Cooling Philosophy Study

CO_2 Capture Facility

Kårstø, Norway

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1.0 INTRODUCTION

This report outlines the cooling water philosophy used in the system and equipment design for the Karsto CO_2 Capture and Compression (CCC) Project Front End Engineering Design (FEED) Study.

The Karsto CCC Project is located adjacent to the Karsto gas terminal and the combined cycle power plant (CCPP) owned and operated by Naturkraft AS. The CCC plant is owned by Gassnova SF. The CCC project's technology is based on the use of amine for the bulk removal of CO_2 from a flue gas stream by liquid chemical absorbents. The amine plant mainly consists of flue gas ducting and blowers, direct contact coolers, absorption columns, a stripper column, reboilers, reclaimer, and CO_2 compression and drying, along with other equipment such as pumps, filters, and heat exchangers.

Flue gas from the adjacent CCPP is cooled by water spray cooling and discharged into the absorber columns for processing. Off gas from the absorbers leaves the absorber stacks and is released to the atmosphere after processing. The CO_2 gas product is dried and compressed into liquid and pumped to the CCC plant battery limit (B/L). Gassnova is responsible for the compressed CO2 pipeline and use outside the CCC plant B/L.

The equipment that requires cooling water is listed below:

- Absorber 1 wash water cooler
- Absorber 2 wash water cooler
- Lean amine cooler
- Overhead stripper condenser
- CO_2 compressor 1st stage intercooler
- CO_2 compressor 2nd stage intercooler
- CO_2 cooler
- Closed cooling water (CCW) heat exchanger

2.0 COOLING PHILOSOPHY

The CCC Plant cooling philosophy is based on the following three system design options:

- Option 1: Combined direct and in-direct cooling system
- Option 2: 100-percent direct cooling system
- Option 3: In-direct cooling system

The combined cooling water system design in option 1 uses seawater as the cooling medium for all of the equipment, except for the CO_2 compressor auxiliaries where an in-direct closed cooling water (CCW) system is used.

The 100-percent direct cooling water system design in option 2 would use sea water as the cooling medium for all of the equipment.

The in-direct cooling water system design in option 3 would use a CCW system to supply cooling water for all of the equipment and seawater would be used to reject the heat from the CCW system.

For any of these cooling water system designs, Gassnova SF is providing new intake and outlet tunnels and pits outside the CCC Plant B/L. The CCC Plant will have its own dedicated seawater supply and discharge piping system.

The major equipment required for the cooling water system designs are listed below:

- Sea water cooling pumps (2x100%)
- Sea water cooling booster pumps (2x100%
- Absorber 1 wash water cooler (1x100%)
- Absorber 2 wash water cooler (1x100%)
- Lean amine cooler (1x100%)
- Overhead stripper condenser (4x25%)
- CCW pumps (2x100%) - Not required for 100-percent direct cooling
- CCW heat exchanger (1x100%) - Not required for 100-percent direct cooling
- CO_2 compressor 1st stage intercooler (1x100%)
- CO_2 compressor 2nd stage intercooler (1x100%)
- CO_2 cooler (1x100%)

The use of plate and frame type heat exchangers is more efficient and economical for similar sizes than shell and tube type. The wash water coolers, lean amine coolers, overhead stripper condenser, and CCW heat exchanger would all be plate and frame type heat exchangers. The design pressures on either cooling medium side of these heat exchangers are relatively low; that makes them ideal for the use of plate and frame. Seawater would be piped directly to this equipment.

Several factors preclude the use of plate and frame type heat exchangers for the CO_2 compressor intercoolers and CO_2 cooler. One factor includes the high design pressures for this equipment that exceeds the ratings available on the market for plate and frame heat exchangers. As a result, shell and tube type heat exchangers would be used for the CO_2 compressor intercoolers and CO_2 cooler. With the CO_2 product having a much higher design pressure than the cooling water side, the CO_2 will be on the tube side of the coolers and cooling water on the shell side for the in-direct cooling system design. For the 100-percent direct cooling design, the CO2 will be on the shell side and the sea water will be on the tube side. To preclude problems with fouling and maintenance (cleaning), the use of direct seawater cooling on the shell side is not recommended.

Table 1 provides a comparison summary of the differences between the three cooling system preliminary designs.

3.0 CONCLUSION

Based on the information in Table 1, Option 3 is not considered a viable design. The evaluation of Option 1 shows an additional capital cost of approximately $600,000 ($900,000 for the CCW system verses the added cost of $300,000 to provide for the special material for the CO2 Compressor coolers for Option 2), and with a penalty for present net value of the life cycle cost of energy of $1.3M for the CCW pump operation. This verses Option 2. As a result, the 100-percent direct cooling water design of Option 2 will be used for the Karsto CCC plant.

This study is based on the information available during the short duration and preliminary design of the FEED phase. We appreciate that the decision on cooling approach is a critical aspect of the Karsto overall project design and impacts capital costs, operating costs, the environmental impact and the project risk profile. During the EPCI phase, this decision will be revisited to ensure that all aspects of the design, costs, and environmental impact and risks are assessed in detail.

TABLE 1

Component	Option 1 - Combined Cooling Design	Option 2 - 100-Percent Direct Only Cooling Design	Option 3 - In-Direct Only Cooling Design	Comparison Remarks
Seawater cooling pumps	Req'd	Req'd	Req'd	Same size vertical pumps w/duplex SS materials for all three design options.
Seawater cooling booster pumps	Req'd	Req'd	Req'd	Same size horizontal centrifugal pumps w/duplex SS materials for Options 1 & 2. No booster pumps for Option 3.
Absorber 1 wash water coolers	Req'd w/Titanium Plates	Req'd w/Titanium Plates	Req'd w/SS Plates	No difference in size between Options 1 & 2. For Option 3, the cost of the SS cooler would be approximately one-half of the one with titanium plates. Based on the Option 3 costs associated with the large CCW pumps, piping, etc. no further evaluation of this option as a viable design is considered necessary. All three design options use plate & frame type heat exchangers.
Absorber 2 wash water coolers	Req'd w/Titanium Plates	Req'd w/Titanium Plates	Req'd w/SS Plates	No difference in size between Options 1 & 2. For Option 3, refer to the statement above. All three design options use plate & frame type heat exchangers.
Lean amine cooler	Req'd w/Titanium Plates	Req'd w/Titanium Plates	Req'd w/SS Plates	No difference in size between Options 1 & 2. For Option 3, refer to the statement above. All three design options use plate & frame type heat exchangers.
Overhead stripper condenser	Req'd w/Titanium Plates	Req'd w/Titanium Plates	Req'd w/SS Plates	No difference in size between Options 1 & 2. For Option 3, refer to the statement above. All three design options use plate & frame type.
CCW pumps	Req'd w/SS impellers	Not Req'd	Req'd w/SS impellers	CCW pumps are not required for Option 2. For Option 1, the additional OOM cost of the two CCW pumps, CCW heat exchanger and CCW expansion tank is approximately $900,000. The energy consumption is higher by

				approximately 195 kW for Option 1. This present worth of this energy cost over 25 years is approximately $1.3M. For Option 3, the CCW pumps would be larger than for Option 1 so 3x50% pumps would be required in lieu of 2x100%. The additional cost for Option 3 is significant and the additional energy consumption is approximately 1650 kW. Option 3 is not considered an economically viable design. Both Options 1 & 3 designs require horizontal centrifugal pumps.
CCW heat exchanger	Req'd w/Titanium Plates	Not Req'd	Req'd w/Titaniu m Plates	CCW HX's are not required for Option 2. For Option 1, the additional cost is included in the CCW pump above. For Option 3, the CCW Hx's will be approximately 10-times larger than for Option 1. The larger size will require additional CCW HXs (i.e., 5x20%). Again, Option 3 is not considered an economically viable design. Both Option 1 & 3 designs require plate & frame type.
CCW expansion tank	Req'd	Not Req'd	Req'd	CCW expansion tank is not required for Option 2. For Option 1, the additional OOM cost is included in the CCW pump above. For Option 3, the CCW expansion tank would be larger than for Option 1.
CO_2 compressor 1st stage intercooler	Req'd w/SS tubes & CS Shell	Req'd w/Titanium tubes & CS Shell	Req'd w/SS tubes & CS Shell	Shell & Tube type cooler is required. No difference in size between Options 1 & 3. For these two options, the CO2 is on the tube side and the CCW is on the shell side. For Option 2, the CO2 is on the shell side and the sea water is on the tube side. The cooler for this option requires approximately 50% additional surface area, titanium or SeaCure tubes, and neoprene lined channels. The additional OOM cost of the cooler for Option 2 is approximately $100,000.
CO_2 compressor 2nd stage intercooler	Req'd w/SS tubes	Req'd w/Titanium tubes	Req'd w/SS tubes	Shell & Tube type cooler is required. No difference in size between Options 1 & 3. For these two options, the CO2 is on the tube side and the CCW is on the shell side. For Option 2, the CO2 is on the shell side and the sea water is on the tube side. The cooler for this option requires approximately 12% additional surface area. titanium or SeaCure tubes, and neoprene lined channels. The additional OOM cost of the cooler for Option 2 is approximately $80,000.
CO_2 cooler	Req'd w/SS tubes	Req'd w/Titanium tubes	Req'd w/SS tubes	Shell & Tube type cooler is required. No difference in size between Options 1 & 3. For these two options, the CO2 is on the tube side and the CCW is on the shell side.

				For Option 2, the CO2 is on the shell side and the sea water is on the tube side. The cooler for this option requires approximately 12% additional surface area, double the wall thickness of the carbon steel shell, titanium or SeaCure tubes, and neoprene lined channels. The additional OOM cost of the cooler for Option 2 is approximately $120,000.
Piping	Fiberglass (Sea Water) & Carbon Steel (CCW)	Fiberglass	Fiberglass (Sea Water) & Carbon Steel (CCW)	The difference in piping quantities & cost would be approximately the same between Options 1 & 2. For Option 3, the quantity and size of CCW piping to and from the various heat exchangers is approximately the same as the sea water cooling piping. Also, the quantity of large (60" dia) sea water piping is approximately the same between Options 1 & 3. Option 3 is not considered an economically viable design.