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Title	**Purchase Specification for the Wet Scrubber in the Combined NW PlasGas / Waste Oil Demonstration Facility**
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1 INTRODUCTION

Wet scrubbing (otherwise referred to as gas absorption with chemical reaction) is required for the removal of entrained, toxic and acidic components from the process gas streams leaving the plasma reactor in Necsa's Low-Level Waste Plasma Gasification (NW Plasgas) and Uranium Contaminated Waste Oil Plasma Gasification (CWOPG) Demonstration Facilities. These two facilities share the same scrubber. The main component to be scrubbed from the gas in the NW PlasGas project is hydrogen chloride (HCl), and from the gas in the CWOPG facility, it is HCl and hydrogen fluoride (HF). The scrubbing liquid of choice is a 30% (w/w) potassium hydroxide (KOH) solution. Owing to the large amount of carbon dioxide (CO_2) also present in the gas, this component is also scrubbed in parallel to the HF and HCl. A packed bed scrubbing column is chosen for this purpose.

2 PURPOSE AND SCOPE

2.1 Purpose

The purpose of this document is to define the technical specifications for the KOH scrubber (S1501), so that a supplier may provide the process equipment required for use in the PTFE Filter Destruction Facility.

2.2 Scope

The scope of this document is to provide potential suppliers with the necessary information to design and manufacture the required KOH scrubber. The scrubber includes all of the following components:

- Scrubber sump tank
- Scrubber packed bed column (including packing, internal supports, liquid redistribution, etc.)
- Demister (installed internally at the top of the column)

3 REFERENCES, ABBREVIATIONS AND DEFINITIONS

3.1 References

This document refers to the following documents:	
[1]	ENS-NWPVR-REP-24015: Mass Balance Report for NW PlasGas Demonstration Facility
[2]	ENS-NWPVR-SPE-24020: Specification Sheet for the Wet Scrubber in the Combined NW PlasGas / Waste Oil Demonstration Facility
[3]	ISO 9001:2015: Quality Management Systems - Requirements
[4]	ENS-NWPVR-PID-24002: P&ID Diagram – NW PlasGas Demonstration Plant Subsystem 15
[5]	ENS-OWPVR-PID-24005: Uranium Contaminated Waste Oil Plasma Gasification Basic Engineering Design P&ID – Off-Gas Handling System
[6]	ENS-OWPVR-CLC-24006: Scrubber Design for Uranium Contaminated Waste Oil Plasma Gasification Project

3.2 Abbreviations

Abbreviation	Description
CO_2	Carbon dioxide
CWOPG	Contaminated Waste Oil Plasma Gasification
HF	Hydrogen fluoride
HCl	Hydrogen chloride

Abbreviation	Description
H_2O	Water
K_2CO_3	Potassium carbonate
KF	Potassium fluoride
KCl	Potassium chloride
$KHCO_3$	Potassium bicarbonate
KOH	Potassium hydroxide
N_2	Nitrogen
NW PlasGas	Nuclear Waste Plasma Gasification
O_2	Oxygen
P&ID	Piping and Instrumentation Diagram
PTFE	Polytetrafluoroethylene
QMS	Quality Management System
w/w	Weight per weight

3.3 Definitions

Phrase	Definition
Normal temperature and pressure	Taken as 20°C and 101.325 kPa
Nm^3/h	Volumetric flow rate of gas at the defined normal temperature and pressure

4 SYSTEM DESCRIPTION

4.1 Process Overview

A KOH scrubber (S1501) is required to service Necsa's NW PlasGas and CWOPG facilities. The section of each facility located upstream of the scrubber, hereafter referred to as the "feed-reactor section", will be totally independent and separate of the other facility. The product gas streams from the plasma reactors in each facility will then tie into the same scrubber, which is considered here. From the scrubber downstream, all major equipment will be shared between the two facilities, until the scrubber off-gas is eventually discharged into the building stack via the process ventilation system. However, the two facilities will not operate simultaneously. Instead, all runs will be conducted with one of the facilities and, only once they are completed, will operation of the second facility commence. To this end, it is essential that provision be made to physically isolate the scrubber from the feed-reactor section of each facility. Furthermore, both the NW PlasGas and CWOPG facilities are demonstration facilities for experimental testing and developmental work only. They are not full-scale production plants. Therefore, the facilities will not operate continuously, but rather for a maximum of 8 hours per day, which includes 1 hour for starting up and 1 hour for shutting down.

The main purpose of the KOH scrubber is to neutralise HCl and HF present in the gaseous stream coming from the plasma reactors in the NW PlasGas and the CWOPG facilities. Due to the nature of the reactions taking place, CO_2 will also be removed from the gas feed. The scrubbing liquid enters via internal spray nozzles located above the packed bed, near the top of the column and flows downward over the packing surface. The gas feed is introduced near the bottom of the column and rises upward,

counter-current to the liquid. Mass transfer then takes place between the gas and liquid phases as they interact.

The packed bed column is mounted on top of a scrubber sump tank, which is situated inside a bunded area (B1517). The entire scrubber system is housed inside a secondary enclosure (Y1410) to prevent hazardous gases from reaching the wider operating area traversed by personnel, in the event of leakage from the scrubber system. In turn, the secondary enclosure is installed inside the Laboratory 150 in Building V-H2 on Necsa's Pelindaba-East site.

Figure 1 provides a schematic representation of the scrubber system to show its main dimensions and connection points. Note that this is not intended to be a mechanical or assembly drawing for the system. A more detailed orientation of process connection location is provided in Appendix A. A description of lines entering and exiting the scrubber system is provided in Table 1. Seeing that not every line identified services both the NW PlasGas and WOPG facilities, certain lines will need to be blanked off when a particular facility is in operation. Provision must be made for this.

All equipment numbers are as per the P&ID [4]. However, the P&ID is provided for context only. The scrubber and process connections (as per the scope in Section 2.2) are part of this specification. All peripheral equipment, valves, pipelines and instrumentation shown in the P&ID are outside the scope of this supply, unless otherwise stated in this document.

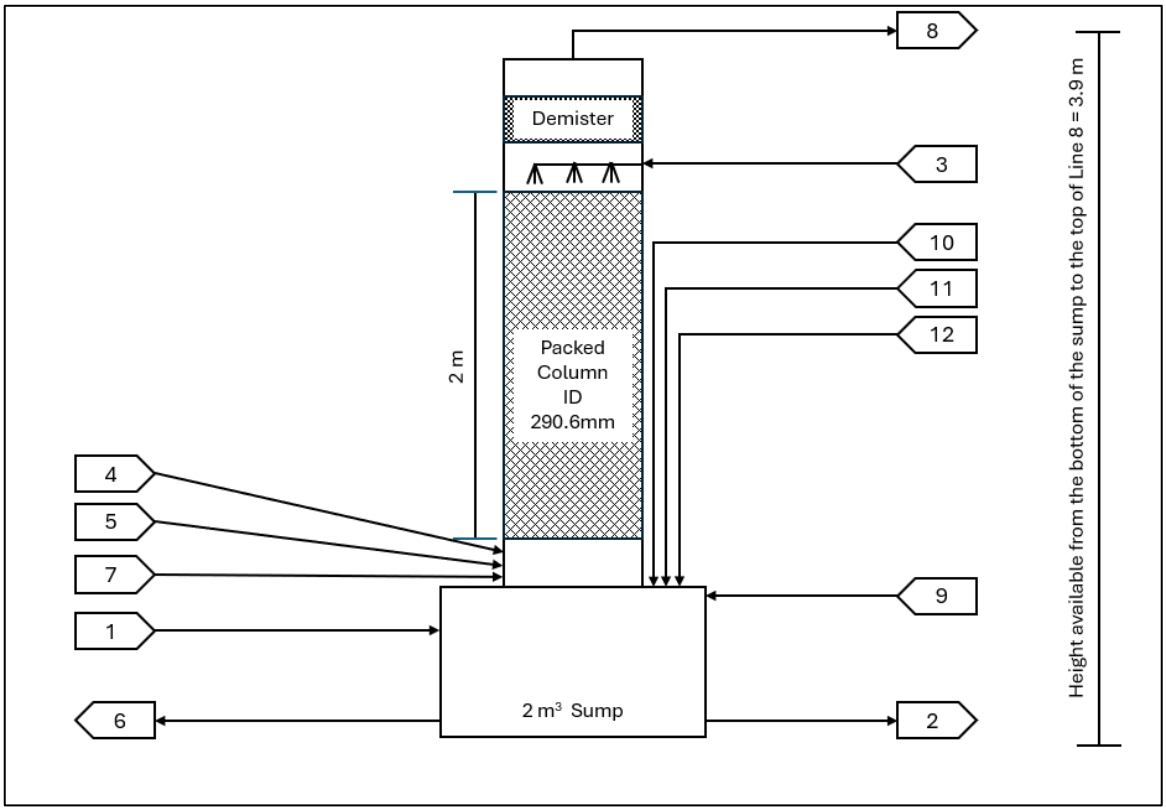


Figure 1: Schematic drawing of the packed scrubber S1501

Table 1: Description of lines in Figure 1

Line number	Description	Service	
		NW PlasGas	WOPG
1	Inlet for fresh scrubbing solution from the KOH solution top up tank T83155 [1] (ad hoc batch process prior to start of scrubbing)	✓	✓
2	Outlet for scrubbing solution recycle stream, transfer to external plate heat exchanger H1504. Also, used to drain spent scrubbing solution from sump tank.	✓	✓
3	Inlet for scrubbing solution recycle stream, return from external plate heat exchanger H1504	✓	✓
4	Inlet for NW PlasGas two-phase mixture discharging from wet quench H1406. Mixture consists of scrubbing solution which is used as cooling medium in the quench and product gas from the plasma reactor R1403, as well as products formed via chemical reaction in the quench. Liquid component discharges into scrubber sump, while the gas rise upwards through the packed column.	✓	—
5	Inlet for common facility off-gas header feeding into scrubber	✓	✓
6	Outlet for supply of scrubbing solution to CWOPG liquid ring pump P1408	—	✓
7	Inlet for return of CWOPG two-phase mixture from liquid ring pump P1408. Mixture consists of scrubbing solution and product gas from the plasma reactor R1205, as well as products from reactions that take place in the liquid ring pump. Liquid component discharges into scrubber sump, while the gas rise upwards through the packed column.	—	✓
8	Outlet for exhaust gas (off-gas) from scrubber to the process ventilation system	✓	✓
9	Inlet for process water supply line to scrubber sump – not part of the main process but included in design to cater for future needs, which may arise during the demonstration phase of the project	✓	✓
10	Inlet for liquid drain line from the moisture trap Y1511 installed in the scrubber off-gas line	✓	✓
11	Connection point for level transmitter (no process line attached)	✓	✓
12	Connection point for viewing window (no process line attached)	✓	✓

Note 1: Tank T83155 is part of a separate facility, not described here

The composition of the gas feed stream to the scrubber from the plasma reactors in the respective facilities is shown in Table 2.

Table 2: Composition of the product gas stream from the plasma reactor system

Chemical formula	Composition (% w/w)	
	NW PlasGas	CWOPG
CO_2	56.97	53.68
HCl	2.98	0.04
HF	–	0.01
H_2O	18.82	22.82
O_2	11.17	14.83
N_2	10.06	8.63

The following reactions are expected to take place in the scrubber for the NW PlasGas facility [1]:

$$KOH + HCl \rightarrow KCl + H_2O \quad (1)$$

$$CO_2 + 2KOH \rightarrow K_2CO_3 + H_2O \quad (2)$$

$$K_2CO_3 + HCl \rightarrow KHCO_3 + KCl \quad (3)$$

$$K_2CO_3 + CO_2 + H_2O \rightarrow 2KHCO_3 \quad (4)$$

$$KHCO_3 + HCl \rightarrow KCl + CO_2 + H_2O \quad (5)$$

In addition to the reactions listed above, the following reactions are expected to take place in the scrubber for the CWOPG project [6].

$$KOH + HF \rightarrow KF + H_2O \quad (6)$$

$$K_2CO_3 + HF \rightarrow KHCO_3 + KF \quad (7)$$

$$KHCO_3 + HF \rightarrow KF + CO_2 + H_2O \quad (8)$$

Solids generated from these reactions (KF, KCl, K_2CO_3, and $KHCO_3$) become entrained in the scrubbing liquid. Based on solubility data, it is expected that KF, KCl and K_2CO_3 will remain in solution at all times. It is, however, possible for some of the $KHCO_3$ to precipitate. The scrubbing liquid collects at the bottom of the scrubber in the sump. From the sump, it is pumped through an external recirculation loop. The liquid passes through an in-line filter (F1503A&B), followed by a plate heat exchanger (H1504) (not shown in Figure 1), before being recycled backed to the top of the scrubber. The filter removes the solid material (precipitated $KHCO_3$) from the solution, while the heat exchanger removes the heat generated by the exothermic reactions taking place in the scrubber.

A fresh batch of scrubbing liquid is an aqueous solution containing 30% (w/w) KOH. It is prepared externally and transferred into the scrubber sump at the start of the process. The batch is then re-used until it is considered spent. At that point, the spent solution is pumped to a waste storage tank (T1506) outside the building, and a fresh batch of scrubbing solution is introduced.

The scrubbing process is divided into three phases, with the liquid effectively changing from an aqueous KOH solution to a K_2CO_3 solution to a $KHCO_3$ solution through the course of this process:

i. Phase 1: For the PlasGas project, it is expected that Reaction (1) and Reaction (2) will dominate during this phase. For the CWOPG project, it is expected that Reaction (1), Reaction (2), and Reaction (6) will dominate. During this time, the KOH concentration will decrease, until all is consumed. The KF (only for CWOPG), KCl and K_2CO_3 concentrations will increase.

ii. Phase 2: For the PlasGas project, Reaction (3) and Reaction (4) are expected to dominate. For the CWOPG project, it is expected that Reaction (3), Reaction (4), and Reaction (7) will dominate. The K_2CO_3 concentration will decrease until all is consumed, while the KF (only for CWOPG), KCl and $KHCO_3$ concentrations will increase.

iii. Phase 3: During the last phase, until the scrubbing solution is considered spent, Reaction (5) is expected to dominate for NW PlasGas, while both Reaction (5) and Reaction (8) will take place in the CWOPG project. The $KHCO_3$ concentration will start to decrease and the KF (only for CWOPG) and KCl concentrations will continue to increase. The process will be terminated before all $KHCO_3$ is consumed.

The change in concentration for PlasGas over time is shown in Figure 2, and the concentration at the end of each phase is shown in Table 3. The change in concentration for CWOPG over time is shown in Figure 3, and the concentration at the end of each phase is shown in Table 4.

Table 3: NW PlasGas: Composition of the scrubbing liquid over time (% w/w)

Chemical formula	At the start	At end of phase 1	At end of phase 2	At end of phase 3
KOH	30	0	0	0
H_2O	70	68.01	59.64	63.81
KCl	0	1.05	1.81	4.35
K_2CO_3	0	30.93	0	0
$KHCO_3$	0	0	38.54	31.84

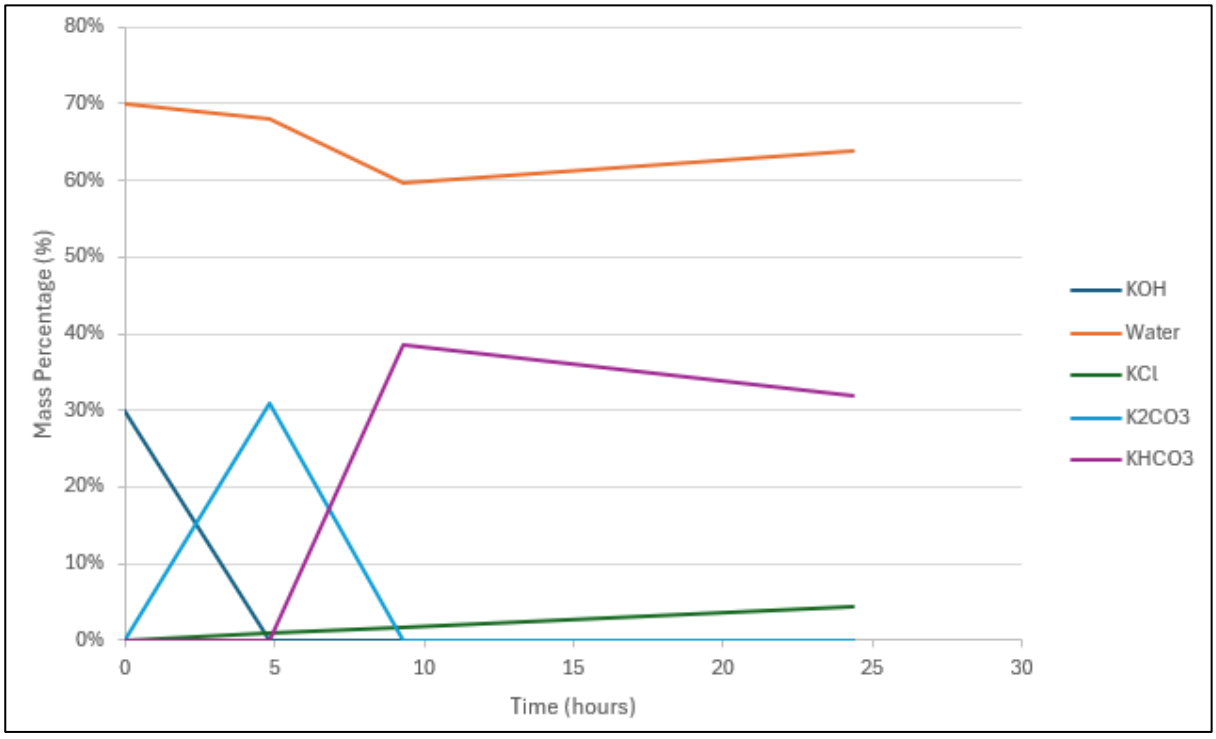


Figure 2: NW PlasGas: Composition of the scrubbing liquid over time

Table 4: CWOPG: Composition of the scrubbing liquid over time (% w/w)

Chemical formula	At the start	At end of phase 1	At end of phase 2	At end of phase 3
KOH	30	0	0	0
H_2O	70	67.22	60.22	65.34
KF	0	0.004	0.007	0.016
KCl	0	0.014	0.024	0.061
K_2CO_3	0	32.76	0	0
$KHCO_3$	0	0	39.748	34.58

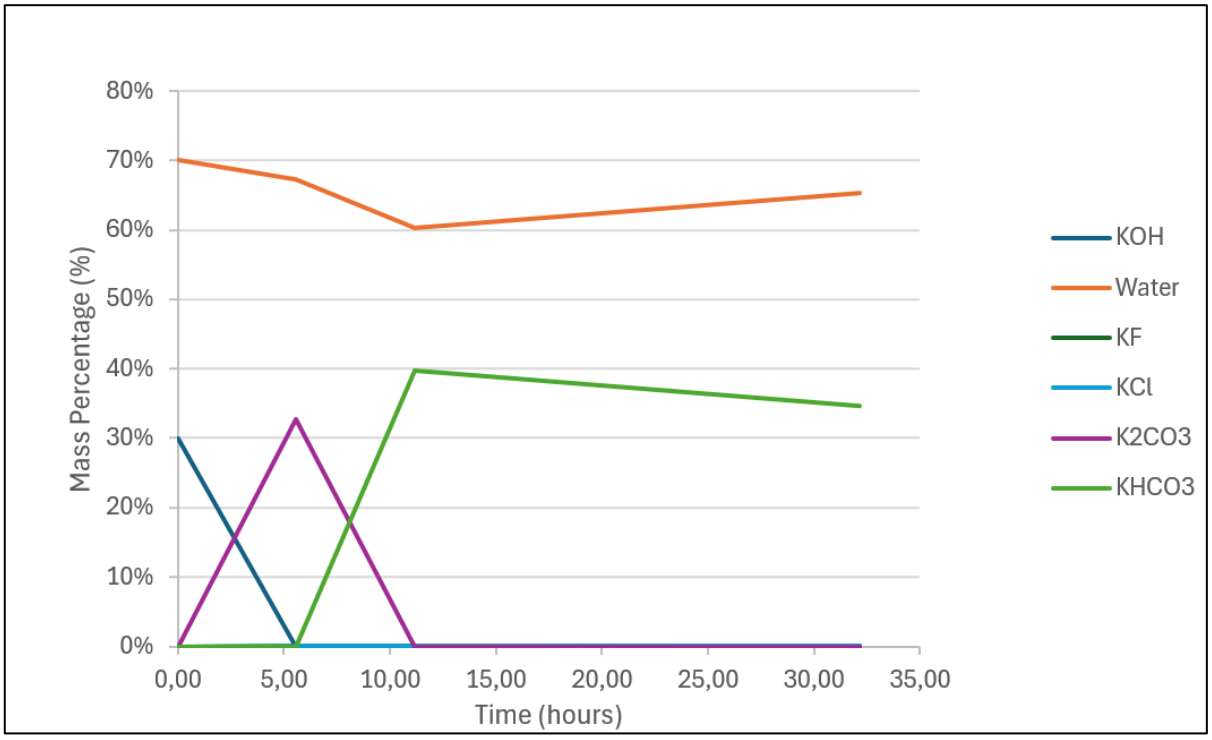


Figure 3: CWOPG: Composition of the scrubbing liquid over time

The gas stream exits the scrubber via the top of the column after passing through a demister to capture any droplets that may be entrained in the gas. Due to the different reactions taking place through the various phases of scrubbing, the composition and flow rate of this off-gas stream will also vary during the different phases of scrubbing. These values are provided in Table 5 for NW PlasGas and Table 6 for CWOPG.

Table 5: NW PlasGas composition and flow rate of off-gas during different phases of scrubbing

Chemical formula	Composition end of phase 1 (% w/w)	Composition end of phase 2 (% w/w)	Composition end of phase 3 (% w/w)
CO_2	1.32	1.32	74.03
HCl	0.07	0.07	0.02
O_2	51.87	51.87	13.65
N_2	46.73	46.73	12.3
Flow rate (kg/h)	12.63	12.63	48.00
Flow rate (Nm^3/h)	9.51	9.51	36.12

Table 6: CWOPG composition and flow rate of off-gas during different phases of scrubbing

Chemical formula	Composition end of phase 1 (% w/w)	Composition end of phase 2 (% w/w)	Composition end of phase 3 (% w/w)
CO_2	10.27	10.27	69.59
HF	0.00	0.00	4.48E-06
HCl	0.01	0.01	2.35E-05
O_2	56.71	56.71	19.22
N_2	33.02	33.02	11.19
Flow rate (kg/h)	15.14	15.14	44.68
Flow rate (Nm^3/h)	11.871	11.871	35.03

4.2 System Location

The scrubber system is housed inside a Secondary Enclosure Y1410. In turn, the Enclosure is located inside Laboratory 150 in Building V-H2 on Necsa's Pelindaba-East site.

5 SYSTEM TECHNICAL DATA

5.1 Site Data

Site specific atmospheric data are provided in Table 7.

Table 7: Atmospheric data

Parameter	Minimum	Maximum
Mean summer temperature	18.9°C	26°C
Mean winter temperature	11.7°C	16.4°C
Design dry bulb temperature	2°C	32°C
Design wet bulb temperature	-1°C	21.6°C
Atmospheric pressure	87.4 kPa	88.3 kPa

5.2 Process Parameters

Process operating parameters and design conditions for the scrubber are defined in the Specification Sheet [2].

For NW PlasGas, the scrubber must function at an efficiency of 99.5% with respect to HCl, i.e. 99.5% of the mass of HCl entering in the gas feed stream to the scrubber must be removed during operation. For CWOPG, the scrubber must function at an efficiency of 95% with respect to HCl and HF, i.e. 95% of the masses of both HCl and HF entering in the gas feed stream to the scrubber must be removed during operation.

5.3 Specific Requirements

Ten connection points must be provided on the scrubber, as described in Table 8 (numbers correspond to Figure 1 and Table 1).

Table 8: Scrubber connections points

Number	Process Line	Scrubber Nozzle (Connection Point)	Location[Note]
1	25 NB, Sch 40, 304L stainless steel pipe with Class 150 raised flange	Polypropylene nozzle to be 32 mm OD with slip-on flange	North side of the sump, near the top
2	25 NB, Sch 40, 304L stainless steel pipe with Class 150 raised flange	Polypropylene nozzle to be 32 mm OD with slip-on flange	North side of the sump, near the bottom. Must allow for maximum drainage of sump.
3	25 NB, Sch 40, 304L stainless steel pipe with Class 150 raised flange	Polypropylene nozzle to be 32 mm OD with slip-on flange. Note that at this point, appropriate spray nozzles must be provided for inside the column to allow for the introduction of the scrubbing solution across the full width of the column.	North side of the column, above the packed bed, below the demister
4	100 NB, Sch 40, 304L stainless steel with Class 150 raised flange	Polypropylene nozzle to be 125 mm OD with slip-on flange Inlet at this point must protrude to the centre of the column to allow the gas to rise from the middle and spread across the width of the column. The inlet must cater for a two-phase mixture to enter the column.	East side of the column, above the sump, below the packed bed. Connection at a 15°angle, see Appendix A
5	75 NB, Sch 40, 304L stainless steel pipe with Class 150 raised flange	Polypropylene nozzle to be 80 mm OD with slip-on flange Inlet at this point must protrude to the centre of the column to allow the gas to rise from the middle and spread across the width of the column.	South side of the column, above the sump, below the packed bed Connection at a 45°angle, see Appendix A

Number	Process Line	Scrubber Nozzle (Connection Point)	Location[Note]
6	25 NB, Sch 40, 304L stainless steel pipe with Class 150 raised flange	Polypropylene nozzle to be 32 mm OD with slip-on flange	South side of the sump, near the bottom
7	40 NB, Sch 40, 304L stainless steel pipe with Class 150 raised flange	Polypropylene nozzle to be 50 mm OD with slip-on flange Inlet at this point must protrude to the centre of the column to allow the gas to rise from the middle and spread across the width of the column. The inlet must cater for a two-phase mixture to enter the column	West side of the column, above the sump, below the packed bed
8	100 NB, Sch 40, 304L stainless steel pipe with Class 150 raised flange	Polypropylene nozzle to be 125 mm OD with slip-on flange	On top of the column
9	15 NB, Sch 40, 304L stainless steel pipe with Class 150 raised flange	Polypropylene nozzle to be 20 mm OD with slip-on flange	On top of the sump, on the east side
10	15 NB, Sch 40, 304L stainless steel pipe with Class 150 raised flange	Polypropylene nozzle to be 20 mm OD with slip-on flange	On the top of the sump, on the west side
11	N/A	Polypropylene nozzle to be 90 mm OD with slip-on flange for mounting level transmitter	On the top of the sump, on the north side
12	N/A	Supplier to advise for viewing window requested in Section 5.3	On the top of the sump, on the south side

Note A schematic drawing is provided in Appendix A to show these positions relative to each other

The scrubber shall be fitted with the following instrumentation:

- An ultra-guided radar level transmitter, which will be mounted on the top of the scrubber sump, on the north side. This will allow monitoring of the liquid level inside the sump during operation. The supplier is only required to provide a nozzle for installation of the transmitter, see Table 8 . Necsa will be responsible for sourcing and installing the instrument separately.
- A temperature transmitter, which will be installed in nozzle 4 (refer to Table 8), to monitor the temperature of the two-phase mixture discharging from the quench into the scrubber in the NW PlasGas facility. The supplier is only required to provide a connection point for the installation of the transmitter. Necsa will be responsible for sourcing and installing the instrument separately.

- A differential pressure transmitter, which will be installed across the packed bed in the scrubber. The transmitter will tie into the process lines that connect to nozzles 5 and 8 (refer to Table 8), and not into the nozzles themselves. Therefore, the supplier is not required to make any provision for this. Necsa will be responsible for sourcing and installing the instrument separately.

A viewing window (300 mm diameter) must be provided on top of the sump, on the south side. The window shall remain sealed, leak-tight throughout normal operation, to ensure that air from the surrounding environment is not drawn into the scrubber. However, provision shall be made for removal of the window, to facilitate sampling of the scrubbing liquid inside the sump tank, only during shutdown.

The total floor space available for installation of the complete scrubber system, including the sump, packed column, and all peripheral piping and components, inside the secondary enclosure is 2 m x 2 m. Similarly, the total height available for the installation, from the bottom of the sump tank to the top of the gas outlet line exiting the scrubber (nozzle 8), is 3.5 m, and from the bottom of the sump to the top of the flange for nozzle 8, is 3.25 m.

The specified sump volume is 2 m^3. Owing to the large sump volume required and the limited height available inside the laboratory, it is acknowledged and accepted that the dimensions of the sump may deviate from conventional tank height to diameter ratios. A sump exhibiting a wide diameter and low height is therefore anticipated. Alternative options proposed by the supplier are also welcomed.

The design must make provision for the addition and removal of packing material, as well as accessing the scrubber internals for maintenance and/or other purposes.

Other design parameters for the scrubber are defined in the Specification Sheet [2].

Within the constraints of the above, the supplier shall advise on the following:

- Optimal shape and dimensions of the 2 m^3 sump tank.
- Type, size and materials of construction for the internal demister at the top of the column, liquid spray nozzles for re-introduction of recycled liquid at the top of the column, and liquid redistribution mechanism inside the column.
- All mechanical supports required inside and/or outside the column and sump.

6 SCOPE OF SUPPLY

The following will be required from the supplier:

- To design and manufacture a scrubber system, including sump and column with demister and packing material, that conforms to all of the specifications given in this document. Note that all components identified in this document, which are located external to the scrubber do not fall within the scope of this supply. This includes, but is not limited to the level transmitter, temperature transmitter, differential pressure transmitter, recirculation pump, in-line filters, plate heat exchanger, moisture trap, KOH solution top-up tank, waste storage tank, valves and piping.
- The supplier shall provide Necsa with a preliminary design report and mechanical drawings of the designed scrubber for acceptance, prior to manufacturing thereof.
- Scrubber material will be purchased and supplied with material certificates. The hit-numbers shown on the material certificate will correspond with the hit-numbers punched or engraved on the purchased material.
- Non-destructive examination of the fabricated material will be done where practical. It should be noted that to be able to transfer the unit into the building and the laboratory, it will be necessary to supply the sump and column as separate units, and only assemble them inside the laboratory. Supplier to confirm dimensions with Necsa after design before manufacturing to ensure that the separate units will fit through the laboratory doors. A leak test will be done after installation on site. The non-destructive examination results shall be supplied together with the scrubber on delivery.
- A pre-dispatch factory acceptance test will be carried out in presence of Necsa's engineers, as follows:
    - Verification of all quality control documents.
    - Verification of traceability of materials and components used in the scrubber.
- The manufacturer shall first perform all the above checks/verification on their own, prior to calling Necsa's engineers for pre-dispatch factory acceptance test.
- Installation is excluded from the scope of the supplier.
- In addition to the above, provide the following documentation:
    - General assembly drawings detailing major dimensions and connections
    - Scrubber design and manufacturing package, including non-destructive examination certificates
    - Installation manual
    - Operating manual (includes troubleshooting guides)
    - Maintenance manual
    - List of critical spares
    - Supply of critical spares

7 QUALIFICATION OF THE BIDDER

Based on the quality classification of the scrubber (as per [2]), the minimum qualification criteria for the supplier are as follows:

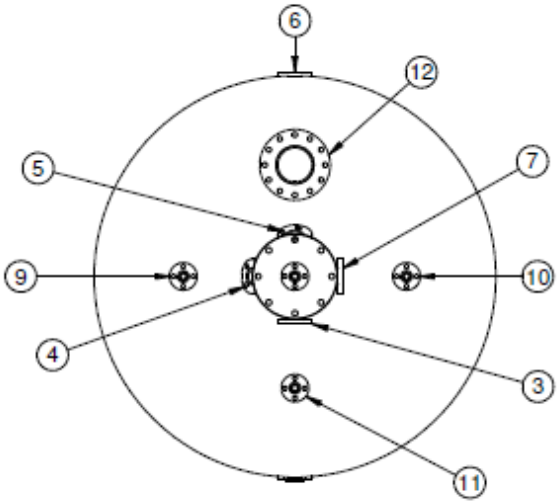
- The supplier shall be ISO 9001:2015 [3] accredited or be able to comprehensively demonstrate that they have a QMS that complies with ISO 9001:2015 [3].

8 REVISION HISTORY

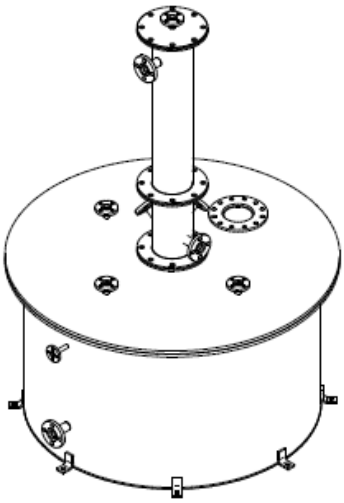
This document has been revised in accordance with the following schedule:

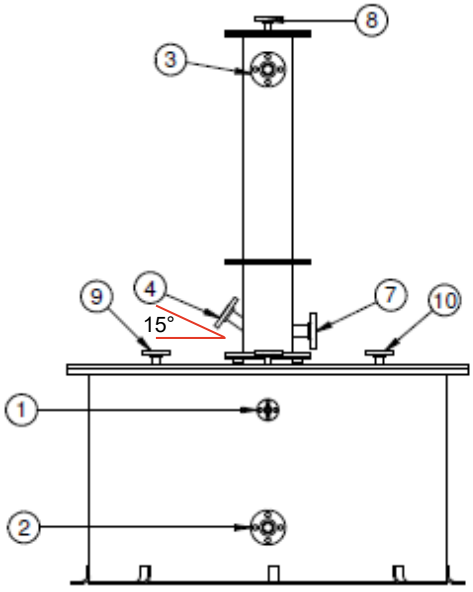
Rev. No.	Date approved	Nature of Revision	Prepared
1	See title page	First issue	M Correia

APPENDIX A: SCHEMATIC TO SHOW LOCATION OF CONNECTION POINTS

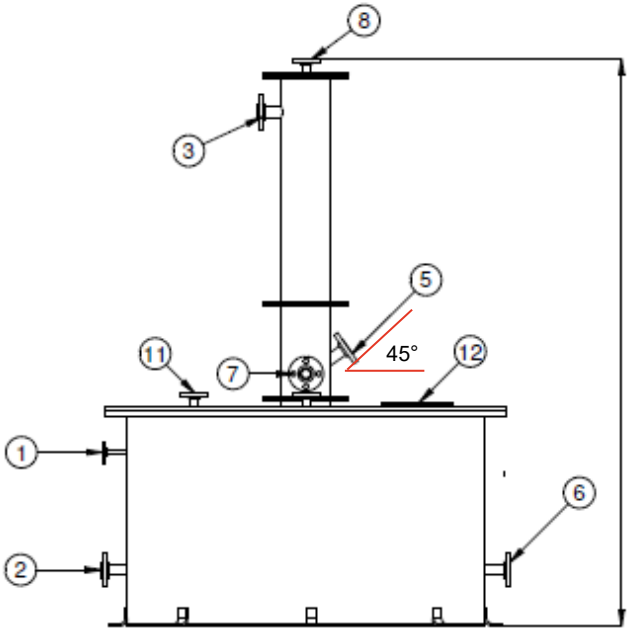


TOP VIEW





FRONT VIEW



SIDE/RIGHT VIEW