was concluded that a process containing a membrane absorber with a PTFE membrane from W. L. Gore and Associates GmbH, a Higee stripper, the compact waste recovery boiler, and aquifer disposal (similar to Sleipner) was feasible. Therefore, it was decided to proceed to the next phase to see if the components performed as required.

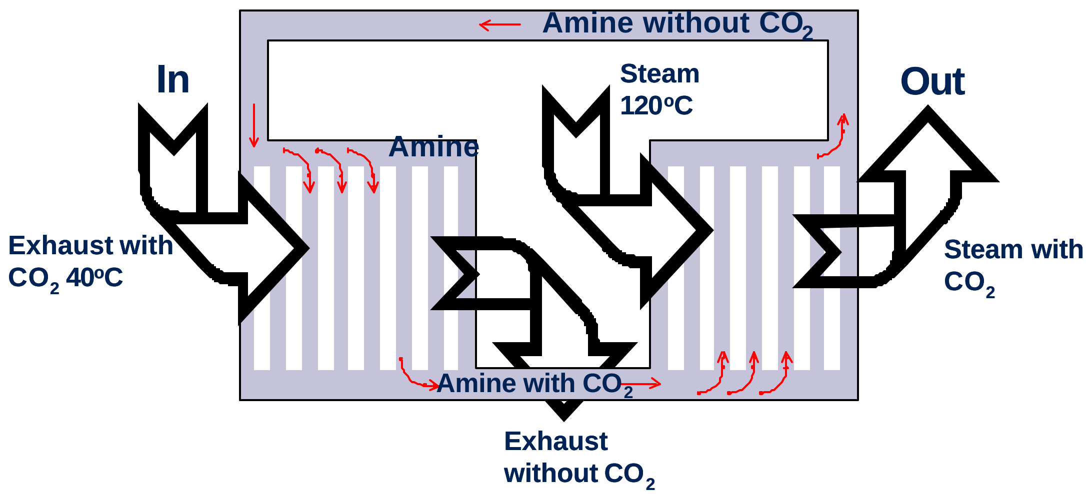

Figure 1: Schematic of a membrane contactor absorber/stripper system.

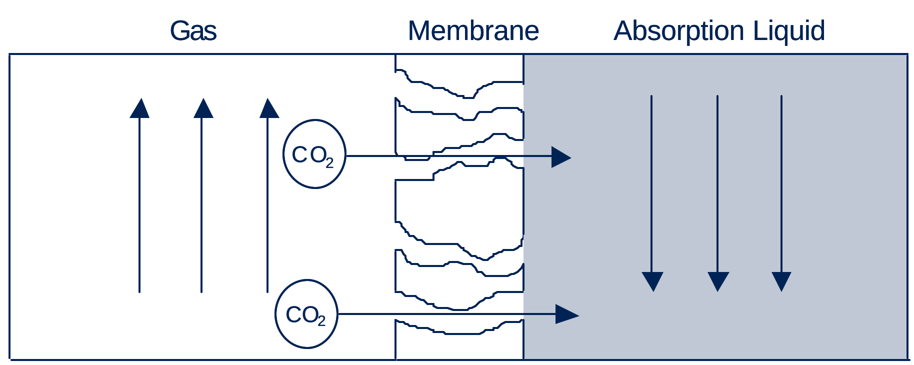

Figure 2: In a membrane contactor, the vapor/liquid contacting is done through a non-selective membrane, improving performance and reducing equipment sizes.

Phase 3 – Performance Testing

The performance tests were initiated in 1995. The membrane absorber was tested simultaneously at TNO, GKSS in Hamburg, and at Gore in Munich. The testing was kept completely independent, with no communications between the different groups. So when all three groups concluded that the membrane absorber met the performance specifications, Kvaerner was confident enough to proceed on future developments.

At the same time, Kvaerner started to look for other applications of the membrane absorber technology. The most obvious was for natural gas treatment (sweetening). Kvaerner was involved in the Sleipner T project, so they had first hand knowledge of the need for improved gas sweetening equipment offshore. Laboratory tests were performed on natural gas and the results were very encouraging. The development project was now split in two, one for the original exhaust gas application and the other for the natural gas treatment market.

The Higee stripper was tested at the University of Texas at Austin. Based on the performed tests, it was decided not to pursue the Higee stripper. Instead, it was decided to test the membrane contactor as a desorber (i.e., stripper). The initial tests looked promising and the membrane contactor replaced the Higee stripper in the process scheme. It was now time for pilot testing and scale-up.

Phase 4 – Pilot Testing and Scale-Up

Pilot tests started on the membrane absorber for natural gas treatment. This had the largest near-term benefits, as natural gas treatment is a commercial operation today. On the other hand, CO_2 removal from exhaust gases has very limited commercial applications today (but may become a very large market in the future). The initial pilot tests occurred at a large gas terminal in Scotland using activated MDEA. The pilot unit was installed in parallel to the existing column and with a capacity of 1% of the process train flow. The gas to liquid ratio was the same as the commercial column. The tests ran from April 1998 until November 1999. A number of different membranes were tested, with the longest test on a single membrane going 5000 hours. Additional tests of the membrane absorber were held at the Shell Fandango field in Texas, where a physical solvent was tested instead of amines. Also, dehydration with glycol was tested.

One example of the types of problems that had to be addressed in this type of testing is pressure regulation. This is not a critical issue for atmospheric flue gas, but is for high pressure natural gas. Test pressures went as high as 88 barg, and a novel system had to be developed to keep the pressures on the liquid and vapor sides of the membrane equal. The natural gas treatment process is now commercially available, offering the following advantages: 70-75% weight reduction and 65% space reduction for the absorber and stripper (see Fig. 3), reduced stripper reboiler duty, reduced solvent loss, and process insensitivity to motion.

Conventional Process **Membrane Process**

Figure 3: Comparison of sizes between conventional amine separation process and a process incorporating the membrane contactor.

The exhaust gas process is undergoing pilot testing at the Statoil Gas Terminal in Kårstø. This unit has about 3200 times the throughput of the smallest laboratory units used in the development. The unit at Kårstø has the identical design to the large scale laboratory unit built at SINTEF. Both are complete CO_2 removal plants with both conventional columns and membrane absorbers and strippers. Some of the issues being addressed included scale-up, durability of the membrane contactors, and verification of the operational benefits. In order to optimize their design, different membrane modules are being tested. Projected benefits of the membrane contactor include reducing installed cost by 30-40% for offshore units, with similar operating cost reductions. Finally, the membrane contactor will enable further cost and energy savings by removing constraints on the solvent, thereby allowing solvent optimization.

INGREDIENTS FOR SUCCESS

The field of carbon management and sequestration has come a long way in the past decade. Starting almost from scratch, a community of researchers has formed and laboratory and modeling work has proliferated. However, very little technology has made it into the marketplace. This is a major challenge for the next decade. That is why learning from the few examples of successful development of commercial technology is so important.

In analyzing the Kvaerner experience, we highlight seven key ingredients that contributed to the successful effort. The first three deal with the economics, the last four with the technology.

- **Incentive**. Whether external or internal, there needs to be an incentive to start the project. In this case it was the North Sea carbon tax.

- **Market**. There has to be a customer for the final product. At the beginning of the project, there was a potential customer for the exhaust gas process. However, as the project proceeded, the customer's interest lessened. By adding the parallel natural gas treatment process, market interest was maintained. Without this addition, the project would likely have been cancelled.

- **Collaboration**. Given the risks and uncertainty, it is hard for one company to proceed alone. That is why Kvaerner formed a JIP and sought government funding.

- **Start with problem, not solution**. Looking around the carbon management and sequestration community, we see too many hammers (solutions) looking for nails (problems). The original objective of this project was not to develop a membrane contactor, it was to reduce CO_2 emissions in the North Sea. The development of the membrane contactor was the end result of an open, objective process that considered many alternatives.

- **Focus**. While the process was very broad to start, the initial phase quickly focused the project (choose chemical scrubbing over oxygen combustion or steam reforming). Also, Kvaerner allowed the development of the waste heat recovery boiler to be taken over by ABB, so they could focus project resources on the absorber and stripper.

- **Don't reinvent the wheel**. Kvaerner did not try to develop a new membrane for the process, rather they did extensive testing of existing ones. As happens quite often, the solution came from a membrane developed for completely different reasons.

- **Flexibility**. You have to be your toughest critic. Set up objective and credible performance testing and listen to the results. When the Higee stripper did not perform as required, Kvaerner initiated a plan B and developed the membrane desorber.

So while the technical achievements of this project are impressive, the lessons it can teach us about technology development for an uncertain market may be even more important.

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