PROCESS DESCRIPTION

BIOGAS UPGRADING PLANT

PROJECT: Padova

PROJECTNR.: 19.5198

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1 BIOGAS UGRADING SYSTEM

The Biogas Upgrading System is divided in several main parts and will be described in this document.

1.1 Reference P&ID's

19.5198-P&ID-01 to 05

2 BIOGAS UPGRADING PART

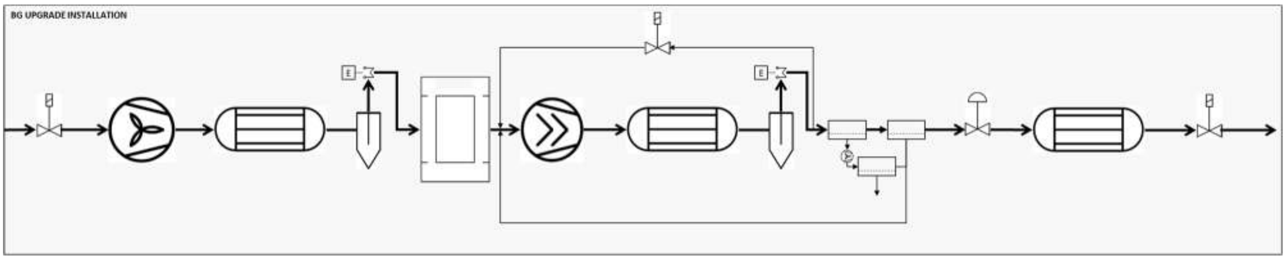


Figure 2-1. Typical Biogas Upgrade Unit Process Flow Diagram.

2.1 Main Biogas upgrading steps

- Increase pressure towards compressor
- Compression in 1 step
- High pressure Dehumidification of the gas
- Separating the CH_4 / CO_2 gas streams by membranes
- Analyzing and injecting of the produced gas into the compressor station via a buffer volume

2.2 Biogas Pre-Treatment

Gas cooling is required for optimal conditioning of the process gas prior to entering the active carbon filter. Dehumidification of the process gas is performed according to the condensation drying principle. The first set is to cool down the incoming biogas via a dry-cooler which takes out most of the energy. After this first cooling step a second cooling step is installed to chill the gas further for optimization which is done by a water-cooled shell-and-tube heat exchanger. In order to achieve the optimum gas condition, which enlarges the absorption capacity of the activated carbon, a heater is installed. By cooling the gas, water condenses and is removed from the gas. Accumulated condensate will be discharged from the collection vessel based on a level control and integrated condensate pump.

The pre-treatment process consists of the following units:

1. LP Cooler.
2. LP Chiller.
3. LP Heaters.
4. H2S Filters.
5. VOC's Filters.

LP Cooler

A LP Cooler is used at the inlet of the biogas plant to cool down the gas as much as possible using hot glycol in order to reduce the heat load in the LP chiller and reduce cooling energy consumption.

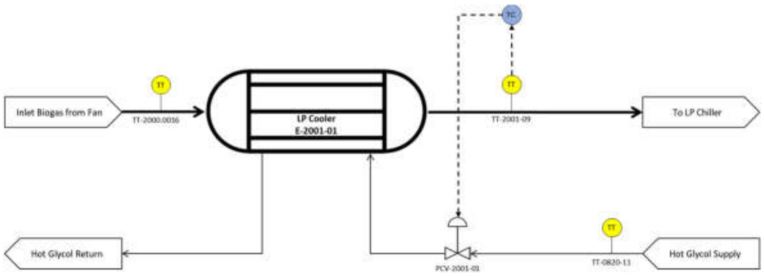


Figure 2-2. Typical LP Cooler Unit Control Loops Diagram.

LP Chiller

The LP Chiller condensate water by cooling down the biogas below its dewpoint but above the freezing point to avoid blockage and damage of the heat exchanger. The gas is cooled down in the heat exchanger where the cold glycol in counter flow, extract heat from the gas. As water condensate, it is removed in the water separator to a closed drain.

The water separator drain function is disable if the water level is too low (LL detection). The drain valve opens (pulse with TOFF delay) if High level is detected only if both LL and HH level are not active.

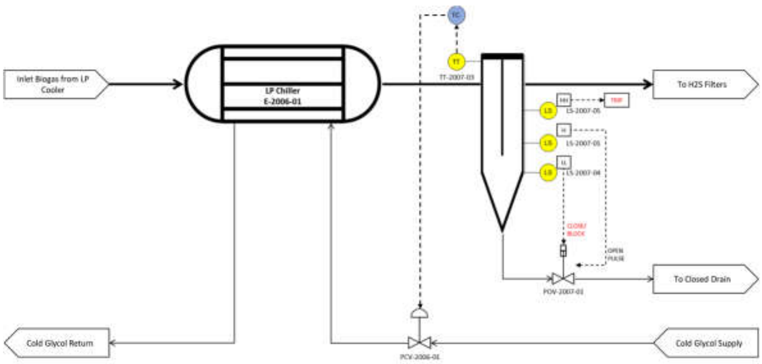


Figure 2-3. Typical LP Chiller Unit Control Loops Diagram.

LP Heaters

At the outlet of the LP Chiller, the gas is water saturated at 100% relative humidity. Downstream the LP Chiller, an electric heater increase the gas temperature to reduce the relative humidity from 100% to about 85%, and decrease the gas dewpoint, in order to improve the life performance and effectiveness of the active carbon in the downstream filters.

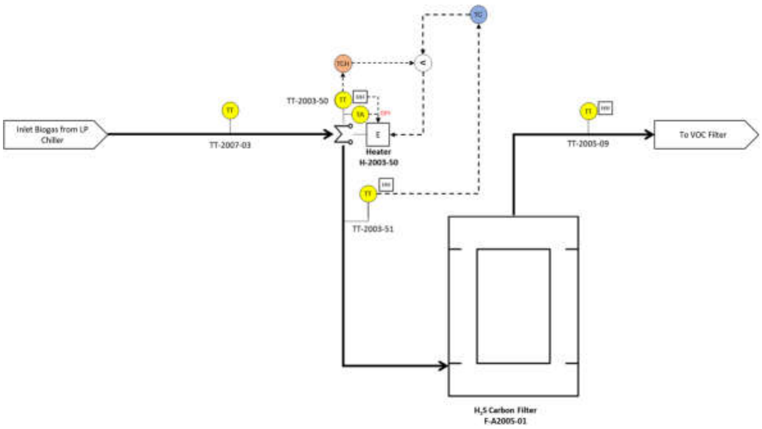


Figure 2-4. Typical H2S Unit Heater Control Loops Diagram.

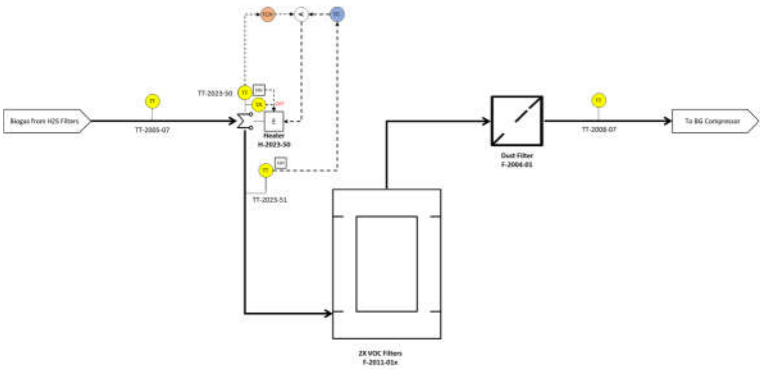


Figure 2-5. Typical VOC's Unit Heater Control Loops Diagram.

H_2S and VOC's Filters.

Heated biogas enters the H2S Filters, which may be placed inside or outside the installation. In these filters, H2S (hydrogen sulphide) present in raw biogas is adsorbed by the activated carbon bed. Requirement of the number of H2S Filters varies with project requirements. H_2S is removed by catalytic absorption on activated carbon bed. First, hydrogen sulfide is physically adsorbed on the internal carbon surface. Then H_2S is oxidized on the activated carbon bed in presence of free oxygen to form Sulphur. This is the principle of operation of H_2S Filters.

With time, bed is saturated with H_2S, no more absorption can occur and activated carbon bed needs to be exchanged. This is being measured by an inline H_2S analyser, which measures a breakthrough of H_2S in the beds.

After H_2S removal, biogas is send to compressor via dust filter. The purpose of dust filter is to catch some carbon particles which might be carried over with biogas from filter bed. Such unwanted material is removed to prevent functional problems and/or damage to the downstream compressor. Dust filter contains a demister to separate moisture along with other unwanted particles from biogas. A drain valve is installed at the bottom of the filter, which will be manually opened based on a certain time period to remove the cached dust and liquid.

Depending on the composition of the raw biogas inlet feed, outlet of H_2S Filter might be send to VOC Filter via additional equipment (typically heater) in between. This configuration is valid only if significant amounts of volatile organic components (VOC) are present in raw biogas. The configuration is project specific. When VOC filter unit is required after H_2S filter, dust filter is placed in the end just before compressor.

The H2S sensor unit monitor the filters condition for any breakthrough, the measuring sequence consists of:

1. **Backflush**. Clean the sampling pipe inside the H2S filter, if applicable. To remove obstructions.
2. **Pre-flush**. Clean the sensor flushing any remaining gas sample with clean air.
3. **Sampling**. Sampling gas is passed through the sensor for pre-defined time to have stable readings.
4. **Store Measurement**. Store the result and update the screens.
5. **Post-flush**. Clean the sensor flushing the sampling gas with air.
6. **Pause**. Waiting time until the sampling time cycle is finished in order to take another sample.

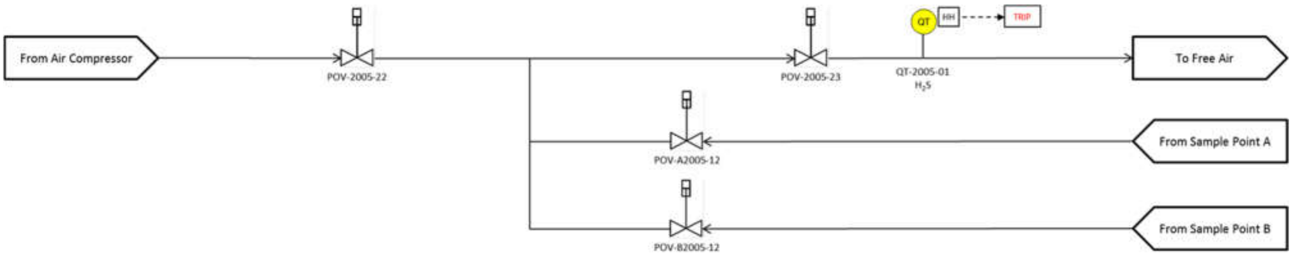


Figure 2-6. H2S Sensor Unit Control Design.

2.3 Biogas Compressor(s)

The biogas compressor compresses the raw biogas to the requested capacity to compressor station pressure. The compression is done in a single stage.

Depending on capacity request, level, or pressure of the digester; the complete system will automatically increase/decrease the speed of the compressors as they each are equipped with inverters. The biogas upgrading system can receive a value on which capacity the plant should operate (tracking mode). This value will be processed and the biogas upgrading plant will increase or decrease the capacity based on this setpoint.

In order to recover the oil leaking from the mechanical seal, a Haffmans Oil Recovery System (HORS) was developed. The recovered oil is injected back to the suction header of the cooling compressor.

Oil is drip from the mechanical seal of screw compressors as part of its normal lubrication method during operation. Normal oil drip rate are between 10 ml/h and 20 ml/h. At maximum drip rate this lead to about 0,5 liter lost oil every 24 hours of operation. This represents about 25% of the total oil charge in a month period, so every 4 months the oil have to replaced completely. Before that happens, the installation will be tripping by Low Oil Level, generating increased operation costs and production losses.

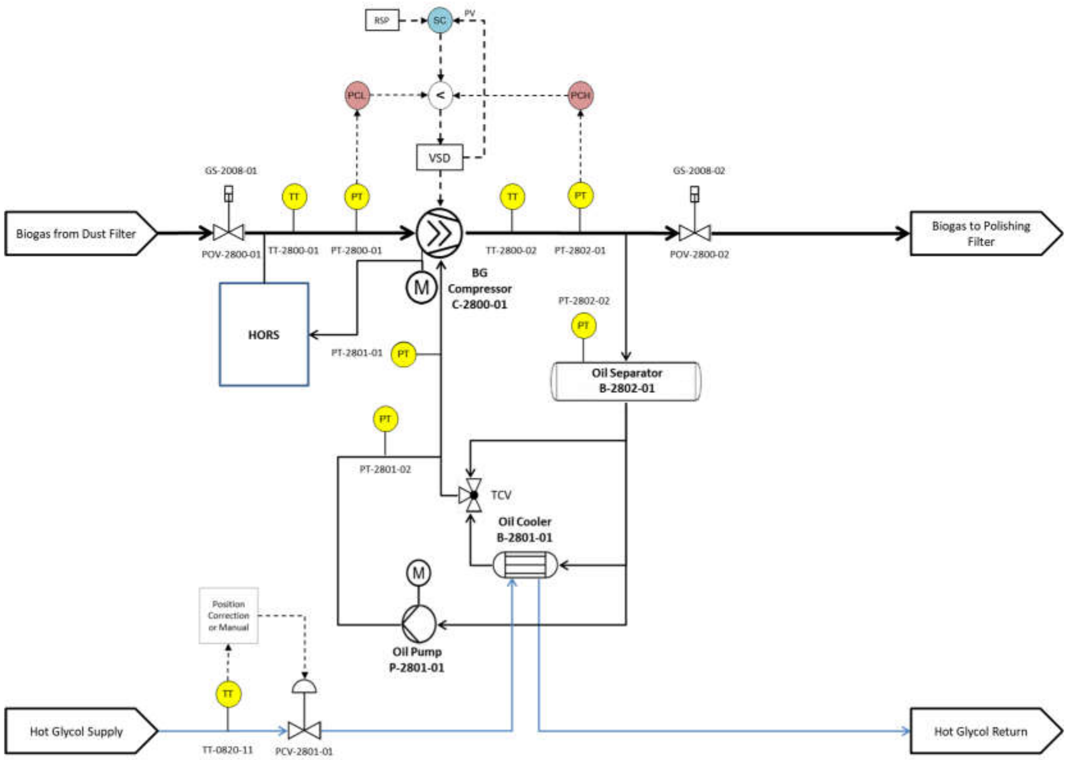


Figure 2-7. Typical BG Compressor Control Loops Diagram.

2.4 After or HP Cooler

A High Pressure or HP Cooler is used at the outlet of the Biogas Compressors to cool down the gas as much as possible using hot glycol in order to reduce the heat load in the HP chiller and reduce cooling energy consumption.

The after cooler chills the biogas coming from the 2nd stage biogas compressor(s) as a first pre-cooling with hot water before it enters the final chiller. Depending on the hot water temperature the after cooler will chills the biogas to the desired condition without the use of the chiller.

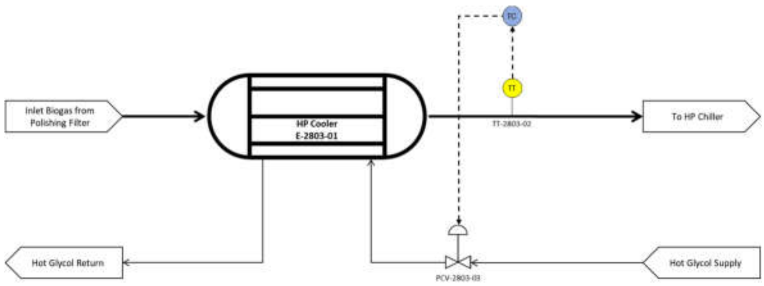


Figure 2-8. Typical After cooler Control Loops Diagram.

2.5 HP Chiller & Water separator

The HP Chiller condensates water by cooling down the biogas below its dew point, but above the freezing point in order to avoid blockage and damage of the heat exchanger. The gas is cooled down in the heat exchanger where the cold glycol in counter flow, extract heat from the gas. As water condensate, it is removed in the water separator to a closed drain. This dehydration process maximize membranes separation performance and avoid water condensation in the membranes.

The chiller & water separator will condition the biogas after the biogas compressor and separate the condensate afterwards the heater. This is the final stage of separation of condensate out of the biogas before entering the super heater and membranes. This water separator is automatically controlled by level. If the level has reached a certain set point a drainage valve will be opened and condensate will be drained.

2.6 Super Heater

The chilled biogas that is coming from the chiller is heated up by the super heater to decrease the relative humidity and maintain a stable biogas temperature to ensure a good working area of the membranes.

The electric heater increases the gas temperature with the following objectives:

1. Prevents condensation in the membranes.
2. Maximize performance of the membranes at ideal operating temperature.

To assure no water condensation in the membranes there is always a minimum superheating between the gas temperature at the outlet of the HP Chiller and the outlet of the heater, without exceeding the maximum design temperature of neither the heater nor the membranes.

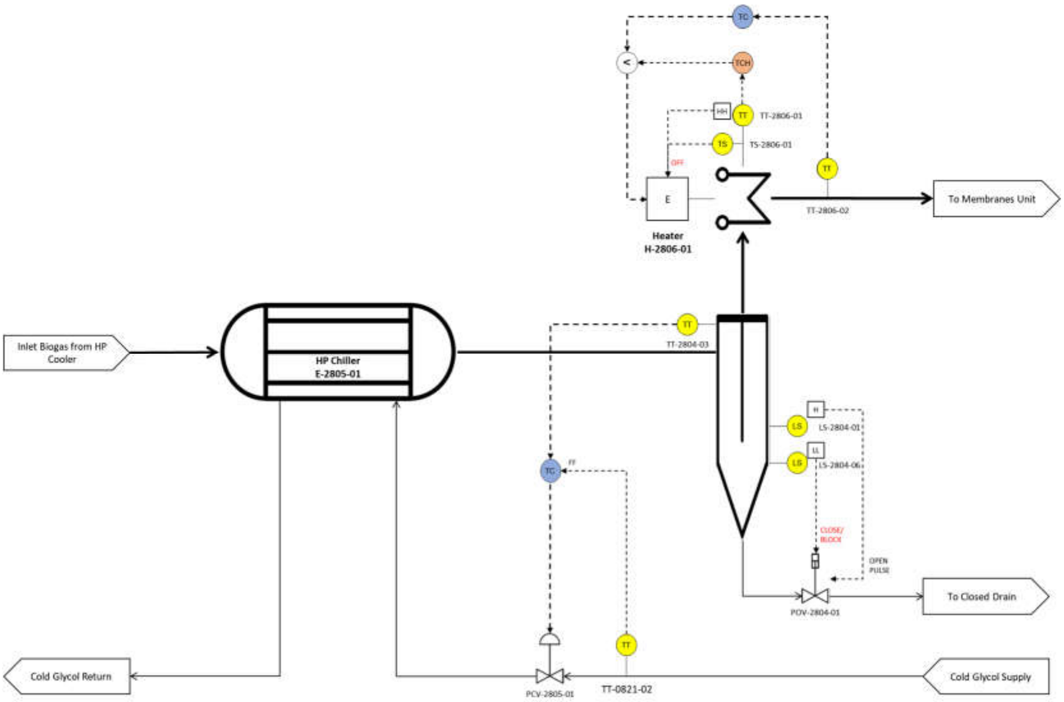
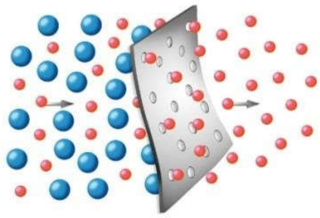


Figure 2-9. Typical HP Chiller, water separator, and Superheater Control Loops Diagram.

2.7 Membranes



The membranes are the final stages in the process before gas can be injected into the compressor station. Membranes operate in two stages (1 street) and depending of the capacity more or less streets will be installed. In the first stage the main stream (retentate) will be enriched with CH_4 but the concentration is still too low for entering the compressor station. The branch of, permeate, is enriched enough after the first stage with CO2 (+/->83%) for entering the CO2 unit. As the retentate stream is not enriched enough with CH_4 it will be led into the second stage. After this stage the main stream has a high purity of CH_4 which can be fed into the gas compressor station. The permeate side of this second stage will be fed back to the suction side of the biogas compressor. Besides the main function of the membranes, separating CO2 and CH4 including some secondary components, it also lowers the dew-point of the mainstream to below -20 ^{0}C at 10 bar(g).

Summarized due to separation of the gasses membranes performs as follows:

- CH_4 and some N_2 & O_2 stays inside the membrane fiber (retentate side)
- CO_2 , H_2O and some N_2 and O_2 pass through the fiber (permeate side)

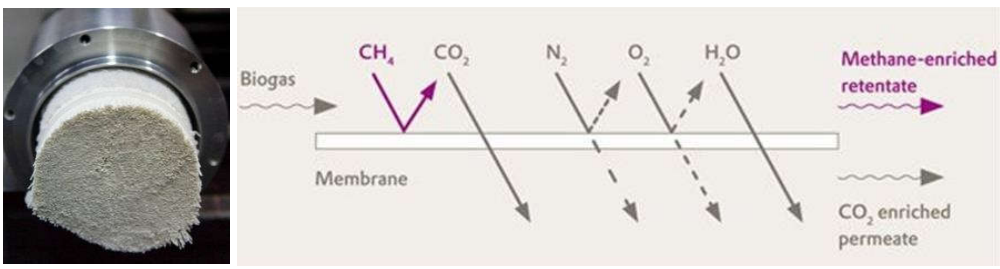


Figure 2-10. Membrane gas separation.

The separation, called selectivity and permeability of the membranes, is depending on the following main parameters:

1. Biogas flow / pressure / temperature / gas composition on the inlet of the membranes
2. Back-pressure on the permeate 3rd stage side (to free air)
3. Back-pressure on the permeate 2nd stage side (recycle stream to inlet compressor)
4. Back-pressure on the retentate 3rd stage side (recycle stream to inlet compressor)
5. Pressure control on the outlet of the Bio-methane outlet (control the inlet pressure)

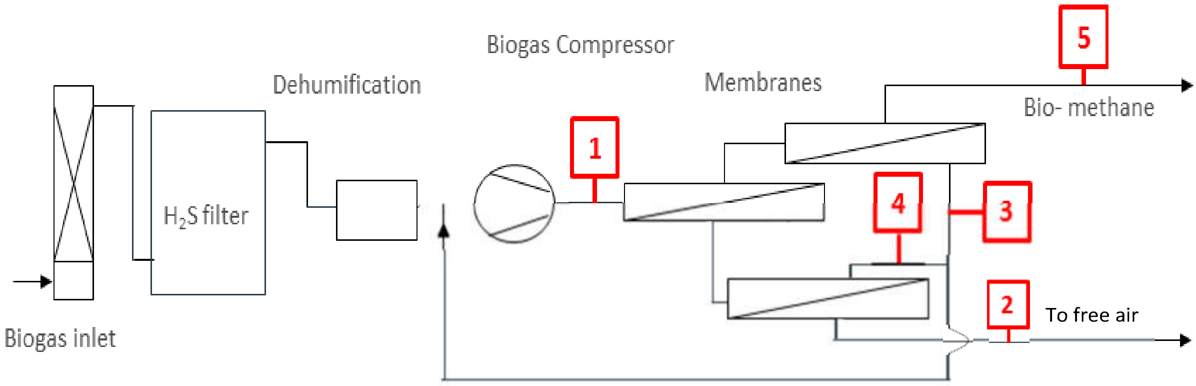


Figure 2-11. Selectivity and permeability factors.

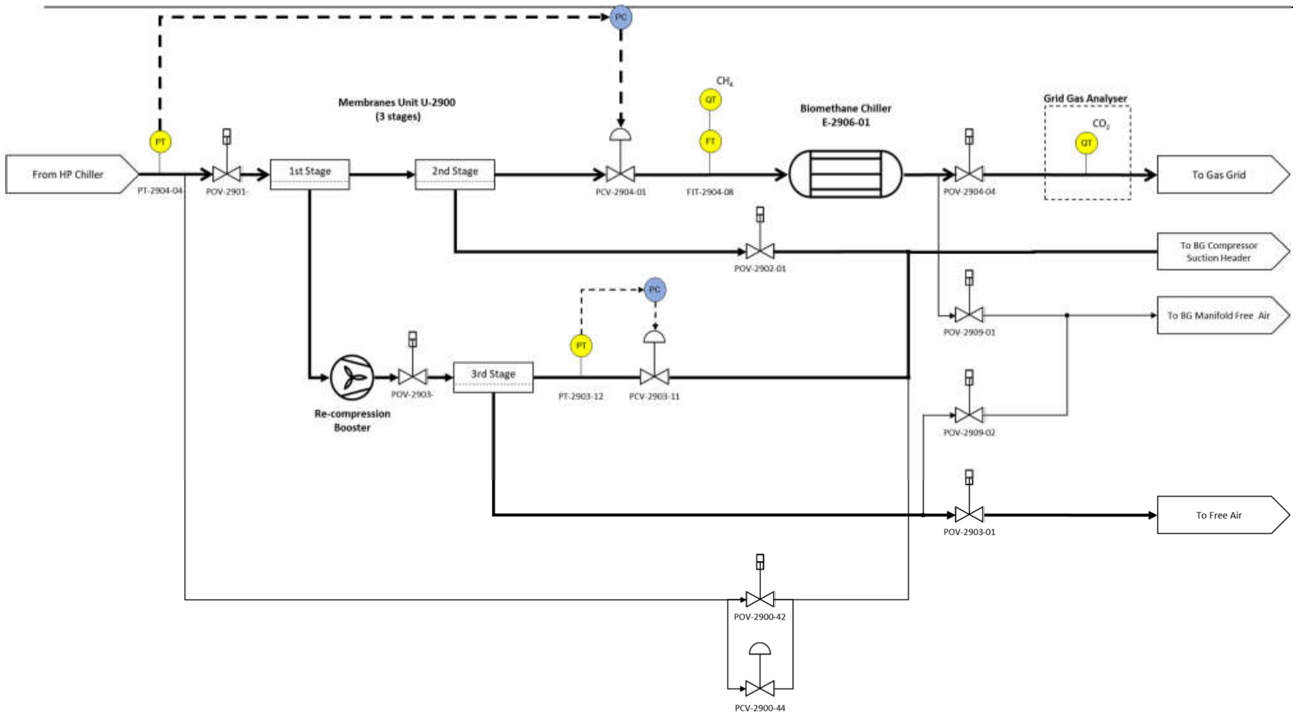


Figure 2-12. Typical Grid CO_2 Membrane Control Loops Diagram.

The membrane performance is depending on the following parameters :

- Biogas flow / pressure / temperature / gas composition on the inlet
  - ➢ Compressor capacity (frequency)
  - ➢ Set point super heater (control valve on temperature)
  - ➢ Biogas inlet composition (mostly CH_4 / CO_2 / Hydro Carbons)
- Back-pressure on the permeate 2nd stage side (to inlet compressor)
  - ➢ Set point pressure permeate 2nd stage (control valve on pressure)
- Back-pressure on the permeate 3rd stage side (to inlet compressor)
  - ➢ Set point pressure permeate 1ste stage (control valve on pressure)
- Pressure control on the membranes inlet
  - ➢ Set point membrane pressure (control valve on pressure set point)

2.8 Inertisation

To create a safe situation before start working on the installation CH_4 gas must be removed which is inside the biogas upgrading system. This is called the inertisation step. It is possible to perform a inertisation of the complete Biogas upgrading system or perform only the inertisation of the CH and H_2S filters depending on the system.

The inertisation must be performed to ensure a save situation is created to work safely on the biogas upgrading plant. After finishing the (maintenance) work we need to perform a new inertisation to ensure no air is in the installation before starting up.

How to realize an inertisation step, a separate work instruction is delivered together with the manual.

3 COOLING SYSTEM

3.1 Cooling tower / Evaporative Condenser

The hot glycol circuit is used to cool down the biogas and the oil of the BG compressors to a temperature range of about 35°C – 60°C. The returned glycol temperature is decreased in the cooling tower, where the ambient air forced flow releases latent heat of evaporation and some sensible heat from the water in counter flow, cooling down the recirculated water which subsequently remove heat from the glycol and transfers it to the environment. Therefore, the glycol supply temperature is adjusted via the fan speed. Additionally, the cooling tower serves also as a condenser for the refrigeration system.

The fully automated combined evaporative cooling tower for condensing the NH_3 and cooling the following plant parts:

- LP cooler of the Biogas side
- Oil cooler of the Biogas side
- HP cooler of the Biogas side
- Inter cooler of the CO_2 compressor
- After cooler of the CO_2 compressor
- Oil cooler of the refrigerant compressor
- Refrigerant condenser
- Refrigerant oil cooler

The collected heat is rejected to environment through the cooling tower.

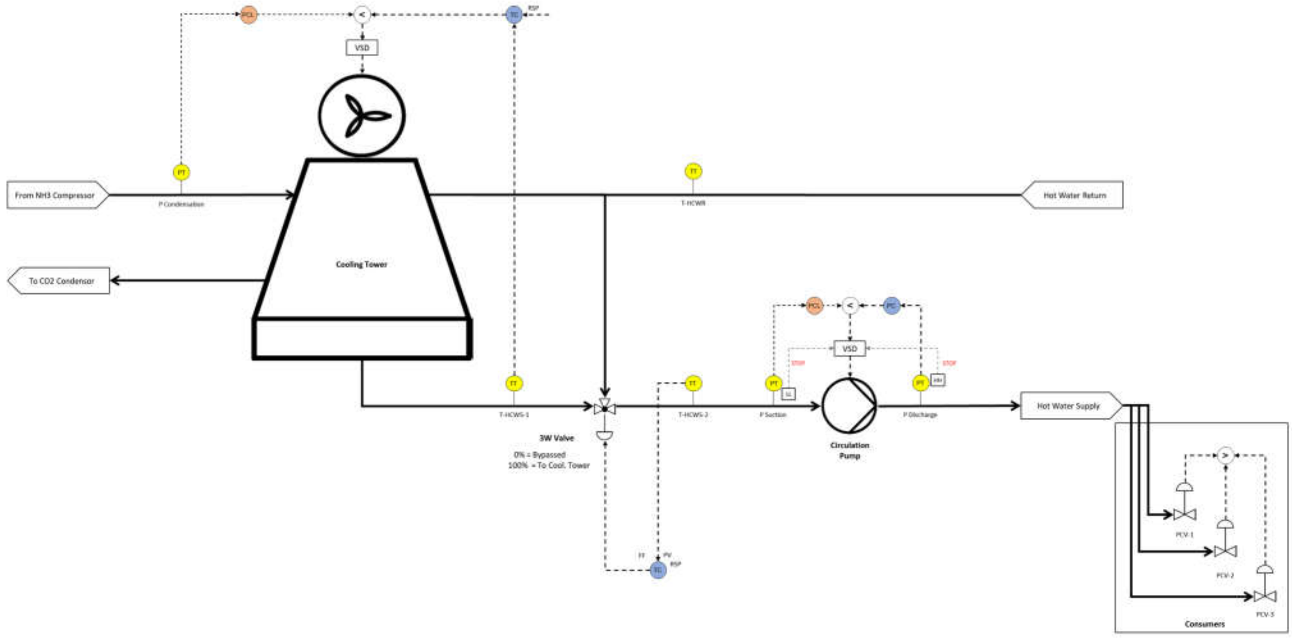


Figure 3-1. Typical Hot Glycol Unit Control Loops Diagram.

3.2 Cold Glycol Circuit (+1ºC)

The Cold Glycol circuit is used in all chillers to cool down the biogas and biomethane to a temperature range of about 4°C – 15°C in order to dehydrate the gas. The returned glycol temperature is decreased in the stand alone cooling unit, where the cooling capacity is adjusted automatically by itself to achieve the supply glycol remote temperature setpoint determined by the Biogas Upgrade Process Control.

The fully automated cooling circuit is designed to cool the following Biogas upgrading parts:

- Inlet biogas chiller (if pre-treatment is included)
- HP chiller of the biogas compressor
- After chiller CO_2 compressor

The collected heat is rejected to the environment through an air cooled condenser which is located outside.

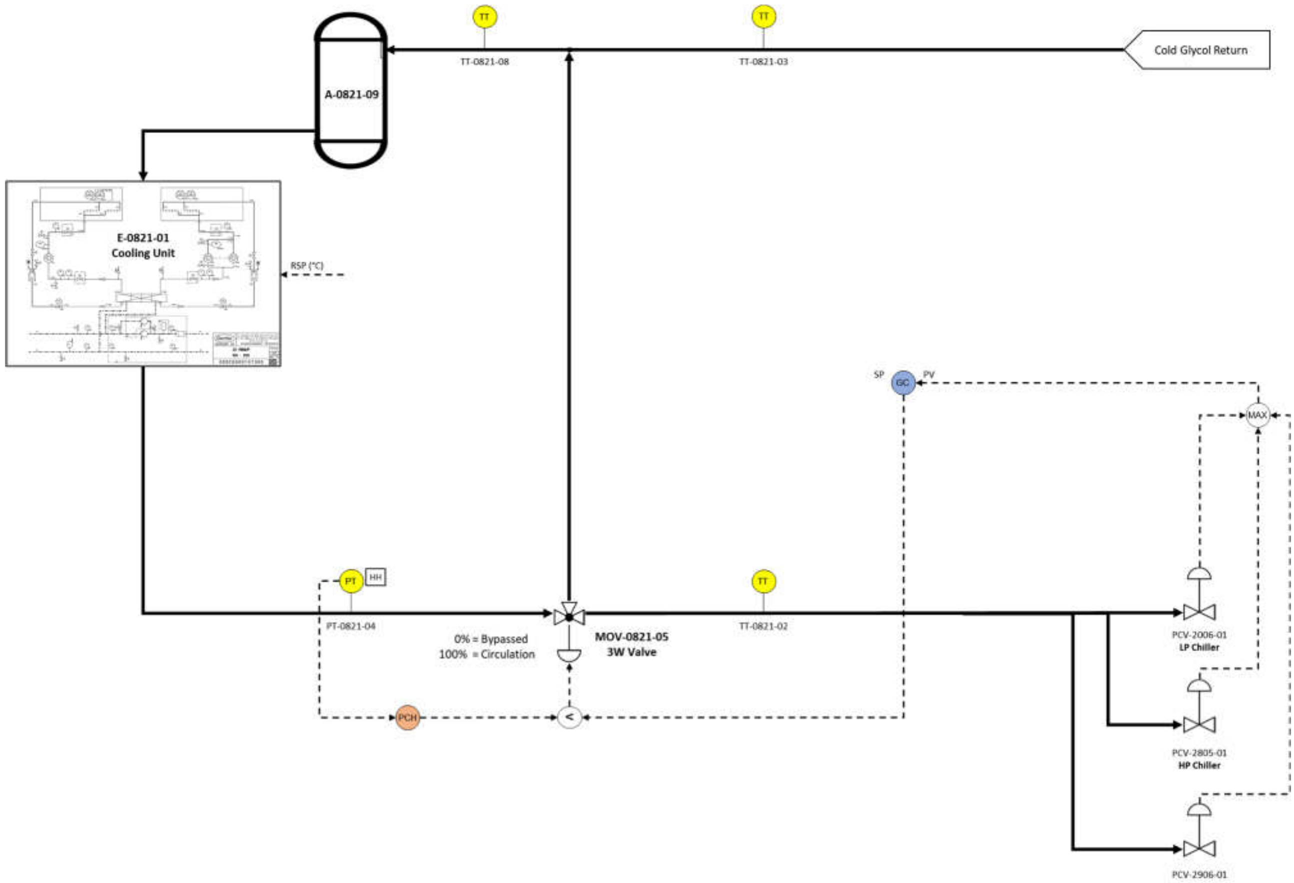


Figure 3-2. Typical Cold Glycol Unit Control Loops Diagram.