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C2FUEL

Carbon Captured Fuel and Energy Carriers for an Intensified Steel Off-Gases based Electricity Generation in a Smarter Industrial Ecosystem

Deliverable

D1.4 – Steel-off gases pretreatment unit design

WP1 – Specifications and demonstration setup

Project information

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Table of content

List of Figures

List of Tables

Deliverable report

1 Executive Summary

1.1 Description of the deliverable content and purpose

Deliverable D1.4 discusses the design of the Blast Furnace Gas (BFG) pretreatment system located upstream the carbon capture and conditioning unit (CCU), where CO_2 is removed by absorption with an amine based solvent and sent to the Dimethylether (DME) production unit. The purpose of this deliverable is to (1) define the requirements of the various pretreatment steps and to lay out their design, and to (2) show how they will be integrated within the demonstrator pilot on the DK6 power plant. **Deliverable D1.4** follows **deliverable D1.2** on BFG characterization.

The BFG produced by the steel factory is transported to the DK6 power plant through the BFG main pipes and a small flow (6 Nm3/h) will be diverted and fed into the CCU brick of the C2FUEL demonstrator. This BFG contains various impurities and solid particles that must be removed before entering the CCU. The objective of this deliverable is to define the pretreatment requirements of the BFG to comply with the CCU and to show how these units will be integrated in the final demonstrator.

1.2 Brief description of the state of the art and the innovation breakthroughs

N/A

1.3 Corrective action (if relevant)

N/A

1.4 IPR issues (if relevant)

N/A

2 Background and Summary of Previous Work

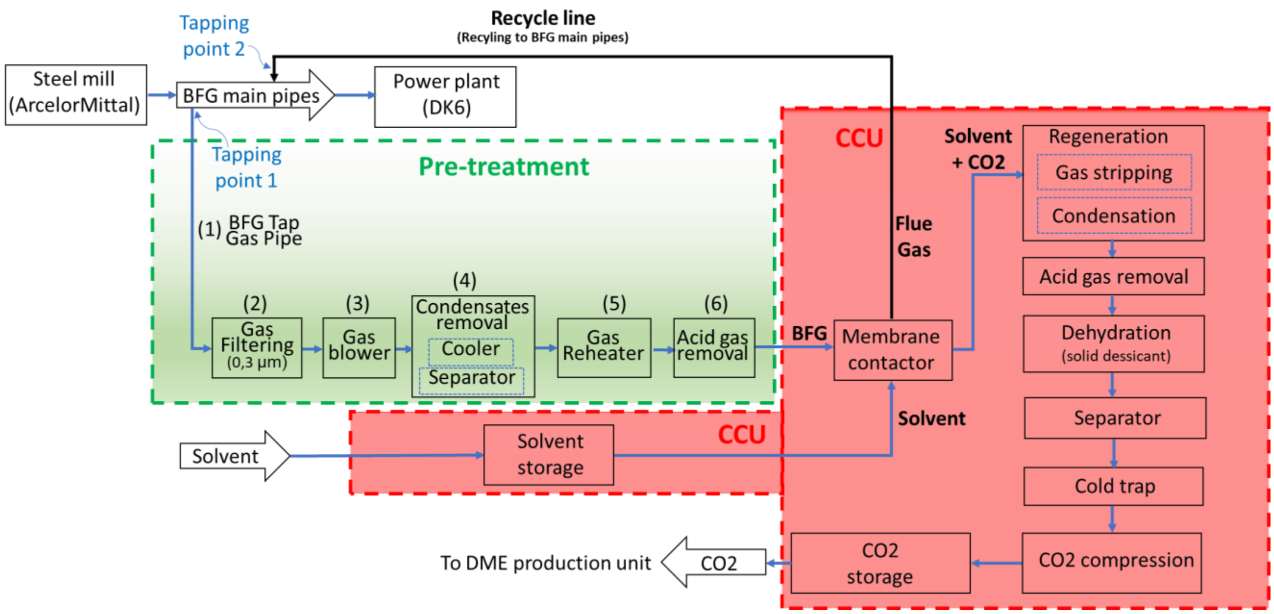


Figure 1: Block diagram of the CO_2 capture unit of 0.5 Nm³/h capacity.

Figure 1 illustrates the block diagram of the BFG pretreatment and CO_2 capture units in the C2FUEL demonstrator. A small flow of BFG (6 Nm3/h) is diverted from the BFG main pipes and sent to the pretreatment section (green section). After being cleaned, the BFG enters the membranes absorption modules where the gas comes in contact with a solvent (monoethanolamine or MEA) (red section). Here, CO_2 is transferred from the gas phase (BFG) to the liquid phase (MEA), therefore a stripping process is required in the next step to recover the CO_2 from the solvent. This process occurs in a distillation unit where water vapor from partial evaporation of the solvent in the reboiler comes in contact with the CO_2-rich solvent to strip CO_2 out of it. Any entrained water in the gas stream is then separated in the downstream condenser before CO_2 is compressed and stored at 45 barg for later use in the synthesis section. This process is described in details in **deliverable D1.1**, which focused on the overall conceptual design of the C2FUEL demonstrator and the specifications of the process requirements; while the detailed characterization of the BFG was given in **deliverable D1.2**. The raw BFG from the main BFG pipes has the following characteristics:

Table 1: Characteristics of the blast furnace gas (BFG) [1].

Density	kg.m^{-3}	1.243
Flowrate	Nm3/h^{-1}	6
Pressure	mbarg	75-77
Temperature	°C	45-50
Dust particles sizes	µm	< 20
Relative humidity	%	>90

Table 2: Characteristics of the BFG measured continuously [1].

Component	Units	Minimum	Mean	Maximum	Equivalent ppmv
H_2	%	3.47	4.94	6.00	
O_2	%	0.02	0.04	0.09	
N_2	%	43.56	46.81	50.92	
CH_4	%	0.01	0.02	0.04	
CO	%	22.58	25.21	28.77	
CO_2	%	21.46	22.98	24.08	
H_2S	mg/Nm³	<1.5	17	27	1-18
COS	mg/Nm³	41	57	78	15-29
SO_2	mg/Nm³	<3	<3	<3	<1
HCN	mg/Nm³	<5	12	39	4-32
Benzene	mg/Nm³	0.6	0.8	1.5	0,2-0,4
Toluene	mg/Nm³	0.3	0.5	1.0	0,1-0,2
Ethylbenzene+xylene	mg/Nm³	<0.2	0.1	0.5	-
Naphtalene	mg/Nm³	<5	<5	<5	< 0,9

Table 3: Characteristics of the BFG, measured at sampling intervals [1].

		Measurement day				
Component	Units	Day 1	Day 2	Day 3	Day 4	Day 5
HCl	mg/Nm³	0.43	<0.2	<0.2	<0.2	<0.2
SO_X	Mg/Nm³ éq H_2SO_4	30	<1	4	<1	<1
NO	ppm	<0.1	<0.1	0.1	0.1	0.2
NO_2	ppm	<0.1	<0.1	<0.1	<0.1	<0.1
NO_X	ppm	<0.1	<0.1	0.1	0.1	0.2
Hg	µg/Nm³	4	29	4	11	18
Naphthalene	µg/Nm³	41	14	15	22	154
Acenaphtylene	µg/Nm³	<10	<10	<10	<10	<10
Acenaphtene	µg/Nm³	<10	<10	<10	<10	<10
Fluorene	µg/Nm³	<10	<10	<10	<10	<10
Phenantrene	µg/Nm³	<10	<10	<10	<10	<10
Anthracene	µg/Nm³	<10	<10	<10	<10	<10
Fluoranthene	µg/Nm³	<10	<10	<10	<10	<10
Pyrene	µg/Nm³	<10	<10	<10	<10	<10
Benzo anthracene	µg/Nm³	<10	<10	<10	<10	<10
Chrysene	µg/Nm³	<10	<10	<10	<10	<10
Benzo(b)fluoranthene	µg/Nm³	<10	<10	<10	<10	<10
Benzo(k)fluoranthene	µg/Nm³	<10	<10	<10	<10	<10
Benzo(a)pyrene	µg/Nm³	<10	<10	<10	<10	<10
Dibenzo(ah)anthracene	µg/Nm³	<10	<10	<10	<10	<10
Benzo(ghi)perylene	µg/Nm³	<10	<10	<10	<10	<10
Indeno(123-cd)pyrene	µg/Nm³	<10	<10	<10	<10	<10

The impurities removal requirements and their respective composition specifications are dictated by the CCU performance requirements and the DME membrane reactor. **Deliverable D3.2** discusses these requirements which are summarized in the following table.

Table 4: Specifications of the BFG after pre-treatment.

Pressure	mbar	200<P< 500 (1)
Temperature	°C	45 (2)
Dust particles sizes	µm	<1,0 (3)
Absolute humidity	%	<6 (4)
[H_2S+COS]	ppmv	<0,005

(1) Limited by the design pressure (0,5 barg) of the absorption column and must account for the pressure drop across the membranes for the gas to recycle back to the main BFG pipe.

(2) Dictated by the temperature of the lean solvent downstream the regeneration unit.

*(3) Experimental study with the laboratory scale pilot indicated a cut-off diameter of 1 µm is required to achieve required separation performance (**D8.14 – Interim financial and technical report**, M25-M30).*

(4) To avoid liquid condensate accumulation inside the membranes in vertical position. The absolute humidity in % to avoid condensation is that of a saturated gas at the solvent temperature i.e. about 45°C.

Table 5: Specifications of the BFG at the outlet of the CCU.

Pressure	atm	~ 1
Temperature	°C	< 20 (1)
Absolute humidity	%	< 3 (2)
[H_2S]	ppm	<0,05 (3)

(1) Specification at the condenser to have less than 3% humidity.

(2) Must not be greater than 3% to avoid damages to CO_2 compressor.

*(3) To avoid catalyst poisoning and decrease in DME production performance. To be on the safe side and since it is easy to implement, ENGIE recommends 0.05 ppm (50 ppbv) which is below 0.1 ppm, the initial value suggested by [**TU/e**] in deliverable D3.2.*

To comply with these requirements, various pretreatment steps have to be implemented before the BFG can enter the CCU where CO_2 will be removed from the BFG. First, the BFG must be transported from the main BFG pipes to the inlet of the pretreatment section. This will be achieved by means of a tap on the main BFG pipes and an electrically heated tube to avoid temperature drop and condensation along the pipe. Then, dust particles greater than 0,3 µm must be removed with an adequate filter before removing condensates with a cooler coupled to a separator. Finally, sulphur components (SO_2, COS, H_2S) via adsorption on activated carbon. A gas blower placed downstream the filters will enable the circulation of the BFG to meet flowrate and pressure requirements.

The main purpose of this deliverable is to define and, where possible, to design the aforementioned pretreatment units of the BFG, which are highlighted in green in Figure 1. These units are, in order:

(1) BFG Tap and transport of the BFG to the CCU with an electrically heated line,

(2) Dust filtering unit with HEPA cartridges filters,

(3) Gas blower to compensate for pressure drops and control flowrate,

(4) Condensate mitigation step: chiller coupled with a separator,

(5) Gas reheater

(6) Acid gas removal unit with activated carbon.

3 BFG Pretreatment Design

As a reminder, the block diagram of the whole CO_2 capture unit is indicated on Figure 2. The next sections are dedicated to the description of each step of the pretreatement unit (in green).

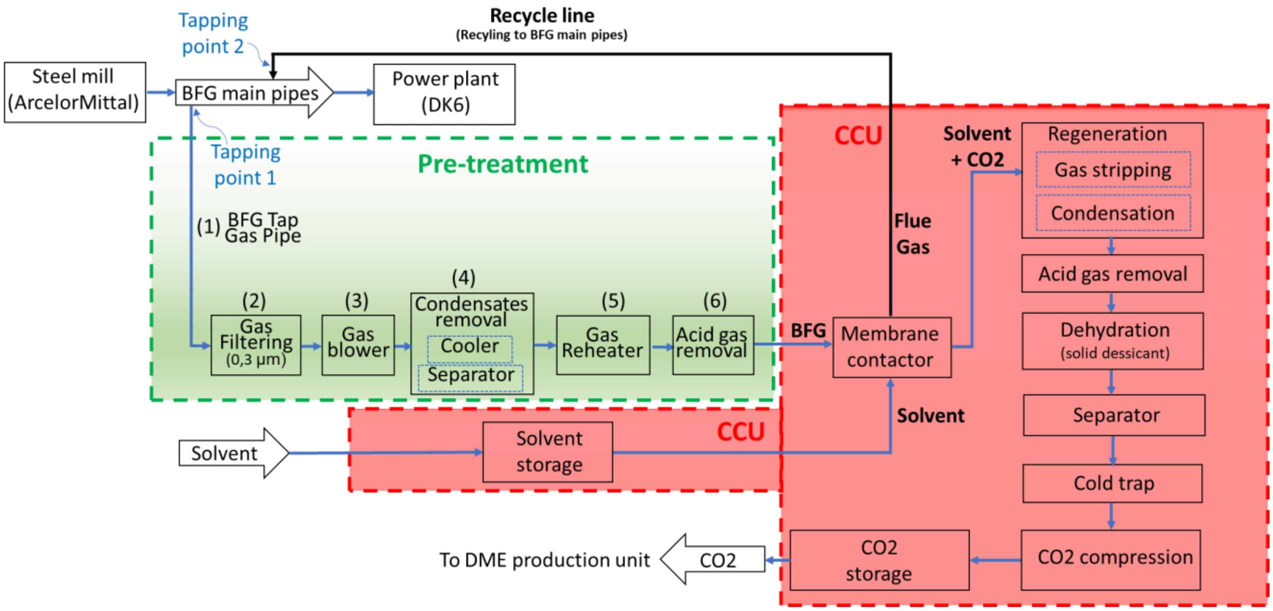


Figure 2: Block diagram of the CO_2 capture unit of 0.5 Nm³/h capacity.

3.1 BFG Tap

About 6 Nm³/h of BFG needs to be diverted from the main BFG stream coming from the steel factory and transported to the inlet of the pretreatment section and the CCU; therefore, a tap is required on the main BFG pipes.

Figure 3,Figure 4 and Figure 5 show how the tap and the heated line will be implemented to ensure that the BFG is flowing to the pretreatment section and the CCU. This section will discuss the requirements and the design of the heated line (diameter) from the tapping point to the pretreatment units with the related pressure drop calculations.

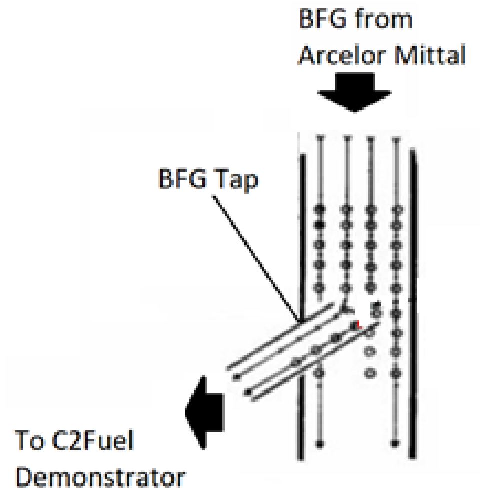


Figure 3: Tapping point on the main BFG pipe.

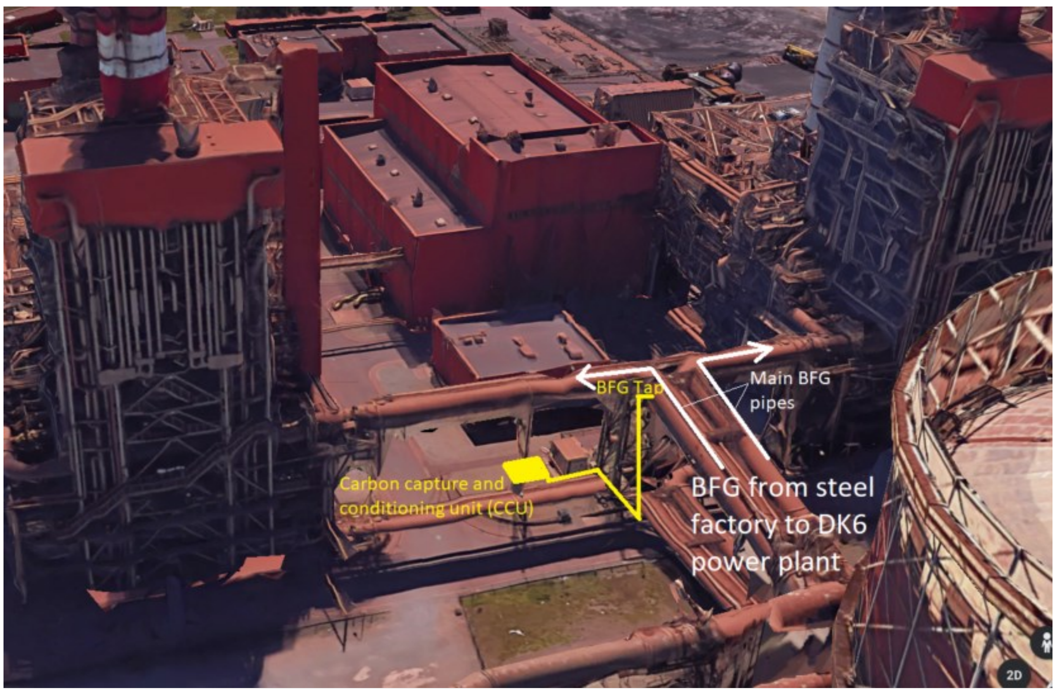


Figure 4: Picture of the DK6 plant showing the BFG main pipes and the BGF Tap pipe.

Figure 5: Close view of the BFG main pipes and the location of the BFG Tap.

3.1.1 Design principles

The characteristics of the BFG are given in Table 1. The principles for the determination of the diameter and the pressure drop inside the heated line are detailed below.

Pressure drop calculation and required diameter

The required flowrate of BFG to produce about 0.5 Nm^3/h of CO_2 was estimated by [CNRS] to be 6 Nm^3/h. The pressure of the BFG inside the BFG main pipes is assumed to be 77 mbarg (see Table 1) and the desired minimum pressure at the inlet of the pretreatment section is specified at 40 mbarg. The pipe that will be used is a pre-assembled electrically heated tube in PTFE which will maintain the gas to about 55°C. The choice of using PTFE is mainly for practical reasons where PFTE can be bended and installed easily; there is no need to install more expensive treated stainless steel tube.

Assuming a pipe length of 30m from the tapping point to the inlet of the CCU and an elevation of -10m, the total pressure drop was estimated across the pipe for a given and assumed diameter. The total pressure drop ΔP_{TOTAL} is the sum of individual pressure drops due to (1) the hydraulic frictions in the pipe ($\Delta P_{Frictions}$), (2) the change in elevation ($\Delta P_{Elevation}$) and (3) the fittings such a elbows or tees ($\Delta P_{Fittings}$). The diameter of the pipe was first assumed and then a goal seek function was used to determine the diameter that gives the specified downstream pressure of 40 mbarg.

- **(1): Pressure drop due to frictions:**

The friction losses due to hydraulic flow in the pipe is given by the Darcy-Weisbach [2]:

$$\Delta P_{Frictions} = F_D . \frac{L}{D} . \frac{\rho v^2}{2}$$

Equation 1 : Darcy-Weisbach equation for single phase flow

The friction factor **F_D** can be determined using the Colebrook equation [2] which is admitted as being accurate for most industrial applications but requires an iterative solution. The equation proposed by Churchill is a direct solution with good accuracy and is given as follow for a turbulent flow regime (Reynolds number, Re>4000) [3]:

$$F_D = 8 \times \left[\left(\frac{8}{\mathrm{Re}^{12}} \right) + \frac{1}{(A+B)^{\frac{3}{2}}} \right]^{\frac{1}{12}}$$

Equation 2

Where:

$$A = \left[2.457 \times \ln \left(\frac{1}{(\frac{7}{Re})^{0.9} + \frac{0.27 * \varepsilon}{D}} \right) \right]^{16}$$

Equation 3

And:

$$B = \left(\frac{37530}{Re} \right)^{16}$$

Equation 4

All the symbols are explicated in the following table.

Symbols
$\Delta P_{Frictions}$: pressure drop due to friction in pipe, Pa
$\Delta P_{Elevation}$: pressure drop due to change in elevation, Pa
$\Delta P_{Fittings}$: pressure drop due to fittings, Pa
ΔH: change in elevation, m
D: internal diameter, m
L: Pipe length (or equivalent length), m
F_D: Darcy factor
ξ: loss coefficient
Q: volumetric flowrate, m^3/h
W: mass flowrate, kg/h
ρ: density, kg / m^3
μ: viscosity, Pa.s
Re: Reynolds number
v: velocity, m/s
g: acceleration of gravity, 9.81 m/s^2
Ɛ: Pipe roughness, m

- **(2): Pressure drop due to change in elevation:**

$$\Delta P_{Elevation} = \rho . g . \Delta H \ [2]$$

Equation 5

with the change in elevation, ΔH= -10 m. The gas is gaining energy when it is flowing downward from a higher point (BFG tapping point) to a lower point (pretreatment and CCU).

- **(3): Pressure drop due to fittings**

The pressure drop due to fittings such as 90° bends, elbows, tees or reducers/enlargers is calculated with the loss coefficient ξ as follow [4]:

$$\Delta P_{Fittings} = \xi . \frac{\rho v^2}{2}$$

Equation 6

Here, the BFG Tap piping system is assumed to have at least four regular elbows of 90°. The typical value of the loss coefficient ξ for a 90° regular elbow is 1.5 [4][5].

- (4): Calculations:

The flowrate of BFG to be transported to the pretreatment section is 6 Nm³/h or about 6.78 m³/h considering a gas temperature of 55°C. The details of the calculation are given below and are summarized in Table 6.

Assumed pipe diameter: $\boxed{\boldsymbol{D = 1.56\ cm}}$

Section of the pipe: $S = \frac{\pi D^2}{4} = \frac{\pi * (1.56 * 10^{-2})^2}{4}$ *Equation 7*

$$\boxed{\mathbf{S = 1.91 * 10^{-4}\ m^2}}$$

Velocity of the BFG in the pipe: $v = \frac{Q}{S} = \frac{6.78}{1.91 * 10^{-4} * 3600}$ *Equation 8*

$$\boxed{\boldsymbol{v = 9.89\ m/s}}$$

Number of Reynolds: $Re = \frac{\rho v D^2}{\mu} = \frac{1.243 * 9.89 * 1.56 * 10^{-2}}{1.53 * 10^{-5}}$ *Equation 9*

$$\boxed{\mathbf{Re = 12\ 510}}$$

A coefficient:

$$A = \left[2.457 * ln\left(\frac{1}{\frac{7}{Re}^{0.9} + \frac{0.27 * \varepsilon}{D}}\right)\right]^{\frac{1}{16}}$$

$$A = \left[2.457 * ln\left(\frac{1}{\frac{7}{12\ 510}^{0.9} + \frac{0.27 * 3 * 10^{-6}}{1.56 * 10^{-2}}}\right)\right]^{16}$$

$$\boxed{\mathbf{A = 2.88^{19}}}$$

B coefficient:

$$B = \left[\left(\frac{37530}{Re}\right)\right]^{16}$$

$$B = \left[\left(\frac{37530}{12\ 510}\right)\right]^{16}$$

$$\boxed{\boldsymbol{B = 4.30^{7}}}$$

Darcy factor:

$$F_D = 8 * \left[\left(\frac{8}{Re}\right)^{12} + \left(\frac{1}{(A+B)^{\frac{3}{2}}}\right)\right]^{\frac{1}{12}}$$

$$F_D = 8 * \left[\left(\frac{8}{12\ 510}\right)^{12} + \left(\frac{1}{(2.88^{19} + 4.30^{7})^{\frac{3}{2}}}\right)\right]^{\frac{1}{12}}$$

$$\boxed{\boldsymbol{F_D = 0.0296}}$$

Pressure drop due to frictions:

$$\Delta P_{\text{Friction}} = F_D \frac{L}{D} \frac{\rho v^2}{2}$$

$$\Delta P_{\text{Friction}} = 0.0296 * \frac{30}{1.56 * 10^{-2}} \frac{1.243 * 9.89^2}{2}$$

$$\boxed{\Delta P_{\text{Friction}} = 3458\ Pa}$$

Pressure drop due to change in elevation:

$$\Delta P_{\text{Elevation}} = \rho g \Delta H = 1.243 * 9.81 * (-10) = -122\ Pa$$

$$\Delta P_{\text{Elevation}} = 1.243 * 9.81 * (-10)$$

$$\boxed{\Delta P_{\text{Elevation}} = -122\ Pa}$$

Pressure drop due to fittings:

$$\Delta P_{\text{Fittings}} = 4 * \xi * \frac{\rho v^2}{2}$$

$$\Delta P_{\text{Fittings}} = 4 * 1.5 * \frac{1.243 * 9.89^2}{2}$$

$$\boxed{\Delta P_{\text{Fittings}} = 364.5\ Pa}$$

Total pressure drop:

$$\Delta P_{Total} = \Delta P_{Friction} + \Delta P_{Elevation} + \Delta P_{Fittings} \quad \text{Equation 10}$$

$$\Delta P_{\text{Total}} = 3\,458 + (-122) + 364.5$$

$$\boxed{\Delta P_{\text{Total}} = 3700\ \text{Pa}}$$

Outlet downstream pressure: $P_{\text{outlet}} = P_{\text{inlet}} - \Delta P_{\text{Total}}$

$$P_{\text{outlet}} = 7700 - 3700 = 4000\ \text{Pa}$$

$$\boxed{P_{\text{outlet}} = 4000\ \text{Pa or } 40\ \text{mbarg}}$$

- <u>**(5): Conclusion:**</u>

A pipe diameter of 1.56 cm is required to have an outlet pressure of 40 mbarg and enable a flowrate of 6 Nm^3/h of BFG from the tapping point to the pretreatment units and the CCU to produce about 0.5 Nm^3/h of CO_2. Pipes are usually manufactured and supplied in standard sizes, therefore a diameter of 2 cm (or 20 mm) will be selected. Details of the calculations can be found in Table 6. The pressure drop and the outlet pressure for a pipe diameter of 2 cm are respectively 1070 Pa and 66.3 mbarg (Table 7) which is more than enough for the operation of the pretreatment section and the CCU.

Table 6 : Pressure drop calculation of the BFP Tap pipe from the BFG main pipe to the demonstrator.

GAS	Volumetric flowrate, **Q**	m^3/h	6,78
	Mass flowrate, **W**	kg/h	8,43
	Viscosity, **μ**	cP	0,0153
		Pa.s	1,53E-05
	Density, **ρ**	kg/m³	**1,243**
PIPING	Diameter, D	cm	**1,56**
		m	0,016
		mm	15,58
	Rugosité, Ɛ (défaut=0.045, steel)	mm	0,003
		m	3,00E-06
	Lenght , **L**	m	**30**
GEOMETRY	Elevation, **ΔH**	m	-10,00
	Elbow, Threaded Regular 90°	Number	**4,00**
	ξ, minor loss coefficient for Elbow, Threaded Regular 90°	-	1,50
	Total ξ	-	6,00
FRICTION LOSS	Section, **S**	m2	0,00019
	Velocity, **v**	m/s	9,89
	Reynolds Number, **Re**	-	12510,09
	Flow Regime	-	**Re > 4000 --> Tuburlent flow**
	F_D, the Darcy friction factor (also called flow coefficient λ)	-	**0,0296**
	Coefficient A in Churchill's correlation		2,88E+19
	Coefficient B in Churchill's correlation		4,30E+07
	Pressure drop per meter of pipe, ΔP/m	Pa/m	115,25
PRESSURE DROPS CALCULATION	ΔP fittings	Pa	364,46
	ΔP straight pipe	Pa	3457,43
	ΔP elevation	Pa	-121,94
	ΔP TOTAL	Pa	3699,96
OUTLET PRESSURE CALCULATION	Inlet Pressure	mbarg	77,00
		barg	0,077
		Pa	7700
	Outlet Pressure	Pa	4000,04
		barg	0,04
		mbarg	40,00

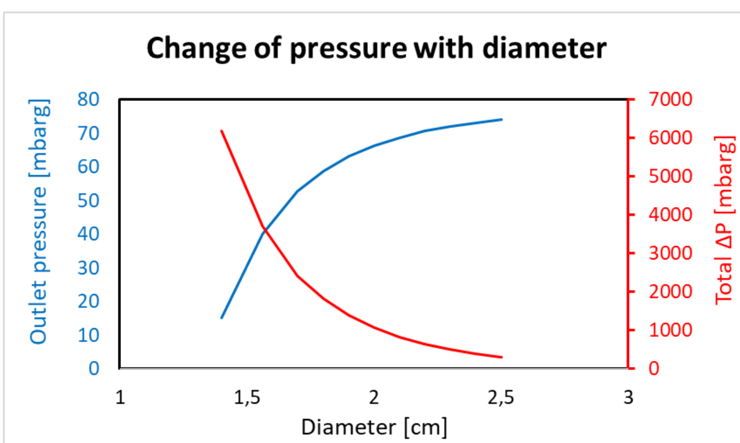


Figure 6: Change of pressure drop and outlet pressure for various pipe diameter.

Table 7 : Pressure drops and outlet pressure for varying pipe diameter, BFG flowrate of 6.7 Nm³/h

BFG Flowrate, Q= 6 Nm^3/h		
Diameter	Outlet pressure	ΔP TOTAL
cm	mbarg	mbarg
1,4	15,2	6180,3
1,56 (1)	40,0	3700,0
1,7	52,8	2416,2
1,8	58,8	1821,6
1,9	63,1	1388,5
2 (2)	66,3	1067,5
2,1	68,7	825,9
2,2	70,6	641,7
2,3	72,0	499,3
2,4	73,1	388,0
2,5	74,00	300,16

(1) Required diameter.

(2) Selected diameter.

Heated line technology

The temperature of the BFG at the inlet of the tap is about [45-50] °C (Table 1). An electrically heated line will maintain the temperature of the BFG at 55°C to avoid condensation of water due to temperature drop along the pipe during normal operation or during cold winter days, where the ambient temperature can drop down to -11.6 °C.

Various suppliers of electrically heated pipe bundles were identified and contacted for their quotes, [**DK6**] will have to select one supplier based on [**ENGIE**] calculations and suggestions. At this stage, it is not known yet which model and supplier will be selected by [**DK6**]. Figure 7 illustrates a typical tube bundle from THERMON. The entire length of the line, from the BFG tap to the pretreatment section, i.e. about 30 m of 20 mm diameter will be heated. It will be ATEX with a power and voltage of 37 W/m and 230 V.

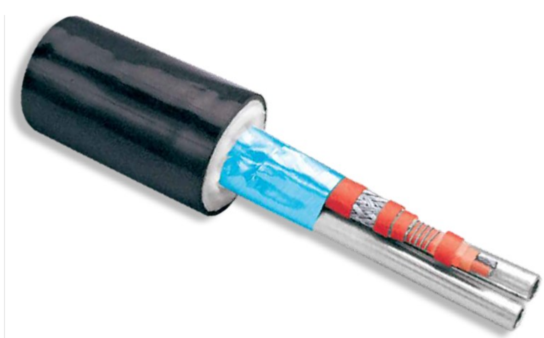


Figure 7: Electrically heated tube bundle that will be used for the BFG Tap pipe

Table 8: Properties of the heated tube bundle from THERMON.

Diameter	20 mm
Length	30 m
Power	37 W/m at 230 V
Model	SE-20Tc1-67-7-ATP-1-M
Supplier	THERMON

3.1.2 Safety requirements of the BFG line

As shown in Table 1, the BFG contains fine solid particles of dust (< 20 μm) that could clog the pipe all along the 30 m length of the tube. Therefore, to avoid deposition and adhesion of charged dust particles on the walls, the pipe should be made with an anti-static material. This will also eliminate the risk of electrostatic spark inside the line that could potentially be hazardous. This is particularly important as the heated line will cross an ATEX zone of the DK6 plant. The solution provided by THERMON (see Figure 7) uses a treated anti-static PTFE for the tube material and is ATEX-zone 2 certified, therefore it will not pose any safety problems on the existing facilities of the power plant.

3.2 Dust Removal

Dust particles as large as 20 μm are present in the raw BFG coming from the steel factory. [**CNRS**] was involved in the design of the particles filtration unit and suggested to use HEPA cartridges filters (glovebox model 640902 from Camfill) that will eliminate 99.97% of particles with diameter greater than 0.3 μm (see Figure 8).

These filters were used onsite with the mini-pilot on real BFG and have proven to be performant in eliminating dust particles. Furthermore, minimal pressure drop increase was observed over 6-7 months of operation at 1.6 NL.BFG/min, indicating the absence of blockage and no equipment malfunction occurred on the entire process with these filters. Finally, no dust particle was visually observed downstream the filters and the highly sensitive analytical equipment has not been damaged. Therefore, this experimental feedback – in addition to the factory recommendation that particles entering the fibers should remain below 1 μm – has demonstrated that these filters can safely be used to ensure efficient separation of the dust from BFG for the demonstrator pilot.

The nominal flow rate of the model proposed by [**CNRS**] is 50 Nm^3/h, so the lower process flow rate of 6 Nm^3/h implies less maintenance for replacing the filter cartridges. The expected pressure drop across the filter, given by the manufacturer, is less than or equal to 250 Pa and the maximum operating temperature is 70 °C. Figure 9 illustrates the change of pressure drop with the flowrate of gas; at 6 Nm^3/h, the expected pressure drop will be about 24 Pa or 0.24 mbar. This pressure drop will be compensated by a blower located at the outlet of the filter and will not have any impact on the downstream process.

Figure 8: Picture of the dust particles filters.

Table 9: Properties of the dust particles filters.

Type	HEPA
Manufacturer	CAMFILL
Model	glovebox model 640902
Estimated pressure drop	250 Pa
Maximum operating temperature	70°C
Nominal flowrate	50 Nm3/h
Cut-off diameter	0.3 µm

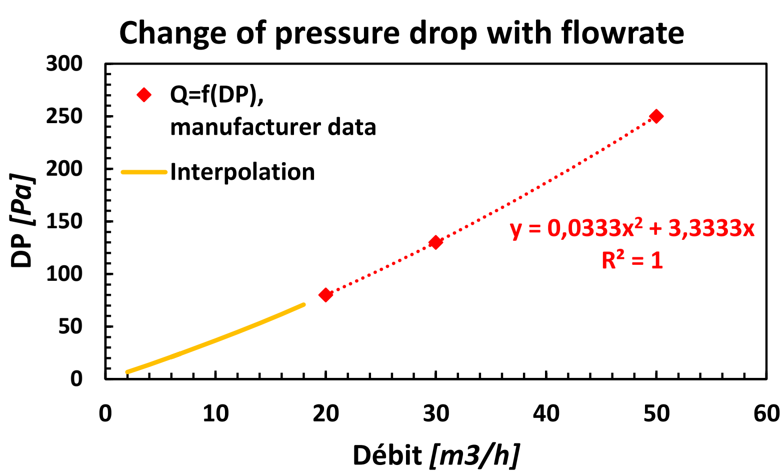


Figure 9: Change of pressure drop across the filter with the flowrate of gas.

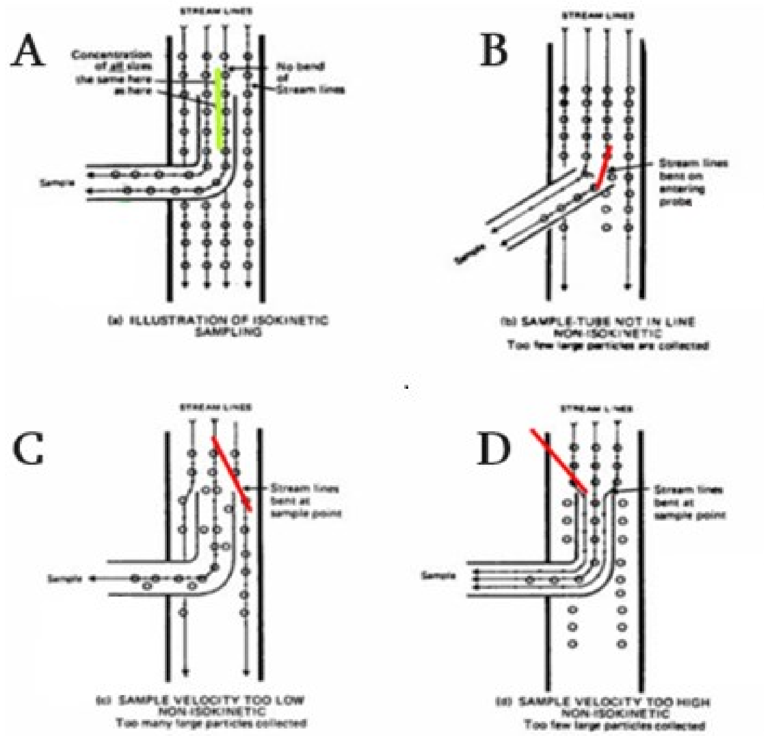


Figure 10: Various BFG tap configurations.

The BFG tap from [**DK6**] to the CCU outlined in Section 3.1.1. is not isokinetic as illustrated in Figure 10A but is rather similar to Figure 10B in design. This leads to an underrepresentation of larger dust particles in the sampled gas line. Due to the operational and safety concerns related with the installation of such a pipeline in one of the two main arteries of the [**DK6**] powerplant, an isokinetic sampling is not feasible for the C2FUEL project. Therefore, it is expected that the tests with the CCU unit will underestimate the overall filter blockage expected with HEPA filters at a larger scale.

3.3 Gas blower

A pressure drop calculation was performed by [**ENGIE**] to determine the optimal position of the gas blower which should be positioned right after the filters. This will ensure that the flowrate and the pressure requirements are met for the circulation of the BFG throughout the rest of the pretreatment units i.e. the cooler and its associated separator and the acid gas removal unit. Results of this calculation are presented in Annex 1.
After consulting PIGNAT, the manufacturer of the CO_2 capture pilot, [**CNRS**] has proposed KNF for the supplier of the blower [**6**]. [**ENGIE**] has discussed with KNF who proposed the N1400 model while [**CNRS**] has proposed the model N1200. The final decision will be made by PIGNAT during the detailed engineering and construction phase of the pilot. The characteristics of both blowers are summarized in the following table and their performance curves are given in Figure 11. These blowers are able to provide the required flowrate (6 Nm^3/h) at a pressure of about 6 bar for the KNF1400 and 1.5 bar for the KNF1200. The flowrate of BFG will be controlled

with a variable frequency drive (VFD) on the blower and a by-pass line. A throttling valve at the discharge will control the outlet pressure of the BFG.

Table 10: BFG blower characteristics.

Model	N1400 ST.9 E	N1200 ST.9 E
Type	Diaphragm	
Flowrate (L/min)	300 L/min	120 L/min
Maximum operating pressure	6.0 bar	
Permissible ambient temperature	[5 to 40]°C with a possibility to go up to 55°C with some minor modifications and using a dedicated cooler	
Permissible gas temperature	[5 to 40]°C with a possibility to go up to 55°C with some minor modifications and using a dedicated cooler	
Motor	Three-phase motor	
Frequency	60 Hz	50 Hz
Power	1850 W	900
Imax	8.50	7.80

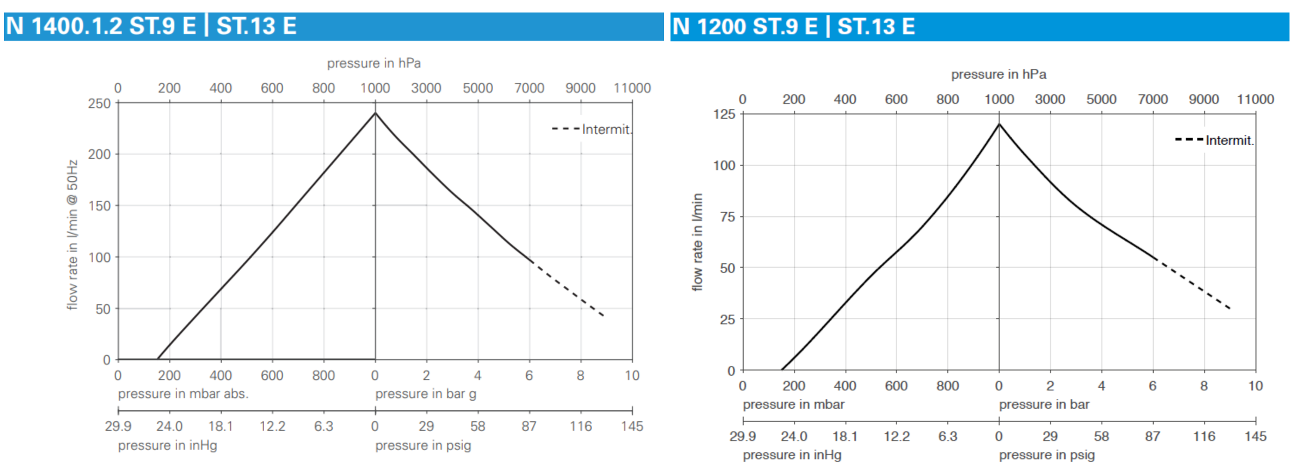


Figure 11: Blower characteristics curve. Left: KNF's N1400 ST.9 E. Right: KNF's N1200 ST.9 E.

Figure 12: Left: KNF's N1400 ST.9 E. Right: KNF's N1200 ST.9 E.

3.4 Condensate Mitigation

A condensation mitigation unit will be implemented to remove condensates of water (relative humidity of BFG >90%, Table 1). The principle is to cool down the BFG stream to cause condensation, then to remove this liquid phase in a separator.

The definition and design of this unit is still under discussion between [CNRS] and PIGNAT, the manufacturer of the CCU pilot. A gas-liquid heat exchanger coupled with a separator will be installed to ensure enough condensate is removed. Thus, water vapor will be condensed from the BFG by cooling it from 55°C to about 45 °C with on-site industrial cooling water. This heat exchanger will need to have a low pressure drop and be suitable for ATEX zone. The estimated amount of condensate at 45°C is about 2 L/day; therefore, the hold-up volume of the separator will be such that it can accumulate liquid for 5 consecutive days (about 10-15 L) without intervention before an operator will need to empty the separator with the manual valve at the bottom.

It is important that the BFG is not cooled down to below the operating temperature of the absorption membranes (about 45°C) to not evaporate much water from the solvent. This will avoid frequent makeup and refilling of the system with the solvent.

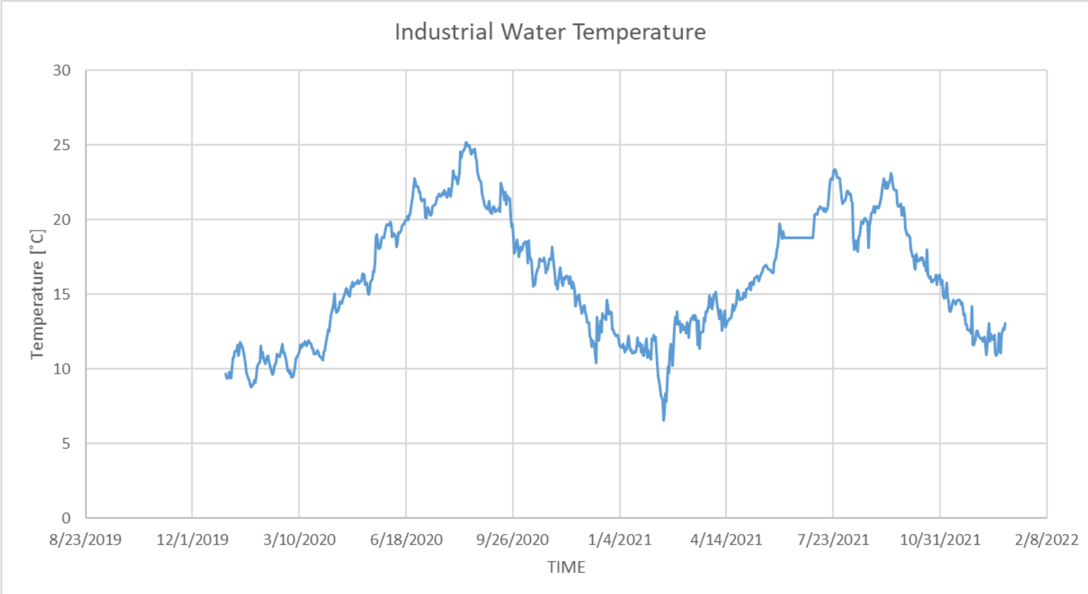


Figure 13: Temperature change of the industrial water available on-site for cooling.

3.5 Gas reheater

As aforementioned, the temperature of the BFG downstream the condensate mitigation step must not be below the operating temperature of the absorption membranes. To avoid further condensation due to temperature losses across piping and to enable optimal performance of the acid gas impurities removal unit, the temperature of the BFG must be maintained at 45°C between the separator and the membrane absorption modules. This will be achieved by means of a gas reheater. At this stage, [CNRS] has already identified OMICRON TECHNOLIES as the provider for this reheater but the selection of this model is not yet definitive and still subject to discussion with PIGNAT.

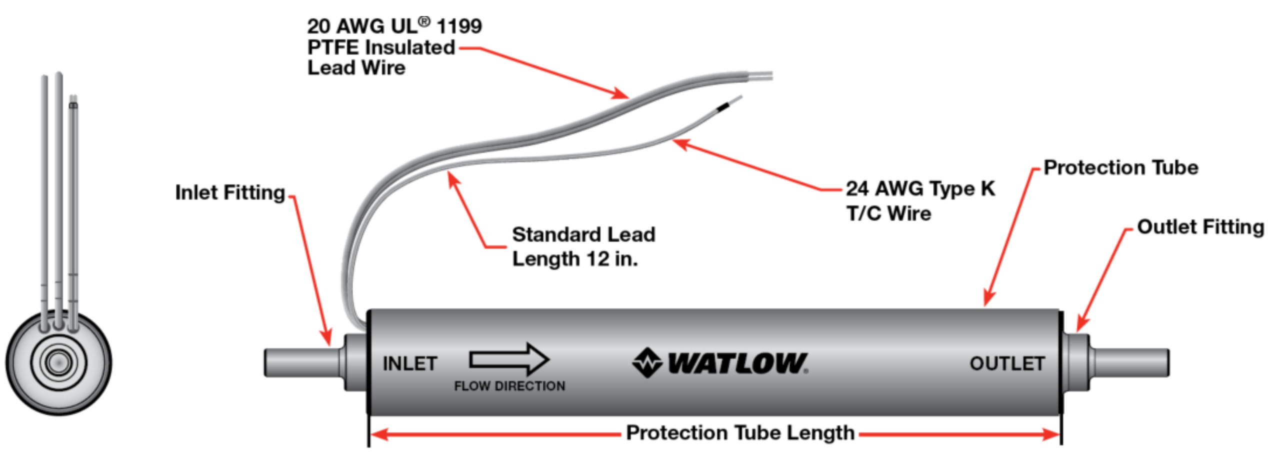


Figure 14: In-line gas heater from OMICRON TECHNOLOGIES, model FLUENT.

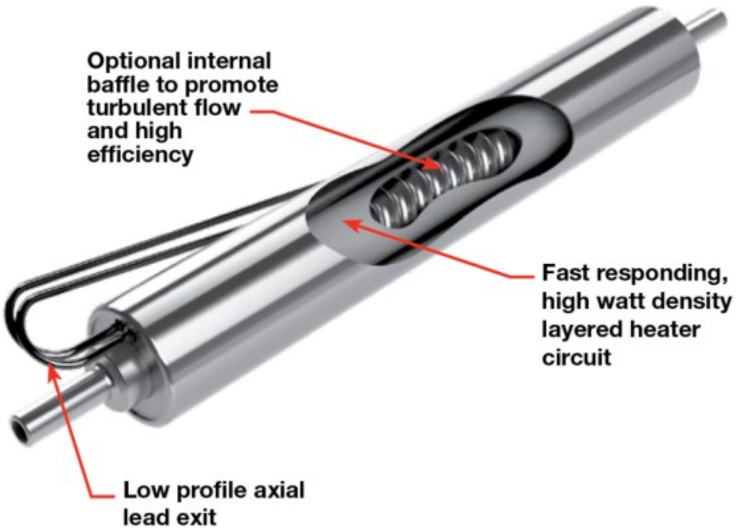


Figure 15: Inside view of the gas heater from OMICRON TECHNOLOGIES, model FLUENT.

Table 11: Properties of the gas reheater.

Tube material	Stainless steel 444 SS
Voltage	240 V
Intensity	Up to 15A
Typical maximum watt densities	Air: 23 W/cmn^2 Water: 70 W/cmn^2
Maximum pressure	10.2 bar
Maximum temperature	350 °C

3.6 Impurities Removal

The most problematic impurities present in the BFG (see

Table 2) are H_2S (<18 ppm), COS (<29 ppm) and SO_2 (<1 ppm). It is crucial that these impurities are removed from the BFG prior to the CCU and the downstream DME synthesis unit because they will reduce the overall process performance. H_2S is a direct competitor with CO_2 for absorption to the chemical solvent, and it will regenerate along with the CO_2 downstream, leading to catalyst poisoning in the DME reactor. COS, in the presence of a weak base like MEA, will either: 1) hydrolysis to form H_2S and CO_2 (dominant mechanism) or 2) react directly with MEA forming a heat-stable species and degrading solvent performance. SO_2 will form a heat-stable salt with the chemical solvent, impacting its long-term performance as well. It is imperative that H_2S levels remain below 50 ppbv for the DME reaction. Thus, these impurities will be removed by adsorption, and [**CNRS**] has suggested to use impregnated activated carbon inside a series of cartridges provided by EFILTEC. [**CNRS**] is still in discussion with them for the selection of the appropriate model of cartridges, which much enable a contact time of the gas with the sorbents of 5 seconds. These cartridges will be very similar to the ones currently in use on the mini-pilot on [**DK6**] site and provided by Cintropur [**7**]. The cartridges will be located downstream the condensate removal unit. The activated carbon is provided by CarboTech (model D 47/4 Extra KC 10) and is suitable for the removal of sulphur trace substances from industrial gases at temperature between 40 to 60°C [**8**]. Sampling points at the inlet of the absorption membrane modules and upstream the adsorption cartridges will enable the monitoring of these impurities during normal operation.

Figure 16 : Cartridges from Cintropur containing the activated carbon from Carbotech [7].

Table 12: Properties of the activated carbon from CarboTech.

Model	CarboTech D 47/4 Extra KC 10
Apparent density	500 kg/m3
Surface area (BET)	1000 m^2/g
Particle diameter	4 mm
Estimated pressure drop	0,2 bar
Moisture content	0,8% max

Table 13 : Characteristics of the cartridges from Cintropur currently in use on the minipilot on DK6.

Maximum pressure	16 bar
Operating pressure	10 bar
Maximum temperature	50°C
Fittings diameter	¾" or 1" (26,5mm or 33,6mm)
Weight	1,23 kg
Dimensions	376x155x126 mm

The activated carbon was tested onsite on real BFG with the mini-pilot designed by [**ENGIE**] and [**CNRS**]. Experimental results have shown that H_2S can be removed to ppbv levels, but results regarding the removal efficiency of other components – especially COS – are inconclusive with the analytical systems used. Therefore, a rudimentary model (see Figure 17) was developed to simulate the necessary removal efficiency of the adsorption beds to achieve < 50 ppbv H_2S in the regenerated CO_2 stream. The following assumptions/objectives were defined:

1) CO_2 absorption by the contactor membranes was set at 39.6%, which is the amount necessary to ensure 0.5 $Nm^3.CO_2/h$ in stream S9, 2) H_2S and COS absorption by the contactor membranes was tested at 39.6% and 100%, and 3) COS hydrolyzes completely during regeneration.

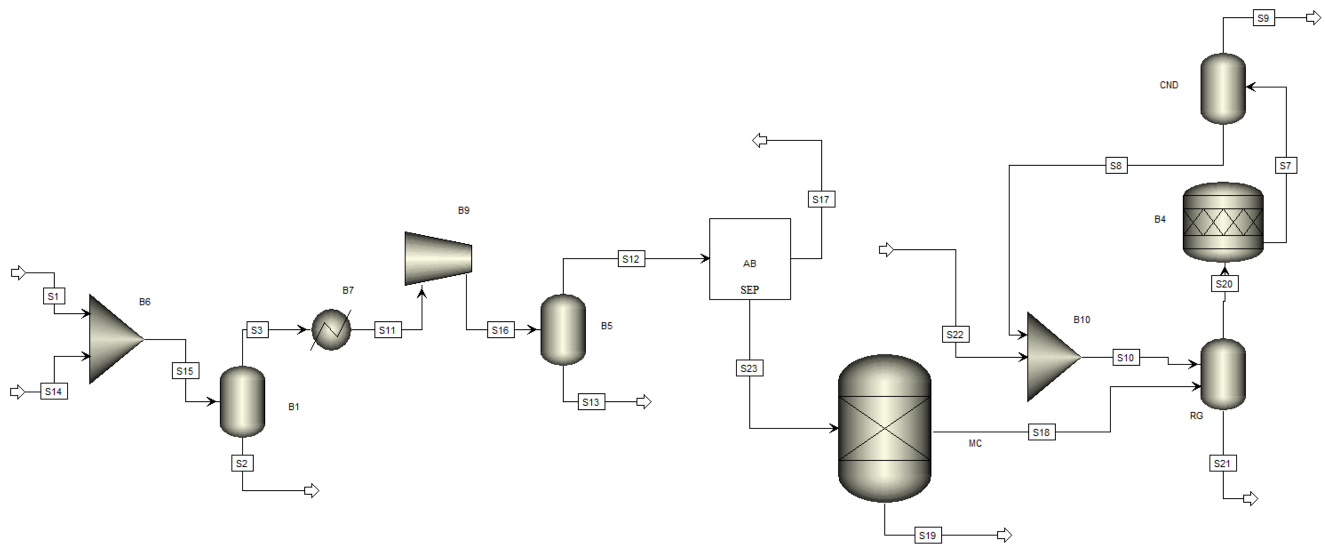


Figure 17: Model developed to study acid gas removal requirements.

Table 14: Flow and composition of the BFG in the simulated model.

Mole Flow	mol/hr	267.58
Mole Fractions	-	
N2	v%	42.86
CO	v%	23.08
CO2	v%	21.04
H2	v%	4.52
O2	v%	0.04
CH4	v%	0.02
H2S	ppmv	16.47
COS	ppmv	26.55
SO2	ppmv	0.91
HCN	ppmv	29.29
H2O	v%	8.44

Modelling of the system (see Table 15) demonstrates that a removal efficiency of >**99.99%** for H_2S and COS from the BFG is required to respect the 50 ppbv upper bound for regenerated H_2S. Given the analytical complexity of measuring low levels of sulfur-containing compounds in a complex gas matrix such as BFG, it is not possible to establish with certainty that COS is below the required threshold with the µGC or FTIR technologies tested during the mini-pilot campaign.

Table 15: Required removal efficiency of the adsorption beds to reach <50 ppbv H_2S in the regenerated CO_2 stream.

MEA Absorption [%]	Component [ppmv]	Acid Gas Removal [%]		
		00.00	90.00	99.99
-	H2S-BFG	17.241	1.724	0.002
-	COS-BFG	27.788	2.779	0.003
100	H2S-Reg	503.927	50.430	0.050
39.60		199.784	19.984	0.021

[**ENGIE**] tested a new configuration for the adsorption beds, placing them after the regeneration column and introducing unpurified BFG in the contactor membranes for absorption. The conditions for regeneration are shown in Table 16. As shown in Figure 19, initial CO_2 flow spikes at roughly 6.4 NL/min before decreasing as solvent flows through the system. Given that the regeneration unit is over-sized relative to the absorption unit of the mini-pilot, this behavior is expected and dynamic in nature. When bypassing the adsorption bed, H_2S content peaks at 35 ppmv before subsiding. A relative delay in peaks is seen in Figure 19, and this is due to the misassignment of the analyzers internal clock. Despite the suboptimal gas temperature at 20 ˚C, Figure 20 shows acceptable H_2S removal performance from the regenerated CO_2 stream when flow is then passed through the adsorption bed. Furthermore, pressure drop at peak CO_2 flow did not exceed 80 mbarg. Given that required flow for the demonstrator pilot is 8.33 NL.CO_2/min, the expected pressure drop across the adsorption beds should not exceed 105 mbarg assuming a simplistic linear behavior as a first approximation. Therefore, [**ENGIE**] recommends installing an additional adsorption unit downstream the CO_2 regenerator to properly mitigate risk, should the adsorption beds in the BFG pre-treatment line prove ineffective. Further tests will be conducted to assess durability over time.

Table 16: Test conditions of the regeneration with the adsorption beds placed downstream the regeneration column.

Parameter	Units	Value
Reflux Temperature	˚C	102-103
Stripper Volume	L	6
Solvent Inlet Flow	L/hr	20
Solvent Inlet Temperature	˚C	80
Average Solvent Residence Time	min	10

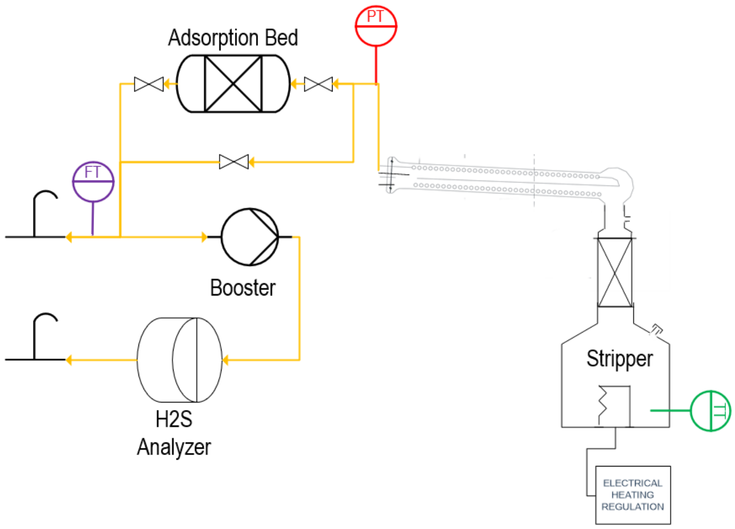


Figure 18: Setup on the mini-pilot for H_2S removal in the CO_2 stream at the outlet of the condenser.

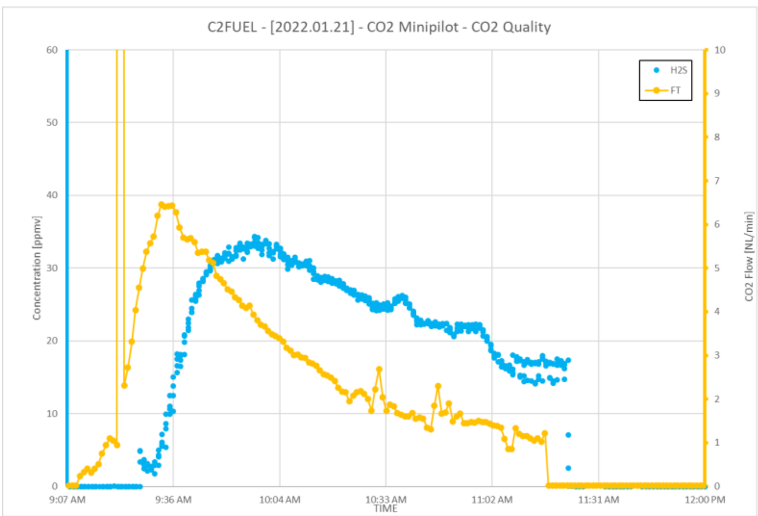


Figure 19: Concentration of H_2S when the adsorption beds are by-passed in the test.

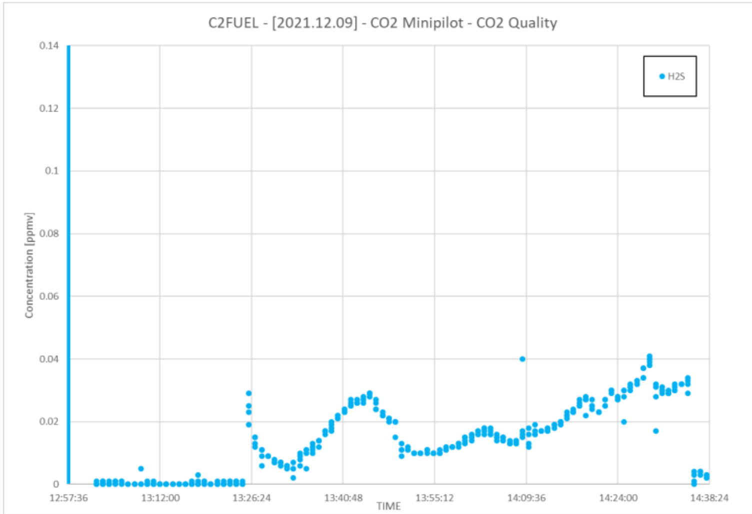


Figure 20: Concentration of H_2S when the regenerated flow of CO_2 is passed through the adsorption beds.

3.7 Dehydration with solid desiccant

Figure 13 illustrates the change of temperature of the industrial cooling water with the period of the year. During summertime, the cooling water could reach up to 25°C which poses the risk of not sufficiently cooling the produced CO_2 at the condenser. The downstream CO_2 compressor can only admit a gas with less than 3%v of absolute humidity; therefore, to avoid potential damages to the compressor, the CO_2 stream must be dehumidified. Thus, a gas dehydration unit using silica gel as desiccant will remove moisture to ensure that dry CO_2 is sent to the compressor. The design of this unit, which is part of the CCU system designed by PIGNAT, is not in the scope of this deliverable.

3.8 Separator

A separator of about 5 L will be installed downstream the dehydration unit to collect any entrained mist. The sizing of this separator is still to be determined by PIGNAT and [CNRS]; it is not in the scope of this deliverable.

3.9 Cold trap combined with a cryocooler

As a last barrier to mitigate the risk of sending humid gas to the compressor, a cold trap combined with a cryocooler will be installed at the outlet of the separator. The supplier and the model of cryocooler have not yet been selected at this stage; this is in the scope of PIGNAT. Figure 21 illustrates how the cold trap is working. A double-envelope vessel contains a coolant, typically glycol or ethanol, in the inside of the vessel where the cryocooler is immersed. The gas flows in the envelope of the vessel where it is cooled down to condense any remaining humidity. The temperature of the coolant can be set by the cryocooler.

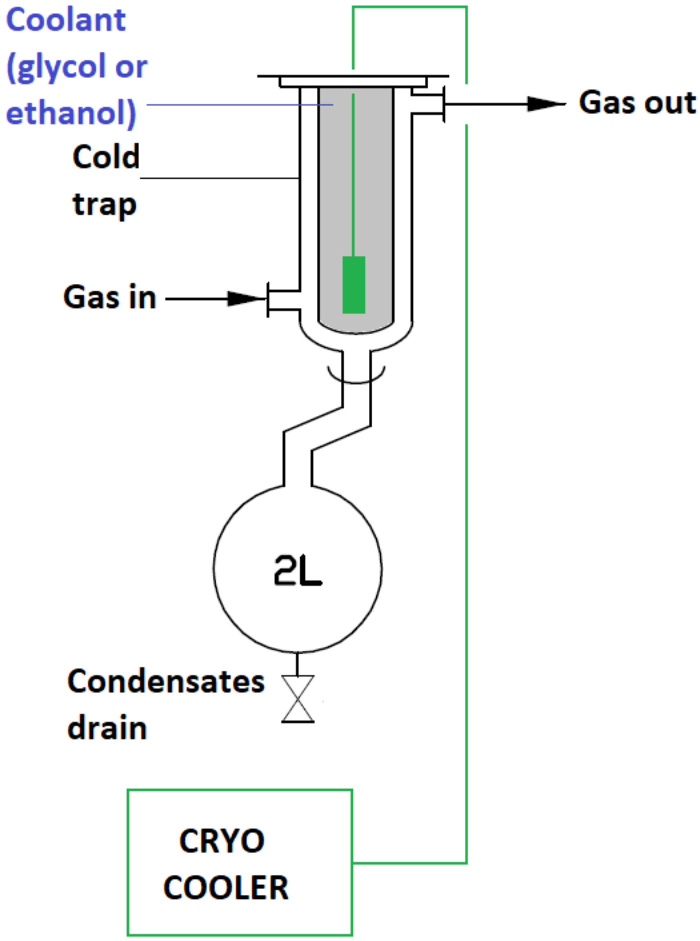


Figure 21: Illustration of the cold trap.

3.10 BFG recyling

The CO_2-lean BFG at the outlet of the membranes absorption modules, namely Flue Gas on Figure 1, has a flowrate of (4 to 5) Nm^3/h and a temperature of about (35 to 45°C) with the following composition.

Table 17: Flue gas composition at the outlet of the membranes' absorption modules.

Component	Composition (v%)
CO	15-20
CO_2	35-40
N_2	50-60
H_2	1-5
H_2O	3-5

This effluent gas will be recycled back to main BFG pipes that feeds the power plant. A second tapping point will be installed downstream the first tapping point (see Figure 1). A demister will remove the humidity from the stream to ensure that no liquid will accumulate in the recycling line and a gas blower will ensure the pressure is greater than (70-80) mbarg to allow the gas to flow back into the main BFG pipes. At this stage of the project, it was decided that this BFG recycle line will replace the catalytic burner initially planned for the treatment of this flue gas prior to releasing it to the atmosphere. The dimensions of this recycle line (diameter and length) have not been determined yet and will be determined by [**CRNS**] and [**ENGIE**] once the design of the pilot is validated with PIGNAT, the constructor of the CO_2 capture pilot.

4 Integration of the unit within the demonstrator pilot

The demonstrator pilot is composed of three unitary bricks:

(1) the pretreatment and CCU with its associated CO_2 compressor,

(2) the High Temperature Electrolyser (HTES) with its associated H_2 compressor

(3) the DME production and its associated DME purification section.

Each unitary brick is being designed separately based on global specifications defined within WP1 and will be housed inside their own containers to be assembled and integrated together on the [**DK6**] power plant.
The pretreatment section and the CCU unit of the demonstrator will be housed inside a standard 20-foot dry container (see Figure 22 and Figure 23). This container constitutes a protection layer that will protect the process and equipment from the outside environmental fluctuations (i.e. wind, rain, snow) and protect the [**DK6**] plant operators and installations. In addition, the container has to ensure the following functions:

(1) Continuous ventilation of the confined space inside the container to mitigate any risk of toxic gas accumulation,
(2) Be able to contain any potential liquid spill,
(3) Enable an easy intervention during operation and for maintenance,
(4) Have gas detection alarms (H_2, CO, CO_2, O_2),
(5) Contains all the necessary roxtec modules, fixation plates and lights,
(6) Contains electrical heater to warm up the container during winter.

Figure 22 and Figure 23 illustrate a standard 20-foot dry container that was used to house the H_2-compressor of the HTES unitary brick. The container that will house the pre-treatment units and the CCU will somewhat resemble to this one; however, at this stage it has not yet been designed because the design will depend on the safety studies (HAZOP and ATEX) of this section which are expected on week 31 (January 2022). Accordingly, a 3D plan of the container design will also be made and will be describer in **deliverable D1.7**.

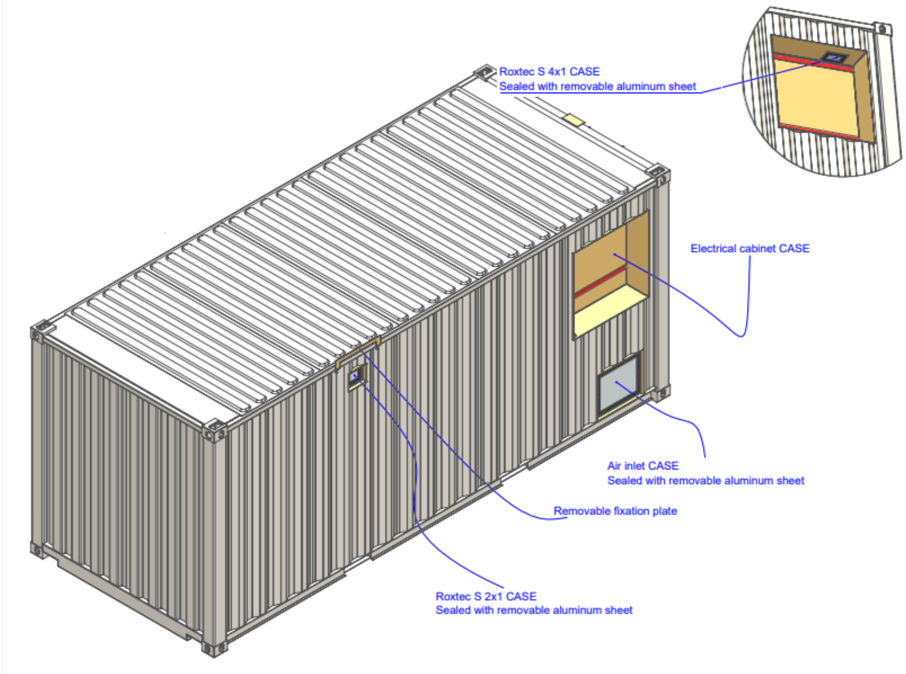


Figure 22: Standard 20-foot Dry container that will host the pretreatment section and the CCU (view from outside).

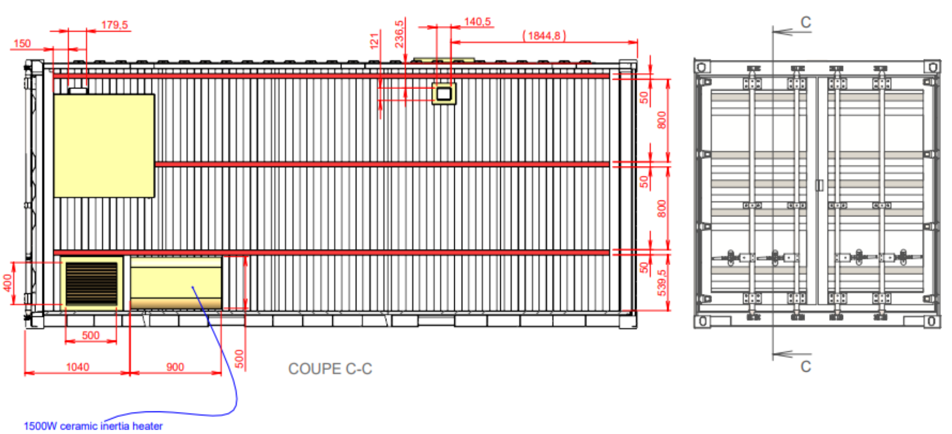


Figure 23: Standard 20-foot Dry container (view from inside).

The layout of the various unitary brick housed in their respective container is illustrated in Figure 24.

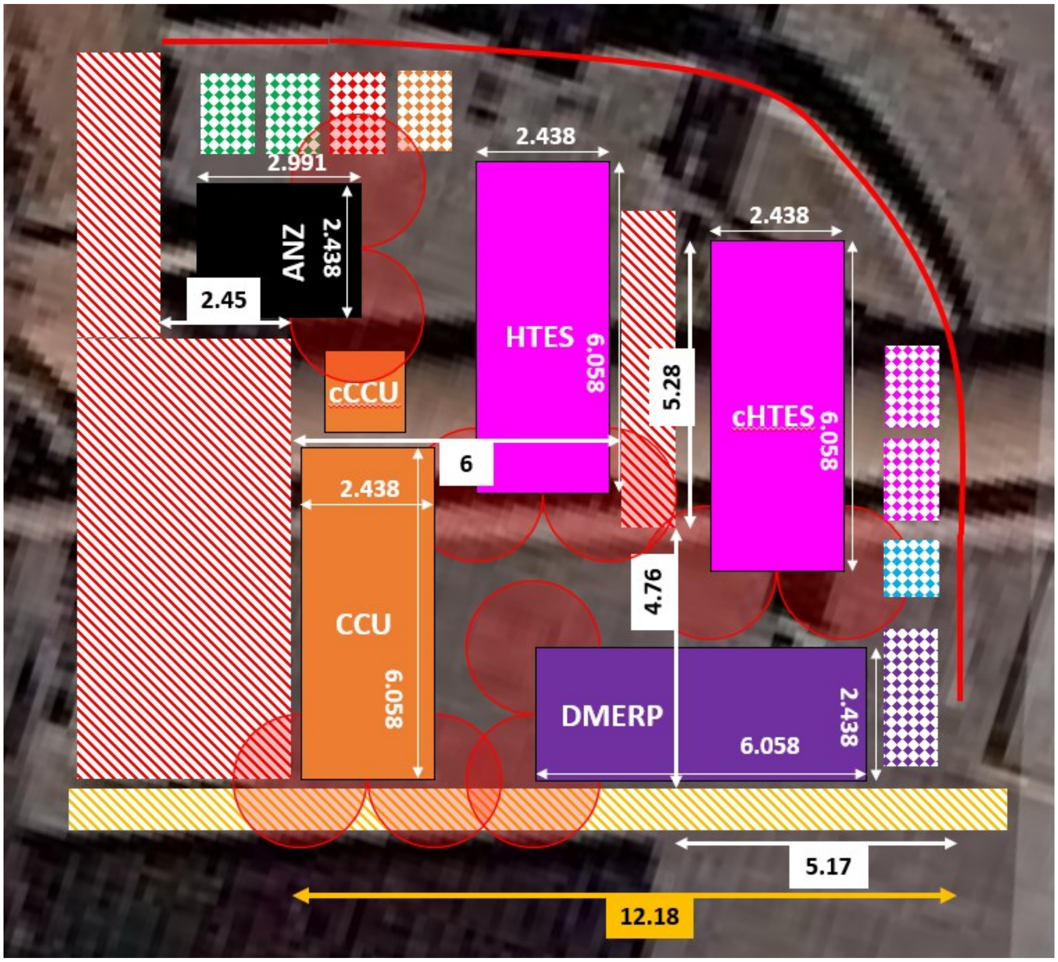


Figure 24: Layout of the demonstrator with the position of all three bricks (ANZ: Analyzers, HTES: Electrolyzer, cHTES: H2 compressor, DMERP: DME production and purification, CCU: CO2 capture, cCCU; CO2 compressor).

5 Conclusions

The BFG pretreatment requirements to comply with the CCU steps were defined and some equipment have already been selected. The pretreatment steps consist of:

(1) transporting the BFG from the main BFG pipes to the CCU through a tapping point and a heated line,
(2) remove fines dust particles (<0.3 µm) with HEPA filters,
(3) condensates mitigation with a chiller coupled with a separator,
(4) impurities, mainly sulphur compounds, removal via adsorption on activated carbon.

For that purpose, the design of this section has been achieved based on the following equipment.

Table 18: Summary of the required pretreatment units and equipment.

Description	Equipment/Unit	Properties	Manufacturer	Model
BFG Tap	Electrically heated line at 55°C	Length: 30 m Diameter: 20 Power: 37 W/m Voltage 230 V	Thermon	SE-20Tc1-67-7-ATP-1-M
Dust particles removal	HEPA filter cartridges with a cut-off diameter of 0.3 µm	Pressure drop: 250 Pa Maximum operating temperature: 70°C Nominal flowrate: 50 Nm3/h Cut-off diameter: 0,3 µm	Camfill	Glovebox 640902
BFG pressure/flow increase	Gas blower	Flowrate at atmospheric pressure: 300 L/min for N1400 and 120 L/min for N1200 Maximum Operating pressure: 6 bar Maximum temperature: 40°C Power: 1850 W for N1400 and 900 W for N1200 Frequency: 60 Hz for N1400 and 50 Hz for N1200 Intensity: 8.50 A for N1400 and 7.80 for N1200	KNF	N 1400 ST.9.E or NK 1200 ST.9.E
Condensate mitigation	Cooler (gas-liquid heat exchanger) coupled with separator	Cooler cooling temperature: 45°C Pressure drop of cooler: TBD Pressure drop of separator: TBD Separator volume: 10-15 L	TBD	TBD
Gas reheater	Heater	Temperature: 45°C	TBD	TBD
Impurities removal (sulphur compounds)	Cartridges	TBD [**CNRS**] and EFILTEC are currently in discussion for the selection of the appropriate model of cartridges.	TBD	TBD

		Specification: the contact time of the gas with the sorbents bed must be at least 5 seconds. This contact time will determine the dimensions of the cartridges.		
	Activated carbon	Apparent density: 500 kg/m^3 Surface area (BET): 1000 m^2/g Particle diameter: 4mm Pressure drop: 0.2 bar	CarboTech	D 47/4 Extra KC 10
Dehydration	Solid dessicant (silica gel)	TBD	TBD	TBD
Separator	Gas-liquid separator	TBD	TBD	TBD
Cold trap and cryocooler	Gas-liquid separator	TBD	TBD	TBD
Flue gas recycle line	Electrically heated line	Length TBD Diameter	TBD	TBD

For each of these units, specific design and sizing methodologies were used. They were also checked based on feedbacks collected from the CO_2 capture mini-pilot currently being tested on [**DK6**] power plant site.
Once cleaned, the BFG is then sent to the CCU section where CO_2 is captured from the BFG before being compressed up to 45 bars and stored in gas cylinders for later use in the DME production brick. The global pretreatment unit will be integrated with the CCU unit into 20-foot dry container. The detailed 3D design of this integrated unit will be made available in the coming months and integrated into **deliverable D1.7.**

6 References

[1]: Results from campaign of measures on blast furnace gas in DK6 by EXPLORAIR, 23.04.2020

[2]: GPSA Engineering Data Book, Eleventh Edition. Section 17, Fluid Flow and Piping.

[3]: Ludwig's Applied Process Design for Chemical and Petrochemical Plants. Volume 1, Fourth Edition, A. Kayode Coker; ISBN 13: 978-0-7506-7766-0.

[4]: Minor loss coefficient for commonly used components in pipe and tube systems. https://www.engineeringtoolbox.com/minor-loss-coefficients-pipes-d_626.html

[5]: https://neutrium.net/fluid-flow/pressure-loss-from-fittings-excess-head-k-method/

[6]: https://knf.com/fileadmin/Global_files/Downloads/Product_OEM_Process/Operating_manuals/BA308926-308929%20N1200_1400-en003%200519.pdf

[7]: https://www.efiltec.fr/carters/carters-cintropur/carter-cintropur-nw25-1-bsp00150002-detail

[8]: Technical data sheet. Activated carbon D 47/3 extra KC 10 (7440-44-0)

[9]: Flow of fluids though valves, fitting and pipe. CRANE, Technical Paper No. 410 M

ANNEX 1: Pressure drop calculation for the positioning of the gas blower.

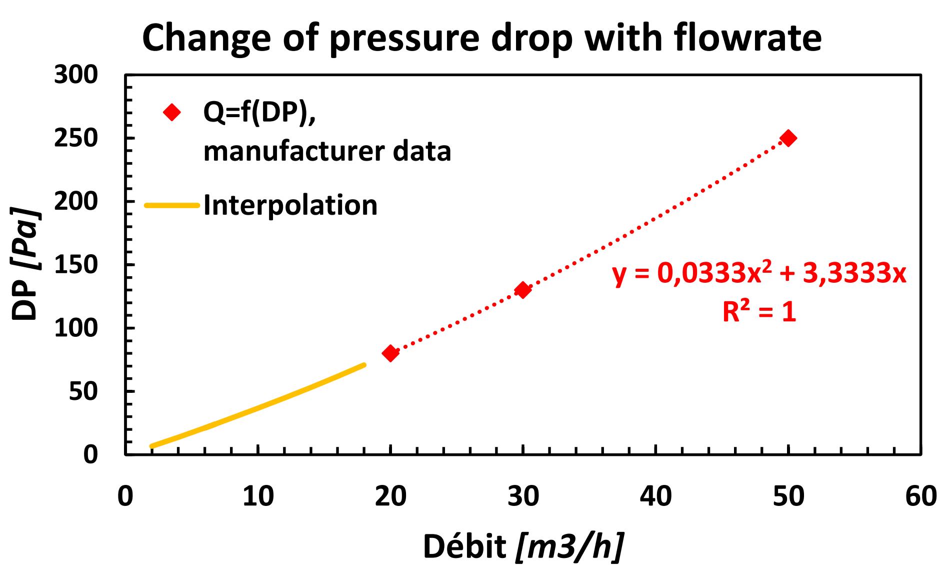
This calculation note estimates the pressure drop of the BFG across the different elements of the pretreatment section in the CCU brick. It calculates the pressure drop of BFG across the filter, the cooler and the separator. Thus, the adequate position of the blower can be determined.

❖ **Assumptions:**

1. Proper determination of pressure drop requires that the piping layout, which includes all the fittings (valves, tees, bend, reducers), is known. As a starting point, we assume that the piping layout of the CO_2 pilot will be similar to the Mini-pilot (see Piping Isometric below).
2. The total pressure drop ΔP_{TOTAL} is the sum of individual pressure drops due to (1) the hydraulic friction in the pipe ($\Delta P_{Frictions}$), (2) the change in elevation ($\Delta P_{Elevation}$) and (3) the fittings such a elbows, tees and valves ($\Delta P_{Fittings}$) as calculated for the BFG Tap pipe explained in Section 3.1.
3. The pressure drop is determined with the Darcy-Weishbach equation and the friction factor F_D is determined with the Churchill equation for a turbulent flow.
4. Fittings: The fittings are based on the piping isometric below.

Fitting	Number	Loss coefficient [1]
Standard 90° bend (elbow)	14	K=30 f_T
Standard Tee, flow thru run	6	K=20 f_T
Standard Tee, flow thru branch	2	K=60 f_T
Gate valve	2	K=8 f_T

5. Length of tube = 50 cm
6. Pressure drop of HEPA filter is given by manufacturer specification as below:



For 6 Nm^3/h of BFG (about 6.78 m^3/h), the pressure drop across the filter is 24 mbar.

7. Assumed pressure drop of cooler = 20 mbar (based on the Peltier cooler on the Mini-pilot)
8. Pressure drop of separator = 20 mbar

❖ **Conclusion:**

The results of the pressure drop calculation are shown in the table below.
Provided that the pressure drop of the cooler and the separator are respectively 20 mbar and 20 mbar respectively (or combined 40 mbar); and for a pipe diameter of DN20 (18 mm internal diameter) and a total length of 50 cm, the pressure at the outlet will be about 15 mbarg.
The condenser and the separator have not yet been designed and purchased so their related pressure drop can only be estimated. Therefore pressure drop of these elements are taken from the specifications of the minipilot currently in use and designed for a lower flowrate. Therefore, it can be safely assumed that for a much greater flowrate (6 Nm3/h of BFG), the combined pressure drop of the condenser and the separator will likely be greater than the assumed 40 mbarg.
Hence, it is more appropriate to put the blower right after the filter, upstream the cooler and the separator.

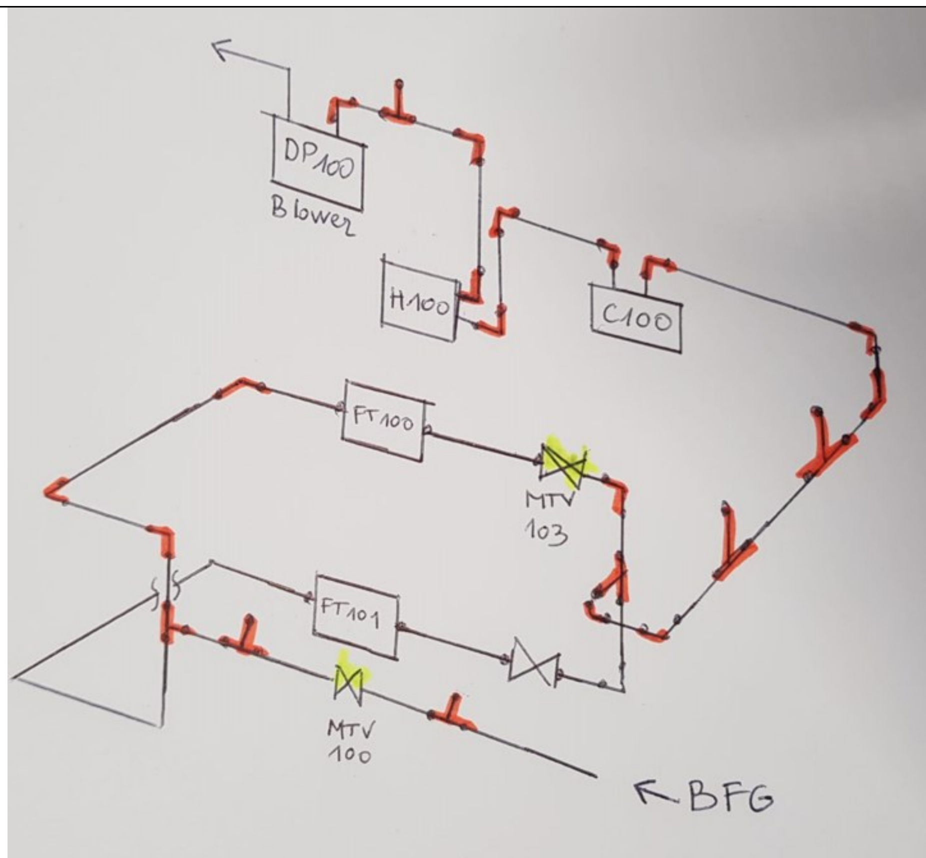


Figure a: Piping Isometric of the Minipilot

Table a: Results of the pressure drop calculation.

DIAMETRE OD = 20 mm --> ID = 18 mm (standard pipe diameter)			
GAS	Volumetric flowrate, Q	m^3/h	6,78
	Mass flowrate, W	kg/h	8,43
	Viscosity, µ	cP	0,0153
		Pa.s	1,53E-05
	Density, ρ	kg/m³	1,243
PIPING	Diameter, D	cm	1,80
		m	0,018
		mm	18,00
	Rugosité, ε (défaut=0.045, steel)	mm	0,045
		m	4,50E-05
	Lenght, L	m	0,5
GEOMETRY	Elevation, ΔH	m	0,00
	Elbow, Standard 90°	Number	14,00
	Tee, Standard, Flow thru run	Number	6,00
	Tee, Standard, Flow thru branch	Number	2,00
	Gate Valve	Number	2,00
	ξ, loss coefficient for Elbow, Standard 90° (=30 x F D)	-	1,03
	ξ, loss coefficient for Tee, Standard, Flow thru run (=20 x FD)	-	0,689
	ξ, loss coefficient for Tee, Standard, Flow thru branch (=60 x FD)	-	2,07
	ξ, loss coefficient for Gate Valve, Standard (=8 x FD) *variant configuration assumed	-	0,28
	Total ξ	-	23,28
FRICTION LOSS	Section, S	m2	0,00025
	Velocity, w	m/s	7,40
	Reynolds Number, Re	-	10825,26
	Flow Regime	-	**Re > 4000 --> Tuburlent flow**
	F D, the Darcy friction factor (also called flow coefficient λ)	-	**0,0344**
	Coefficient A in Churchill's correlation		8,48E+18
	Coefficient B in Churchill's correlation		4,36E+08
	Pressure drop per meter of pipe, ΔP/m	Pa/m	65,16
PRESSURE DROPS CALCULATION	ΔP fittings	Pa	792,85
	ΔP straight pipe	Pa	32,58
	ΔP elevation	Pa	0,00
	ΔP TOTAL	Pa	825,43
OUTLET PRESSURE CALCULATION	Inlet Pressure	mbarg	**66,30**
		barg	0,066
		Pa	6630
	Outlet Pressure (frictions + fittings)	Pa	5804,57
		barg	0,06
		mbarg	**58,05**
FILTER	**Pressure drop due to HEPA Filter**	mbar	**0,24**
HEATER	**Pressure drop due to Heater**	mbar	**20,00**
SEPARATOR	**Pressure drop due to Separator**	mbar	**20,00**
FINAL OUTLET PRESSURE	**OUTLET PRESSURE (-frictions - fittings - filter - heater - separator)**	mbarg	**17,81**