Base Load Power Hub (BLPH)

Chemicals-Utility Consumption report

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1 INTRODUCTION

1.1 PROJECT OVERVIEW

Crosswind, a Shell and Eneco joint venture, was awarded the tender to develop the offshore Hollandse Kust Noord (HKN) wind farm, located 18.5km off the coast of Netherlands near the town of Egmond aan Zee. The consortium plans to have HKN operational in 2023 with an installed capacity of 759MW generating at least 3.3TWh per year. This is sufficient renewable power to supply more than 1 million Dutch households with green electricity.

Offshore wind farms produce intermittent electricity and balancing these dips and peaks and integrating this electricity into the national energy system requires new technologies. For this reason, the offshore wind farm will include several new technologies that could be implemented at full-scale in the future. The new technologies being explored include a floating solar park, a short-duration battery storage as well as long-term storage via green hydrogen produced by water electrolysis and subsequently consumed in a fuel cell. The combination of these individual measures, herein referred to as the Base Load Power Hub (BLPH) will ensure a continuous power supply regardless of the wind situation.

1.1.1 Project Location

The Hollandse Kust Noord (HKN) wind farm is located 18.5km off the coast of the Netherlands near the town of Egmond aan Zee.

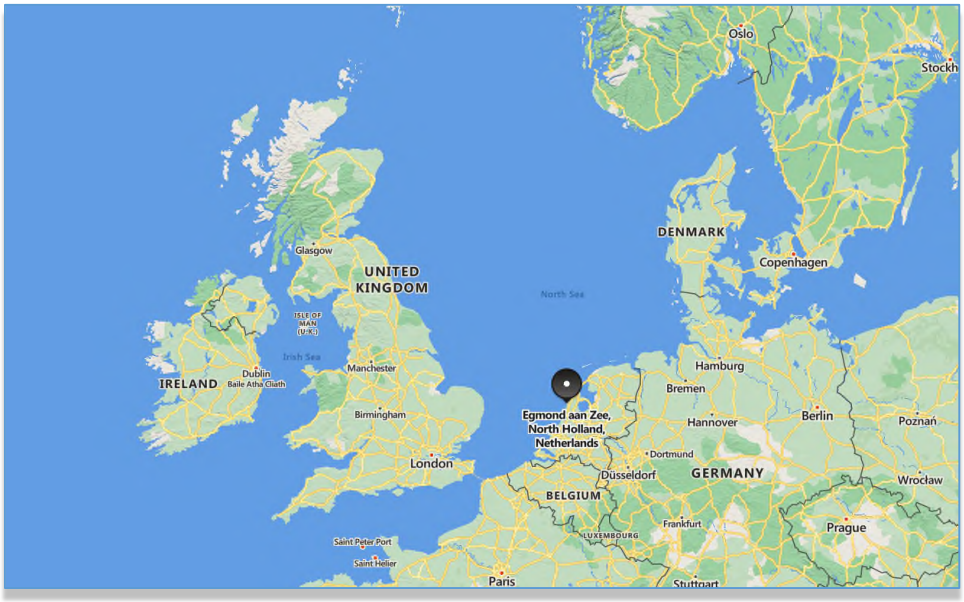


Figure 1 HOLLANDSE KUST NOORD WIND PARK Location Map

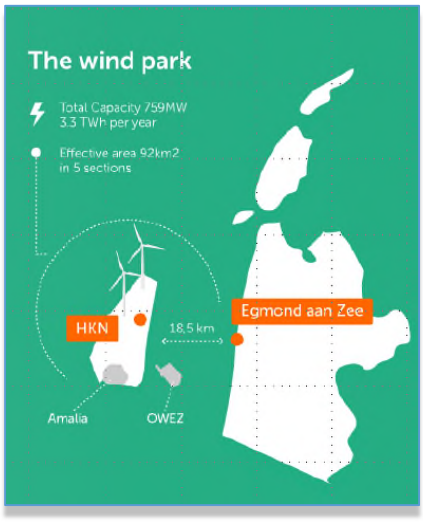


Figure 2 - Wind Park Details

The wind farm will consist of No. 69 x 11.5MW wind turbine generators each to be installed on a dedicated monopile structure. A 70th monopile located on coordinates E 590719.1, N 5841602.3 is reserved for installing the platform accommodating the BLPH. The monopile structure was designed and installed by Van Oord Offshore Wind (VooW) and therefore not part of the BLPH scope.

1.1.2 Project Concept

All components included in the BLPH will be integrated onshore on a topsides and installed in an offshore location within the boundaries of the HKN wind farm. At its simplest, the BLPH will store energy during periods of high electricity generation from renewable sources (a wind turbine generator and the floating solar PV farm) and release it during periods of low generation. In practice. It is expected that the energy stored will supplement generation from renewable sources to ensure that at least 1.0MW of power is exported to the electrical grid regardless of wind/solar availability.

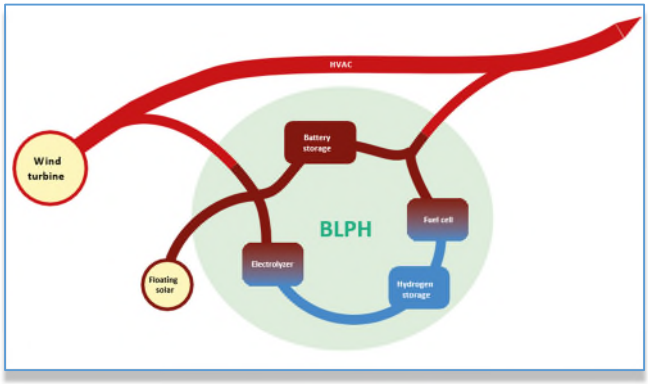


Figure 3 – BLPH Concept

Electricity in the BLPH will be stored in the form of electrons in a battery energy storage system (BESS) as well as converted into green hydrogen via water electrolysis. When the power output from the connecting wind turbine drops to below 1 MWe, the BLPH will return its stored energy to supplement the remaining power output. This will be by discharging the BESS, while stored hydrogen will be converted back into electricity using a fuel cell to extend the discharge duration.

The purpose of the BLPH is to function as a testbed for the integration of energy storage technologies with renewable generation. It is expected that equipment installed on the BLPH will operate as Normally Unmanned Installation for at least two (2) years with no or minimal maintenance and it will have its own independent control room with the ability to communicate with Crosswind's control room.

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2 DOCUMENT SCOPE

The scope of this document is to present the basis, assumptions, input data and chemicals/utility consumption calculation within the boundaries of BLPH project.

In particular, it covers the following consumptions:

- Instrument Air (and Plant Air)
- Nitrogen as inert gas for purging
- Non-oxidising biocide

This document sholud be read in conjunction with the "Process Flow Diagrams" (Ref. [5] to Ref. [10]) and the H&MB (Ref. [2]).

2.1 REFERENCES

Project Documents

Ref. [1] Basic Design Engineering Package_Rev2 - Document No: K559-2254-PM-PLN-003

Ref. [2] Heat And Mass Balance - Document No: 123A90-DDL-PR-BL-80002

Ref. [3] Equipment Sizing Philosophy and Calculations – Document No: 123A90-DDL-PR-CA-80033

Ref. [4] PSFS - Document No: 123A90-DDL-PR-DG-80038

Ref. [5] BLPH PROCESS FLOW SCHEME ELECTROLYSER AND HYDROGEN DRYING PACKAGE – Document No: 123A90-DDL-PR-DG-80003

Ref. [6] BLPH PROCESS FLOW SCHEME HYDROGEN STORAGE – Document No: 123A90-DDL-PR-DG-80004

Ref. [7] BLPH PROCESS FLOW SCHEME FUEL CELL PACKAGE – Document No: 123A90-DDL-PR-DG-80005

Ref. [8] BLPH UTILITY FLOW DIAGRAM WATER TREATMENT PLANT – Document No: 123A90-DDL-PR-UFD-80006

Ref. [9] BLPH UTILITY FLOW DIAGRAM INSTRUMENT AIR AND NITROGEN SYSTEMS – Document No: 123A90-DDL-PR-UFD-80007

Ref. [10] BLPH UTILITY FLOW DIAGRAM VENT SYSTEMS – Document No: 123A90-DDL-PR-UFD-80008

Ref. [11] Technical Query 123A90-PML-PM-TQ-00101

Ref. [12] Set of P&ID from 123A90-DDL-PR-PID-80011 to 80029

Ref. [13] UTILITIES-CHEMICAIS-CONSUMABLES- LUBRICANTS CONSUMPTION LIST – Document No: 1724000448-MAC-LIS-00020

International Codes and Standards

For a list of external, Industry and/or Vendor Standards as well as for a list of Shell DEPs that shall be applied to the project, reference shall be made to Section 10 of Ref. [1].

2.2 DEFINITIONS AND ABBREVIATIONS

DEFINITIONS

COMPANY or Client (CPY):	Crosswind
CONTRACTOR (CTR):	ROSETTI MARINO S.p.A.
PROJECT:	HOLLANDSE KUST NOORD WIND PARK Project

Table 1 - Definitions

ABBREVIATIONS

BDV	blowdown valve
BESS	battery energy storage system
BLPH	base load power hub
CV	control valve
ΔP	pressure drop
DEP	Design Engineering Practice
ESD	emergency shut down valve
FC	fuel cell
FCV	flow control valve
FEED	front-end engineering design
F&G	fire and gas
H&MB	heat and material balance
HMI	Human Machine Interface
KOD	knock out drum
IA	instrument air
ID	internal diameter
LLLL	Low low liquid level
LP	low pressure
MW	molecular weight
N.A.	not applicable
Nm^3	Normal cubic meter (@ 1.01325 bara and 0°C)
Ncm	Normal cubic meter (@ 1.01325 bara and 0°C)
OD	outside diameter
PA	Plant air
PAH	Pressure alarm high
PAL	Pressure alarm low
PCK	Package
PCV	Pressure control valve
P&ID	piping & instrumentation diagram
PFD	process flow diagram
PSD	Process shutdown
PSV	pressure safety relief valve
PT	Pressure transmitter
RO	restriction orifice
SCADA	Supervisory Control and Data Acquisition
Scfm	Standard cubic feet per minute (@ 1.01325 bara and 15.56°C)
Scm	Standard cubic meter (@ 1.01325 bara and 15.56°C)

SDV	shut down valve
SS	stainless steel
SWRO	Seawater Reverse Osmosis
TAHH	Temperature Alarm High High
UCP	Unit control panel
UF	Ultra filtration
UFD	utility flow diagram
U/S	upstream
XV	to be intended as "on-off type control valve"

Table 2 - Abbreviations

3 INSTRUMENT AIR

3.1 GENERAL

In BLPH facility there are several pneumatic valves related to the on-board processes and various air consumers such as prefabricated packages and maintenance tools. The calculation details are shown in APPENDIX 01- CALCULATION NOTE AIR & N2 DEMAND.

3.2 IA CONSUMPTION CALCULATION BASIS

3.2.1 Control valves and on/off valves

The basis used for estimation of IA demand is shown in table below:

No.	Valves with Operating Mode	Consumption Rate	
		Scfm	Nm³/h
1	CV steady-state	1.00	1.61
2	CV transient	6.25	10.05
3	SDV steady state	0.00	0.00
4	SDV transient	4.80	7.72

Table 3 – IA unitary consumptions based on valve condition

All pneumatic-actuated modulating valves are considered as CV in the calculation. All pneumatic-actuated on-off valves with intermittent consumptions of IA, are calculated with the same basis as SDV. These include BDV, XV and SDV.

Based on the above unitary consumptions, the following assumptions have been taken into consideration:

- For **Normal demand**: 95% CV steady-state + 5% CV transient + 10% SDV transient
- For **Peak demand**: 70% CV steady-state + 30% CV transient + 20% SDV transient

In addition, the operational scenarios considered for estimating of IA demand is as follows:

1. SCENARIO 1: Normal steady state operations / No maintenance
2. SCENARIO 2: Plant undergoing load change (start-up / ramp-up / ramp-down) / No maintenance

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3.2.2 Additional IA Users

For the electrolyzer package **18 Nm³/h** of continuous IA consumption has been considered as per *Technical Query 123A90-PML-PM-TQ-00101 (dated 22/9/2023)*. As per mentioned TQ, this consumption represents the peak IA flow rate (see Ref. [Ref. [11]).

3.2.3 Plant Air

Plant air consumption is not easy to estimate, and it is not considered as normal consumption. Plant air for pneumatic tools and for hose stations is requested only during maintenance campaign and not during normal plant operation.

3.2.4 Total Air Demand

As per APPENDIX 01- CALCULATION NOTE AIR & N2 DEMAND, the whole Air Demand is expected to be near **233.5 Nm³/h**, including N2 generation for electrolyser and Vent inertization.

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4 INERT GAS NITROGEN

4.1 GENERAL

Nitrogen inert gas is generated onsite by means of a N2 generation package under the previously mentioned IA package.

4.2 NITROGEN CONSUMPTION CALCULATION BASIS

4.2.1 N2 Consumers

Nitrogen consumption is mainly (or almost exclusively) and widely demanded during maintenance campaign and inerting activities of vessels and piping.

Within several methods for purging (see NFPA 69 "Standard on Explosion Prevention Systems"), the "sweep-through" method has been judged as the most appropriate method for this application compared to the other methods.

The purging activity is aimed to avoid the potential formation of combustible mixture either during the oxygen removal (prior to hydrogen refilling process) and during the hydrogen removal (prior to maintenance and air ingress).

Except for the above intermittent and infrequent operations, the permanent N2 demand is due to continuous nitrogen demand of the Electrolyser and Vent header.

For further details, the relevant calculation details have been attached to the present report along the APPENDIX 01- CALCULATION NOTE AIR & N2 DEMAND.

Moreover, with regard to calculation of N2 demand for purging, considering the position of the two nozzles (for purging and the hydrogen feed inlet nozzle) on the pressure vessel and considering the difference in molecular weights (H2 vs N2), it's evident that assuming a mixing factor k equal to 0.25 is certainly a conservative estimate. The physical dynamics involved suggest that the actual efficiency could likely be higher. This cautious approach ensures a margin of safety in calculations and design considerations.

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5 BIOCIDE

5.1 GENERAL

The main purpose of BIOCIDE injection solution is to avoid (or remove) the biological content from seawater, or rather to discourage the growth of marine organisms within seawater systems.

5.2 BIOCIDE CONSUMPTION CALCULATION BASIS

5.2.1 Biocide injection points

The chemical injections have been foreseen for the following receptors:

- Wastewater Tank T-55001 (discontinuous)
- Seawater lift pumps caissons B-50013A/B (discontinuous)
- Seawater lift pumps P-50001A/B discharge lines and cans (discontinuous, when pumps are offline)
- Biocide on container inlet (discontinuous)

For all the above and in accordance with the calculation performed by the Water Treatment System Vendor (see [Ref. [13]), it has been obtained the following results:

	DOSAGE	FLOWRATE	FREQUENCY OF DOSAGE		TYPE OF CHEMICAL	CONSUMPTION	
	mg/l	l/h	type	h		liters/6 months	liters/year
Biocide on pump caisson B50013A/B	50	0.85	discontinuous shock	20 min every 4 days	non-oxidising (DBNPA), 100% commercial product, density 1.16 g/cm^3, pH 2.5-4	13	26
Biocide on sea water lift pumps P50001A/B	50	0.85	discontinuous shock	20 min every 4 days	non-oxidising (DBNPA), 100% commercial product, density 1.16 g/cm^3, pH 2.5-4	13	26
Biocide on container inlet	2	0.03	discontinuous 2 days/week	12	non-oxidising (DBNPA), 100% commercial product, density 1.16 g/cm^3, pH 2.5-4	21	42
Biocide on WWT	25	0.33	discontinuous shock	1/week	non-oxidising (DBNPA), 100% commercial product, density 1.16 g/cm^3, pH 2.5-4	8	16

6 APPENDICES

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6.1 APPENDIX 01- CALCULATION NOTE AIR & N2 DEMAND

APPENDIX 01 - CALCULATION NOTE AIR & N2 DEMAND

1 AIR & N2 DEMAND

1.1) INSTRUMENT AIR DEMAND by CV,On/Off valves

To determine the Instrument air consumption some assumptions should be made (please note that the following assumption and percentages may differ on each project):

1.1.1) NORMAL INSTRUMENT AIR DEMAND--> 95% CV STEADY STATE + 5% CV TRANSIENT + 10%ON/OFF TRANSIENT

From total number of control valves, 95% of CV operates in stable condition hence requires steady state air consumption only, while 5% could be in unstable condition hence requires transient air consumption.
Shutdown, Blowdown and on/off valves only require instrument air when they are operating which is predominantly during start-up after shutdown, so it is considered intermittent consumption and one can assume that only some number of valve are working simultaneuosly. It could be assumed that just 10% of these valves will operate simultaneuosly for normal air demand calculation.

1.1.2) PEAK INSTRUMENT AIR DEMAND --> 70%CV STEADY STATE + 30%CV TRANSIENT + 20%ON/OFF TRANSIENT

From total number of control valve, 70% of control valve operates in stable condition hence requires steady state air consumption only, while 30% in in unstable condition hence requires transient air consumption. Let's assume 20% On/Off valves will operate in unstable condition during peak air demand

1.1.3) VENDOR DATA/ASSUMPTIONS

The right step is to gather data from vendor catalog which provides information of IA consumption.
Indeed, for actuated valves, the IA consumption depends on size of actuator (swept volume) which could be obtained from vendor catalog. The required opening and closing time of the main valves will also influence the air consumption rate. Where accurate figures are not available the specific consumption of the valves can be averagely assumed as follows (regardless of valve diameter):

- CV steady state $F_{CVSS} := 1\ Scfm = 1.61\ Ncm \cdot hr^{-1}$
- CV transient $F_{CVTR} := 6.25\ Scfm = 10.05\ Ncm \cdot hr^{-1}$
- On/Off steady state $F_{ONOFFSS} := 0\ Scfm = 0\ Ncm \cdot hr^{-1}$
- On/Off transient $F_{ONOFFT1} := 4.8\ Scfm = 7.72\ Ncm \cdot hr^{-1}$

1.1.4) PNENUMATIC VALVES - Normal and Peak Flowrate calculation

Hence, summarizing the number of each valve category from P&ID(Ref.[1]) one can obtain the following flowrate values:

$n_{CV} := 10$ Total number of Control valves

$n_{ONOFF1} := 24$ Total number of ON/OFF valves

The NORMAL IA Flowrate due to control valve and on/off operation is as follows:

$F_{NORM} := 95\%\ n_{CV} \cdot F_{CVSS} + 5\% \cdot n_{CV} \cdot F_{CVTR} + 10\%\ n_{ONOFF1} \cdot F_{ONOFFT1} = 38.81\ \frac{Ncm}{hr}$

While **the PEAK IA Flowrate** due to control valve and on/off operation is as follows:

$F_{PEAK} := 70\%\ n_{CV} \cdot F_{CVSS} + 30\% \cdot n_{CV} \cdot F_{CVTR} + 20\%\ n_{ONOFF1} \cdot F_{ONOFFT1} = 78.43\ \frac{Ncm}{hr}$

1.2) INSTRUMENT AIR DEMAND by other IA users

Further the above-mentioned specific IA consumers, there are several users to be accounted for:

1.2.1) *INTERMITTENT USERS*

Analyser	$F_{AN} := 4.0\ \frac{Ncm}{hr} = 2.49\ Scfm$	(**HOLD1**)	$n_{AN} := 1$

1.2.2) *CONTINUOUS USERS*

Coarse filter	$F_{FIL} := 10\ \frac{Ncm}{hr} = 6.22\ Scfm$	(**HOLD1**)	$n_{FIL} := 1$
Chlorinator	$F_{CHL} := 10\ \frac{Ncm}{hr} = 6.22\ Scfm$	(**HOLD1**)	$n_{CHL} := 1$
UF Unit	$F_{UF} := 10\ \frac{Ncm}{hr} = 6.22\ Scfm$	(**HOLD1**)	$n_{UF} := 1$
Desalination	$F_{DES} := 10\ \frac{Ncm}{hr} = 6.22\ Scfm$	(**HOLD1**)	$n_{DES} := 1$
Electrolyzer	$F_{ELE} := 18\ \frac{Ncm}{hr} = 11.2\ Scfm$		$n_{ELE} := 1$

1.3) PLANT AIR

Consumption is intermittent and not easy to estimate. However, any hose station and powered tool will not be utilized during normal plant operation. Most likely, such a pneumatic users will work only during maintenance campaign. Therefore, the plant air consumption is normally considered nil: $F_{PA} := 0\ \frac{Ncm}{hr}$.

1.4) SUMMARY of AIR CONSUMERS (HOLD1)

Here below the summary table of IA/PA direct consumers:

#	IA CONSUMERS	Specific Consumption (Nm3/hr)		Number	Flowrate (Nm3/hr)	
		Continuous/ Steady State	Intermittent/ Transient		Normal	Max/Peak
1	Control Valves	1.61	10.05	10	20.29	41.39
2	On-Off Valves	0.00	7.72	24	18.52	37.04
3	Coarse Filter	10.00	0.00	1	10.00	0.00
4	Chlorinator	10.00	0.00	1	10.00	0.00
5	UF unit	10.00	0.00	1	10.00	0.00
6	Desalination unit	10.00	0.00	1	10.00	0.00
7	Electrolyser	18.00	18.00	1	18.00	18.00
8	Analyser	0.00	4.00	1	0.00	4.00
TOTAL INSTRUMENT AIR DEMAND					**96.81**	**100.43**
MARGIN FOR UNCERTAINTY AND LOSSES (+20%)					**19.36**	**20.09**
TOTAL INSTRUMENT AIR DEMAND (INCLUDING MARGIN)					**116.17**	**120.51**
TOTAL PLANT AIR DEMAND					**0.00**	**0.00**
MARGIN FOR UNCERTAINTY AND LOSSES (+10%)					**0.00**	**0.00**
TOTAL PLANT AIR DEMAND (INCLUDING MARGIN)					**0.00**	**0.00**
TOTAL AIR DEMAND (INCLUDING MARGIN)					**116.17**	**120.51**

Thus, the design flowrate of the Air Compressor Package shall be adequate to cover at least the following consumption: $\text{MaxAIR} = 120.51 \frac{Ncm}{hr}$ or $\text{MaxAIR} = 127.38 \frac{Scm}{hr}$

1.5) NITROGEN GENERATION and CONSUMPTION

1.5.1) "SWEEP-THROUGH" PURGING DEMAND

The elimination of oxygen from process vessels (and piping) before introducing flammable material such as H2 (e.g.: during a start-up phase), to avoid the potential formation of combustible mixtures is dealt with the sweep-through purging method that consists of feeding nitrogen (the inert gas) into the system from one nozzle and to vent the resulting mixture from another way out nozzle in a continuous once-through operation. Therefore, the concentration of oxygen is progressively reduced in time until it reaches the desired level.

1.5.1.A) CASE (A): REMOVAL OF INSIDE AIR(OXYGEN)(during Start-up)

Assuming the following reasonable conditions:
- vessel full of air at atmospheric conditions
- perfect mixing conditions during purging
- isothermal conditions during purging
- ideal gas behaviour

From a mass balance on O2 one can obtain the following ordinary differential equation:

$$\frac{d}{dt} n_{O2} = M \cdot x_{O2in} - M \cdot x_{O2}$$

where:

n_{O2} = number of oxygen moles in the vessel or system
x_{O2in} =mole fraction of O2 into the purging nitrogen gas(impurity)
M =total molar flowrate of purging nitrogen gas

rearranging the above equation one can obtain:

$$\frac{d}{dt} x_{O2} = \frac{M}{N_{tot}} \cdot \left(x_{O2in} - x_{O2}\right)$$

where:
xO2 = mole fraction of O2 into the vessel or system
xO2in =mole fraction of O2 into the purging nitrogen gas(impurity)
Ntot =total moles of gas mixture into the vessel or system

the integration of this ordinary differential equation gives the following equation form:

$$\int \frac{1}{x_{O2in} - x_{O2}} dx_{O2} \rightarrow -\ln\left(x_{O2} - x_{O2in}\right)$$

rearranging the above integral one can obtain the mole fraction of O2 inside the vessel as function of time, as follows:

$$x_{O2}(t) = \left(x_{O2in} - \left(x_{O2in} - x_{O2s}\right) \cdot e^{-\frac{M}{N_{tot}} \cdot t}\right)$$

Thus, assuming the following INPUT DATA:

$x_{O2in} := 3\%$ mole fraction of O2 into the purging nitrogen gas

$x_{O2s} := 21\%$ mole fraction of O2 inside the vessel at beginning of "start-up"

$M := 42.5 \ \frac{Ncm}{hr}$ molar flowrate of purging gas (**comp.97%N2; 3%O2**)

$P := 1.2 \ bar$ operating pressure during purging activity

$T := 20 \ °C$ operating temperature during purging activity

$V := 96 \ m^3$ total vessel volume

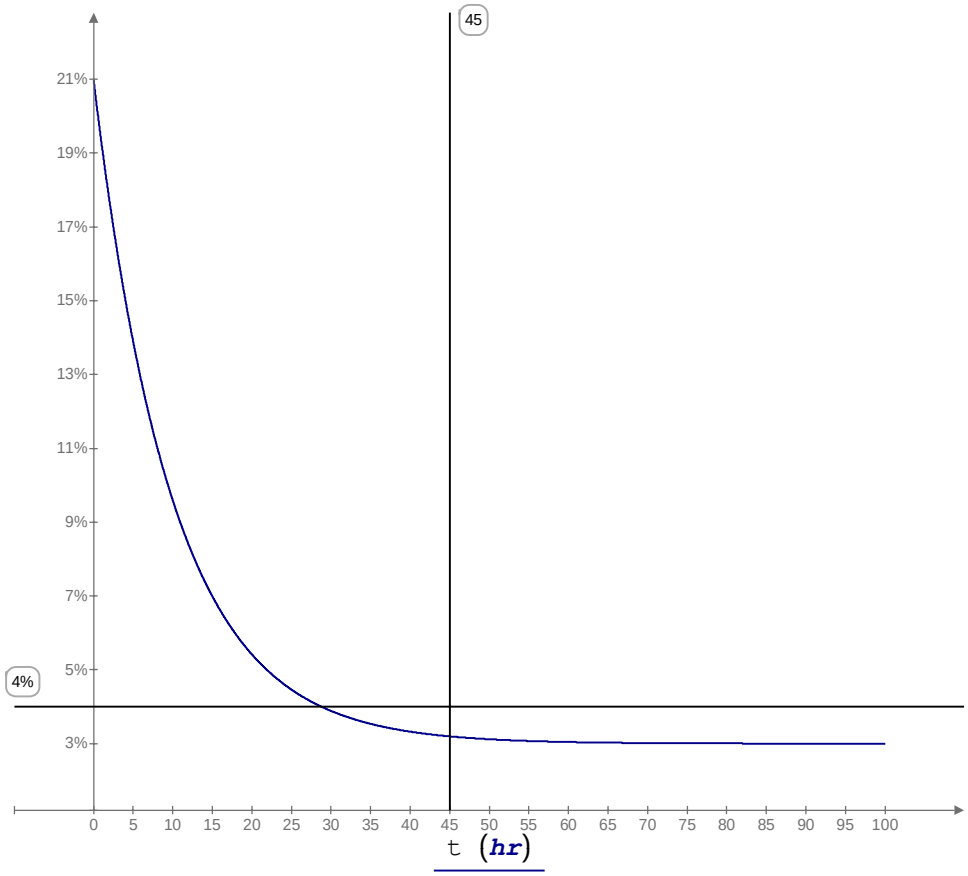
$k := 0.25$ mixing coefficient (to account for mixing inefficiency)

$N_{tot} := \frac{P \cdot V}{R \cdot T} = 4726.4 \ mol$ moles of gas inside the vessel during purging

$$x_{O2}(t) := x_{O2in} - \left(x_{O2in} - x_{O2s}\right) \cdot e^{\frac{-k \cdot M \cdot (Ncm)^{-1}}{N_{tot} \cdot \left(\frac{mol}{22.4 \cdot 10^{-3}}\right)^{-1}} \cdot t}$$ Model equation

$t := 0{,}1\ min..100\ hr$

$x_{O2}(45\ hr) = 3.2\%$ time required to obtain x_{O2} lower than 4%



1.5.1.B) CASE (B): REMOVAL OF LOW PRESSURE HYDROGEN INSIDE THE VESSEL(planned SHUTDOWN)

Similarly to the above theory, making a mass balance on H2 one can obtain the time required to obtain a molar fraction of :

$x_{H20} := 100\%$ initial mole fraction of H2 inside the vessel

$M = 42.5\ \frac{Ncm}{hr}$ assumed molar flowrate of purging gas (**comp.97%N2; 3%O2**)

$P = 1.2\ bar$ operating pressure during purging activity

$T = 20\ °C$ operating temperature during purging activity

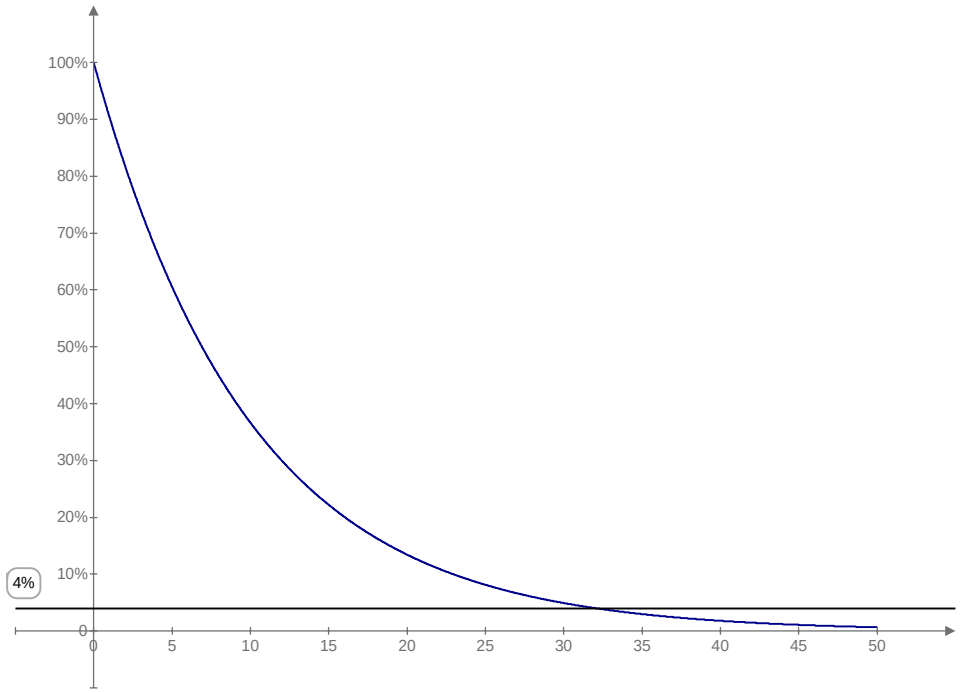
$V = 96\ m^3$ total vessel volume

$k = 0.25$ mixing coefficient (to account for mixing inefficiency)

$N_{tot} = 4726.4\ mol$ moles of gas inside the vessel during purging

$$x_{H2}(t) := x_{H20} \cdot e^{\frac{-k \cdot M \cdot (Ncm)^{-1}}{N_{tot} \cdot \left(\frac{mol}{22.4 \cdot 10^{-3}}\right)^{-1}} \cdot t}$$ Model equation

$x_{H2}(35\ hr) = 2.98\%$ time required to obtain a residual concentration of H2 lower than 4%



$x_{H2}(t)$

In order to estimate the final mole fraction of N2,O2 and H2 at the end of 35 hours, one can solve the following system of linear equations:

Guess Values

$X_{O2} := 1\%$ $X_{N2} := 1\%$ $X_{H2} := 1\%$

Constraints

$X_{O2} + X_{H2} + X_{N2} = 1$

$\frac{X_{O2}}{X_{N2}} = \frac{3\%}{97\%}$

$X_{H2} = x_{H2}(35\ hr)$

Solver

$\begin{bmatrix} a \\ b \\ c \end{bmatrix} := \mathbf{find}(X_{O2}, X_{N2}, X_{H2})$

Thus, the final concentration will be as follows:

$a = 2.91\%$ final mole fraction of O2

$b = 94.11\%$ final mole fraction of N2

$c = 2.98\%$ final mole fraction of H2

$Q_{N2V} := M = 42.5 \frac{Ncm}{hr}$ Assumed Nitrogen flowrate for purging

$Ha := 2.5$ Nitrogen generator "Air Factor" (**HOLD1**)

$F_{N1} := Ha \cdot M = 106.3 \frac{Ncm}{hr}$ Air demand for Nitrogen generator

Thus, as per the above executions (A) and (B), one obtains the time for purging (**considering the reasonable size and then the limitation of the nitrogen generation size being nearly 52.7 Scm/hr**):

$time_A := 45\ hr$ to purge n.1 vessel (say O2 "displacement")

$time_B := 35\ hr$ to purge n.1 vessel (say H2 "displacement")

By considering a "back to back" philosophy it will take the following total time for purging (excluding any "dead time"):

$6 \cdot time_A = 11.25\ day$ to purge n.6 vessel (O2 "displacement")

$6 \cdot time_B = 8.75\ day$ to purge n.6 vessel (H2 "displacement")

1.5.2) ELECTROLYZER PURGING DEMAND

The electrolyzer has a nitrogen demand as follows (Ref.[3]):

$Q_{N2E} := 36 \frac{Ncm}{hr}$ Nitrogen flowrate required for purging of electrolyzer (Ref.[3])

$Ha := 2.5$ Nitrogen generator "Air Factor" (**HOLD1**)

$F_{N2} := Ha \cdot Q_{N2E} = 90 \frac{Ncm}{hr}$ Air demand for Nitrogen generator

1.5.3) PURGE GAS RATE (HUSA's correlation)

The purge gas rate for continuous purge requirements in open flare/vent without the effect of buoyancy seal is given by Husa correlation(Ref.[4]):

$O_2 := 3\%$ Acceptable O2 volume fraction

$C_0 := 98\%$ Volume fraction of N2

$K_0 := 1.707$ Constant for N2

$C_1 := 2\%$ Volume fraction of H2

$K_1 := 5.783$ Constant for N2

$ID := 0.254\ m$ Assumed internal diameter for stack

$y := min(7.62\ m, 10 \cdot ID) = 2.54\ m$ Distance down the stack

$$Q := 190.8 \cdot \left(\left(\frac{ID}{m}\right)^{3.46}\right) \cdot \left(\frac{1}{\left(\frac{y}{m}\right)} \cdot \ln\left(\frac{20.9}{O_2}\right)\right) \cdot \sum_{i=0}^{1} C_i^{0.65} \cdot K_i \frac{Ncm}{hr} = 9.2 \frac{Ncm}{hr}$$ Purge gas consumption

1.6) TOTAL of AIR CONSUMERS INCLUDING N2 GENERATION (HOLD1)

Based on all the above, considering both the totality of air consumers and the nitrogen generator, one can obtain the total maximum air consumption corresponding to about:

$$TOTAL_{AIRcons} := F_{N2} + Ha \cdot Q + MaxAIR = 233.5 \ \frac{Ncm}{hr}$$

or

$$TOTAL_{AIRcons} = 246.8 \ \frac{Scm}{hr}$$

2 REFERENCEs

[1 BLPH PIPING AND INSTRUMENTATION DIAGRAM INSTRUMENT AIR PACKAGE, Doc.n. 123A90-DDL-PR-PID-80027
[2]NFPA69 Standard on Explosion Prevention Systems
[3]Technical Query 123A90-PML-PM-TQ-00101 (dated 22/9/2023)
[4]API STD 521, Pressure-relieving and Depressuring Systems