Process Description

CO_2 Capture Facility

Kårstø, Norway

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1.0 INTRODUCTION

It is the intention of the Norwegian Government to develop a carbon dioxide capture and compression (CCC) project in association with an existing 420 MW gas-fired combined cycle power plant (CCPP) which is located in Karsto, Norway.

The CCC plant will recover at least 85% of the CO_2 contained in the flue gas from the CCPP and deliver liquefied CO_2 to the battery limit of the plant.

2.0 PROCESS DESCRIPTION OF NORMAL OPERATION

The CCC plant consists of the following systems:

- Flue gas diversion – where the flue gas is directed from the existing stack to the CCC plant
- Flue gas cooling – the flue gas as supplied is too hot to process efficiently in the amine system and will be cooled to its saturation temperature before entering the absorber
- CO_2 Absorption – parallel absorbers remove the CO_2 from the flue gas using an amine solution
- Heat Integration – this system recovers heat from internal streams to enhance the energy efficiency of the plant
- CO_2 Stripping – the amine is regenerated for reuse by liberating the CO_2 from the amine solution
- CO_2 Compression and drying – the CO_2 is compressed, dried, further compressed and liquefied to meet the CO_2 specifications
- Amine reclamation – this system removes heat stable salts (HSS) from the amine solution
- Amine storage – fresh amine and lean amine are stored and injected in to the absorption system to maintain the amine solution concentration

These systems are described in detail in the following sections. Refer to the process flow diagrams [Ref 5.1] to facilitate understanding. Any operating conditions are based upon the "normal case, reclaimer on" Heat & Mass Balance.

2.1 FLUE GAS DIVERSION AND COOLING

The flue gas will be diverted from the existing CCPP stack in a manner that will not affect the operation of the power plant. The duct that will direct the flue gas to the CCC plant will be tied in to the existing stack near its base. A shutoff damper will be installed at this point to isolate the duct from the main stack while the CCC plant is shutdown. In normal operation, the shutoff damper will be wide open and the existing stack damper will be closed. The stack damper will be replaced with a modulating tight shutoff damper. The stack damper will be closed when the CCC plant is in operation to divert 100% of the flue gas in to the CCC plant, or modulated during startup/shutdown of the CCC plant or if the CCC plant is operating at a reduced capacity.

The flue gas will be drawn through the duct to the CCC plant by two blowers operating in parallel. The Flue Gas Blowers (K-101 / K-102) will be controlled using variable frequency drives and suction throttling dampers to control the pressure on the main duct and to maintain the desired flow through each blower. It is necessary to maintain precise pressure control on the duct to avoid any negative impact on the CCPP operation and to prevent air ingress in to the CCC plant through the stack opening.

The flue gas duct will be insulated to maintain a minimum surface temperature greater than 75 °C to avoid sulfuric acid condensation.

The flue gas will be analyzed online for CO_2 concentration, and flow to each absorber. These measurements are used by the CO_2 master to adjust the flow of lean amine to the absorbers.

At the inlet to the CCC ductwork, a temperature measurement is used as a feed forward signal to adjust the amount of water injected through the Flue Gas Water Fogger System (X-101 A) which will cool the flue gas from 90 °C to approximately 45 to 50°C. A temperature control signal from downstream of the fogging system is used for final temperature control and will ensure that the gas is maintained above its dew point.

After passing through the Flue Gas Blowers (K-101, K-102), the flue gas temperature increases slightly and a secondary fogging system is installed on the discharge of each blower. The water flow rate to the Flue Gas Water Fogger System (X-101 B/C) is adjusted by a downstream temperature controller. It is advantageous to cool the flue gas as much as possible (without reaching the dew point) for optimum CO_2 absorption.

The water used in the Flue Gas Water Fogger System (X-101 A/B/C) is recycled process water that is directed to the Process Surge Water Tank (TK-104). The Flue Gas Water Fogger Supply Pump (P-109 A/B) increases the pressure of the water to allow the water to be filtered and injected in to the duct through atomizing nozzles to cool the flue gas to the desired temperature.

2.2 CO_2 ABSORPTION

The absorption of the carbon dioxide from the flue gas is accomplished using two absorption towers operating in parallel.

Cooled flue gas enters the bottom of the CO_2 Absorbers (T-101, T-102) through inlet distribution device to ensure equal gas flow across the tower's cross section prior to entering the first packed bed. All absorber beds will be packed with stainless steel structured packing. The flue gas is contacted counter-currently with 35 wt. % monoethanolamine (MEA) solution as it passes through the absorption section of the tower.

Partially regenerated amine (semi-lean amine) is injected part way through the packed bed section to absorb CO_2 from the flue gas. The semi-lean amine is distributed across the packed bed using a liquid distributor.

Fully regenerated lean amine is directed to the top of packed bed section using a liquid distributor to provide the greatest CO_2 concentration gradient between the flue gas and the lean amine solution. The lean amine flow to the absorber is adjusted based on the total amount of CO_2 in the flue gas entering the absorber and in the stack gas as it exits the absorber tower to achieve at least an 85% CO_2 capture rate. As it leaves the absorption section, the flue gas passes through a mist eliminator to limit amine solution carry over in to the water wash section of the absorber tower.

Internal to the absorbers, the water wash section consists of two beds of stainless steel structured packing. Wash water is prevented from entering the absorption section of the column by using a chimney tray. The water is collected on the chimney tray and pumped out by the Wash Water Recirculation Pump (P-102 A/B (absorber 1), P-104 A/B (absorber 2)). The recirculated water is first cooled in the Wash Water Cooler (E-101 (absorber 1), E-104 (absorber 2)) and is then injected above the second bed of packing on flow control. The wash water is distributed across the bed using a liquid distribution tray. The wash water temperature is controlled by a temperature controller in the flue gas exit stream. Above the first bed, fresh process water make-up is supplied from the discharge of the Absorber Makeup Water Pump (P-119 A/B). Level control on the chimney tray sends the excess water (make-up water and water condensed from the flue gas) and collected amine back to the lean amine stream. This blowdown of the water wash system keeps the amine concentration from building up in the water wash system and helps to maintain the lean amine concentration at 35 wt. %. The water wash section serves to reduce both the ammonia and MEA content in the flue gas to < 5 ppm each. In addition, the water wash section cools the flue gas to approximately 40 - 45°C to reduce the amount of water vapor leaving the tower. After passing through a final mist eliminator, the flow rate of the flue gas is measured and is then released to atmosphere.

The rich amine leaves the bottom of the CO_2 Absorbers (T-101, T-102) and through the Rich Amine Pump (P-101 A/B (absorber 1), P-124 A/B (absorber 2)). An equalization line between the two towers ensures that the liquid is pumped out of the towers at equal rates. A high level control signal from the absorber bottoms diverts any excess lean amine to the lean amine solvent storage tank to balance system inventories.

2.3 CO_2 STRIPPING

The rich amine is pumped through the rich amine filter to remove particulates 10 microns in size or greater. Approximately 25% of the rich amine flow is diverted through a series of heat exchangers, which is described in the Heat Integration section (2.4). The other 75% of the rich amine flow is preheated to approximately 115-120 °C in the Lean / Rich Amine Heat Exchanger (E-108) prior to being fed to the Stripper (T-103).

The rich amine falls through the packed section of the Stripper (T-103) where it is counter-currently heated with steam generated in the Stripper Reboiler (E-110). As the temperature of the rich amine increases, the CO_2 is liberated from the solution.

Heat input to the column is achieved through the use of plate and frame thermosyphon reboilers. Liquid is diverted in to the Stripper Reboiler (E-110) via a segregated sump compartment. Excess liquid overflows from the reboiler sump compartment to the lean amine sump compartment for return to the absorber. The heating medium supplied to the Stripper Reboiler (E-110) is approximately 2 barg saturated steam.

Level control in the bottom of the Stripper (T-103) is achieved by balancing the flow of rich amine feed to the Stripper (T-103) with lean amine that is fed to the CO_2 Absorbers (T-101, T-102) in a 3-element arrangement.

Vapor leaves the top of the Stripper (T-103) at approximately 105°C and 1 barg and is fed to the Overhead Stripper Condenser (E-111), cooling the stream to approximately 50°C. The condensed MEA and water are separated from the gas stream in the Stripper Reflux Drum (V-102). From the Stripper Reflux Drum (V-102), approximately 10% of the liquid is pumped back to the column as reflux via the Reflux Pump (P-107 A/B) while the balance is used as process water make-up to the Process Water Surge Tank (TK-104). The gas stream leaving the Stripper Reflux Drum (V-102) is approximately 97% CO_2, with the balance of the composition being predominantly water vapor.

The lean amine flows from the bottom of the Stripper (T-103) to the suction of the Lean Amine Pump (P-105 A/B).

2.4 HEAT INTEGRATION

Approximately 25 wt. % of the rich amine leaving the Rich Amine Filter (F-102 A/B) is diverted to the Semi-Lean / Rich Amine Heat Exchanger (E-103) where it is heated to about 108°C. The rich amine then flows to the Flash Feed Heat Exchanger (E-107) where it is heated by the stripper bottoms stream to approximately 113°C. It then enters the Flash Feed Heater (E-109) where it is heated with steam generated in the compressor section to approximately 120°C. The rich amine is flashed in the Semi-Lean Flash Drum (V-101). The CO_2 - rich vapor leaves the top of the Semi-Lean Flash Drum (V-101) and is directed to the Stripper (T-103). The semi-lean amine leaves the bottom of the Semi-Lean Flash Drum (V-101) and is pumped via the Flash Drum Pump (P-106 A/B) through the Semi-Lean / Rich Amine Heat Exchanger (E-103) where it is cooled to approximately 60°C. The cooled semi-lean amine is then fed to the two CO_2 Absorbers (T-101, T-102).

The Lean Amine Pump (P-105 A/B) forces the stripper bottoms through the Lean Amine Filter (F-105 A/B) to remove particulates larger than 10 microns in size. Approximately 3% of the lean amine mass flow is directed to the Amine Reclaimer (X-102), which will be discussed in section 2.6. The balance of the flow passes through the Flash Feed Heat Exchanger (E-107) where a portion of the rich amine is heated to produce semi-lean amine, which is described above. The stripper bottoms is then further cooled as it exchanges heat with the bulk rich amine flow in the Lean / Rich Amine Heat Exchanger (E-108).

The stripper bottoms is further cooled to about 56°C in the Lean Amine Cooler (E-102) before the flow is split and fed back to each of the two CO_2 Absorbers (T-101, T-102). The temperature of the lean amine returning to the CO_2 Absorbers (T-101, T-102) is a key variable in controlling the overall recovery of CO_2, maintaining the system water balance and the heat input required to the Stripper (T-103). See section 3.3 for further discussion on the system water balance.

2.5 CO_2 COMPRESSION AND DRYING

The gas stream leaving the Stripper Reflux Drum (V-102) is approximately 97% CO_2, with the balance of the composition being predominantly water vapor. Any liquid that is carried over from the Stripper Reflux Drum (V-102) or condenses in the line is removed in the CO_2 Compressor Suction Drum (V-103). The gas enters the CO_2 Compressor (K-103) suction at less than 1 barg and is compressed to approximately 92 barg. Some of the heat generated during compression is recovered by generating steam and using that steam to heat the rich amine in the flash feed heat exchanger.

CO_2 drying to less than 50 ppmw is done by passing the partially compressed gas to the CO_2 Drying Package (X-104) - an adsorption bed type dryer. Two beds are used, one for drying while the other will undergo a regeneration process using a side stream of dried CO2 as a drying media. The regeneration gas is returned to the compressor inlet for recycle.

The gas is then cooled in the CO_2 Cooler (E-117) where the CO_2 stream is totally condensed. The liquid CO_2 is then fed to the CO_2 Surge Drum (V-106), where it is pumped to the battery limit by the CO_2 Product Sendout Pump at a pressure of 200 barg on level control. Any non-condensable gas that collects in the CO_2 surge drum is vented back to the CO_2 Absorbers (T-101, T-102) stack.

2.6 AMINE RECLAMATION

Approximately 0.5 - 1 % of the lean amine mass flow from the Lean Amine Pump (P-105 A/B) discharge is fed to the Amine Reclaimer (X-102). During normal operation, the amine is subject to thermal degradation and undergoes chemical reactions, producing undesirable compounds. Chemical reactions with oxygen and sulfur dioxide in the flue gas can produce acids, which combine with amine, producing heat stable salts. Amine bound in heat stable salts does not absorb carbon dioxide. In the Amine Reclaimer (X-102), amine is released from the heat stable salts by heating with high pressure steam and through a neutralization reaction with soda ash. Water is added to the Amine Reclaimer (X-102) to improve amine recovery and reduce the amount of amine degradation that occurs in the reclaiming process. Much of the amine and water from the lean amine solution is vaporized and returned to the Stripper (T-103). The residual sludge is removed for proper disposal.

2.7 AMINE STORAGE

2.7.1 Concentrated Amine Storage

Fresh, concentrated amine is delivered by truck and stored in the Amine Storage Tank (TK-101). Fresh amine is made up to the system as required using the Fresh Amine Metering Pump (P-110 A/B) to maintain the solution concentration at 35%.

2.7.2 Lean Amine Solvent Storage

The Lean Amine Solvent Storage Tank (TK-102) is used to store lean amine that is removed from the system based on the absorber tower level control as required. During a shut down of the plant, this tank is also used to store the amine inventory. Amine is returned to the system using the Lean Amine Solvent Fill Pump (P-112 A/B).

3.0 PROCESS DESIGN CONSIDERATIONS

3.1 AMINE CONCENTRATION

Generally, increased solvent concentrations provide improved CO_2 removal efficiency. As solvent concentration increases, so does the need to use corrosion inhibitors to reduce corrosion in equipment constructed from carbon steel. For the Karsto CCC plant, a 35 wt% MEA solution has been selected to provide optimum energy efficiency. Stainless steel equipment is selected to avoid the operating costs associated with a corrosion inhibitor program.

3.2 CO_2 RECOVERY

The heat & material balances that have been generated for this plant are based upon 85% recovery of the inlet CO_2. While the plant is to be designed for 97% availability, it has been assumed that maintenance requiring plant shut down will be executed in concert with CCPP outages.
CO_2 recovery in excess of 85% is achievable with this process but will require increased steam consumption.

3.3 PLANT WATER BALANCE

The hot, dry flue gas from the CCPP leaves the CCC plant saturated with water vapor. It is necessary to manage the flue gas temperature by controlling the rate and temperature of the recirculated wash water flow and the temperature of the lean amine fed to the absorbers. If the flue gas temperature is maintained at too high of a level, a significant quantity of externally supplied make-up water will be necessary. Conversely, if the temperature is maintained too low, the flue gas leaving the absorber will not adequately disperse and water will need to be removed from the system and treated. Ideally, the system will be controlled to maintain the water balance – no import or export of water. The design includes a surge water tank to manage fluctuations in the system water balance.

In the event that external water is required, the system design has allowed for approximately 30 gpm of water make-up.

The situation in which water needs to be released from the system needs to be carefully managed. Water generated in the wash section contains 1-2% MEA and reflux purge water generated in the stripper contains less than 0.1% MEA. The flue gas temperature and water balance must be controlled to recycle these streams within the system to reduce amine make-up rates and water treatment costs. Water generated in the compression section contains a small amount of CO_2 and trace amounts of MEA and other components. In situations where the water balance requires water to be removed from the system, the water generated in the compression section - approximately 15 gpm – should be released from the system preferentially.

3.4 LOCATION OF SAMPLING AND MEASURING POINTS FOR ANALYSIS

As a minimum, the following locations have been identified for sampling / measuring:

- Main flue gas duct from CCPP plant – to control the CO_2 recovery rate
- Absorber off gas to atmosphere - to control the CO_2 recovery rate and for air permit reporting requirements
- Lean amine to the absorbers – to ensure that the amine concentration and quality is maintained in the system
- Rich amine exiting absorber – to ensure proper solvent performance and that all CO_2 is removed prior to shutdown.
- The compressor inlet – to ensure the CO_2 entering the compressor will be compatible with compressor requirements
- Stripper overhead condenser liquid – to check contaminants recycling to the surge water tank
- The CO_2 product stream - to ensure the product specifications are being met
- Materials removed from the system, e.g. reclaimer sludge, excess water, amine sump liquid – to ensure proper disposal
- Sea water inlet and outlet headers – to ensure discharge quality specifications are met
- Closed cooling water – to ensure no contaminants in the system
- Steam condensate return lines – to ensure condensate return quality meets CCPP requirements
- Process makeup water – to ensure no contaminants are introduced to the CCC
- Process Water Surge Tank - to monitor amine and ammonia levels
- Wash water return lines to the absorbers – to monitor amine and ammonia levels
- Amine storage tanks (concentrated and 35%) – to confirm correct amine concentration and check for contaminants

Frequency, sampling / analysis method and other locations as required will be determined at a later stage.

4.0 MODES OF OPERATION

4.1 PART LOAD OPERATION

The ability to manage part load operation is easily facilitated with the dual flue gas blower and absorber system. As the pressure in the main flue gas duct drops, a combination of suction throttling and motor speed adjustments (via the blower variable frequency drives), reduce the amount of gas drawn from the CCPP stack. The amine circulation rate is adjusted to maintain the desired CO_2 recovery by the CO_2 master controller.

4.2 STANDBY AND IDLE MODES

While not energy efficient, the amine and CO_2 compression systems can be placed on circulation for a period of time. Equipment must be monitored to ensure that it is operating within manufacturer guidelines. If there is no flue gas flow through the absorbers, air will enter the absorber and contaminate the amine. Amine is degraded by oxygen so the duration of circulation with no flue gas flow should be minimized during startup/shutdown.

If the unit is expected to be idle for sometime, the system should be shut down according to procedures and the entire system be drained and purged.

4.3 START UP OPERATIONS

Start up of the CCC plant needs to be conducted in such a manner that the CCPP is not affected.

Normal procedures for the safe start up of the CCC plant such as ensuring all equipment and control systems are in good working order, purging air from the system, establishing utility systems all apply and are assumed to be in place.

Amine circulation is started and the system is warmed up to operating temperature. Once stable circulation and heating have been established, flue gas from the CCPP stack can be partially directed to the absorbers using the flue gas blowers' variable frequency drives and suction throttling dampers. As the amine system operation is stabilized, the gas flow rate can be gradually increased. CO_2 produced in the stripper would be vented to the stack from the stripper reflux drum until sufficient quantities were available to be fed to the CO_2 compressor. CO_2 can be vented from the CO_2 surge drum to the stack until product specifications are met.

4.4 SHUT DOWN OPERATIONS

Controlled shut down of the system is handled by slowly re-directing CCPP flue gas to the stack from the CCC plant. The amine inventory should be processed in the stripper to ensure that it is lean. Process equipment is shut down as it is warranted and safe to do so. The amine inventory should be transferred from the absorbers to the lean amine solvent storage tank so as to avoid oxygen contamination.

Emergency shutdown will be managed via the emergency shut down (ESD) system and operating procedures to ensure that it is handled in a safe, environmentally acceptable and equipment-protecting manner. The ESD system isolates the CCC plant from the CHPP, isolates steam sources, and shuts down amine circulation within the plant. Following emergency shutdown condition causing the shutdown and the state of the plant will need to be evaluated prior to restart. In general, equipment will need to be reset to the state required for a normal startup, and then the normal start sequence can be followed after an emergency shutdown.

5.0 REFERENCES

5.1 PROCESS FLOW DIAGRAMS

- 25474-000-M5J-YA-00001 / 10112936-PB-P-FLD-0002
- 25474-000-M5-BA-00001 / 10112936-PB-P-FLD-0003
- 25474-000-M5-CN-00001 / 10112936-PB-P-FLD-0004
- 25474-000-M5-CN-00002 / 10112936-PB-P-FLD-0005
- 25474-000-M5-CN-00003 / 10112936-PB-P-FLD-0006
- 25474-000-M5-CN-00004 / 10112936-PB-P-FLD-0007
- 25474-000-M5-CN-00005 / 10112936-PB-P-FLD-0008
- 25474-000-M5-CY-00001 / 10112936-PB-P-FLD-0009
- 25474-000-M5-QG-00001 / 10112936-PB-P-FLD-0010
- 25474-000-M5-QG-00002 / 10112936-PB-P-FLD-0011