PROSIMPLUS HNO3 APPLICATION EXAMPLE

MONO-PRESSURE PROCESS

EXAMPLE PURPOSE
This document presents a mono-pressure nitric acid production process. It is a rather usual process of industrial production of nitric acid. The main equipment specific to ProSimPlus HNO3 simulator are used in this simulation: absorption column of nitrous vapors, nitrous vapors condenser, oxidation reactors, heat exchangers with oxidation volumes, etc. It's an example of pure simulation, without any specification on the outlet streams. The particular points which are detailed in this example are the simulation of a DeNOx reactor on the tail gas and the use of an external stream to take into account the cooling water of the nitrous vapors' condenser.

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Energy

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TABLE OF CONTENTS

1. PROCESS MODELING

1.1. Process description

This example is extracted from [BAD96] and [CLA96], which describe summarily the process. The production of nitric acid includes three main steps:

- ✓ Ammonia oxidation

$$4\,NH_3 + 5\,O_2 \rightarrow 4\,NO + 6\,H_2O$$

$$4\,NH_3 + 3\,O_2 \rightarrow 2\,N_2 + 6\,H_2O$$

$$2\,NH_3 + 2\,O_2 \rightarrow N_2O + 3\,H_2O$$

- ✓ Oxidation of the nitric oxide and condensation of the combustion water

$$2\,NO + O_2 \rightarrow 2\,NO_2 \leftrightarrow N_2O_4$$

$$H_2O|_{gas} \leftrightarrow H_2O|_{liquid}$$

- ✓ Fixing of the nitrogen tetroxide

$$\frac{3}{2}\,N_2O_4 + H_2O \leftrightarrow 2\,HNO_3 + NO$$

The mathematical representations of the equilibria and kinetics of the reactions described here above are complex. Side reactions occur, in particular the formation of nitrogen trioxide:

$$NO + NO_2 \leftrightarrow N_2O_3$$

The mono-pressure process (catalytic oxidation and absorption at the same pressure) relies on the reaction:

$$\frac{3}{2}\,N_2O_4 + H_2O \leftrightarrow 2\,HNO_3 + NO$$

The main characteristic of this reaction is that each time two molecules of nitric acid are formed there is also production of one molecule of nitric oxide (NO). This molecule of NO has to be oxidized in NO_2, and then absorbed and so on. These successive oxidations are mainly done in gas phase in oxido-absorption tower where the reactions of nitric acid production and NO oxidation are performed in parallel:

$$2NO + O_2 \rightarrow 2NO_2$$

In this process, condensation and absorption are done at the same pressure as the oxidation, between approximately 5 and 10 bars. Thus, only one compressor is used. The absorption tower has a bleaching stage in its lower part.

The process flowsheet is given in paragraph 1.2. The liquid ammonia is vaporized by cooling water (E101), filtered before overheating (E102) and sent in an air – ammonia mixer (M101). The filtered atmospheric air is compressed (K101) and then splitted in two streams by the valve V103: the primary air (Air S06) goes to the air – ammonia mixer (M101) and the secondary air goes to the bleaching column (C102). Before, a part of the air is withdrawn for the instrumentation in the valve V102. The air – ammonia mixture is sent to the reactor (R101).

For the reactor modelling, three main reactions are taken into account:

$$4\,NH_3 + 5\,O_2 \rightarrow 4\,NO + 6\,H_2O$$

$$4\,NH_3 + 3\,O_2 \rightarrow 2\,N_2 + 6\,H_2O$$

$$2\,NH_3 + 2\,O_2 \rightarrow N_2O + 3\,H_2O$$

The gas after combustion is composed of nitrogen oxides, nitrogen and oxygen. Its sensible heat is recovered in a series of heat exchangers (E103, E104, E105 and E106). After condensation (E107), a huge quantity of weak nitric acid is formed and sent to the absorption tower (C101). The gas mixed with the air leaving the bleaching tower C102 in the mixer M103 is sent to the sieve trays of the absorption tower (C101). This column has cooling coils on its trays. Process water is introduced at the top of this column and nitric acid at the desired concentration is withdrawn at its bottom. Then, this acid goes to the bleaching column (C102). A stripping by the secondary air (Air S08) is done in this equipment. The gas leaving the main absorber C101 is sent in a series of gas-gas heat exchangers (E108, E109 and E105). Then the gas is mixed with a low quantity of ammonia to react in a catalytic reactor to reduce the amount of NOx in the tail gas. This reactor (R102) is operated around 270°C; the conversion in this reactor can be modelled by the two following reactions:

$$4\,NH_3 + 6\,NO \rightarrow 5\,N_2 + 6\,H_2O$$

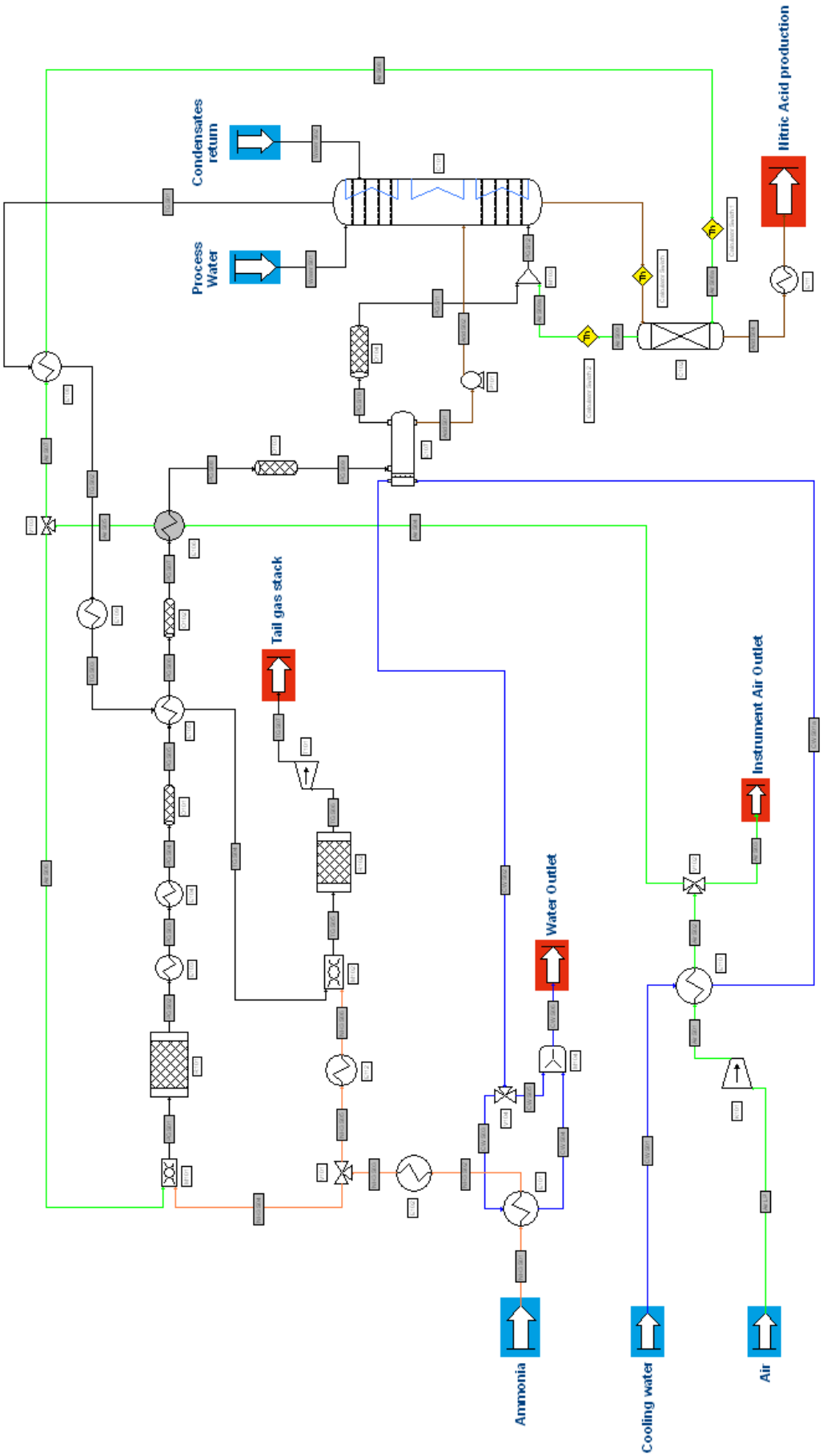
$$8\,NH_3 + 6\,NO_2 \rightarrow 7\,N_2 + 12\,H_2O$$

The NOX-depleted tail gas is sent in an expander (T101) and then to the stack.

In parallel, steam is produced by heat integration (not modelled in this example). In addition, cooling water goes successively in the condenser E107 and in the heat exchanger E101.

The objective of this process is to produce 1 000 t/d of nitric acid (eq. 100%) at a concentration of 58% wt.

1.2. Process flowsheet



1.3. Components

The components involved in the simulation, their chemical formula and CAS Registry Numbers® [1] are presented in the following table. Pure components physical properties are extracted from the ProSimPlus HNO3 specific database ("HNO3").

Component name	Chemical formula	CAS number®
Ammonia	NH_3	7664-41-7
Oxygen	O_2	7782-44-7
Nitrogen	N_2	7727-37-9
Nitric oxide	NO	10102-43-9
Nitrogen dioxide	NO_2	10102-44-0
Nitrogen tetroxide	N_2O_4	10544-72-6
Nitrous oxide	N_2O	10024-97-2
Nitric acid	HNO_3	7697-37-2

1.4. Thermodynamic models

For the main part of the process, the "HNO3 specific" thermodynamic model is selected. This model takes into account the non-ideality of the liquid phase through correlations based on experimental data of partial pressures of water and nitric acid over aqueous solutions of nitric acid. The perfect gas model is used for the gas phase. A correlation based on experimental data is used to take into account the excess enthalpies of the water – nitric acid binary.

For the bleaching column the "Engels (strong acids)" thermodynamic model is used. This model well represents the NOx solubility and the complexity of the H_2O – HNO_3 equilibria. The "H*=DH0f, ideal gas, 25°C, 1 atm" enthalpy basis is selected instead of the default one of this model, to ensure the coherence with the "HNO3 specific" model. This model is also used in the E111 product acid cooler.

For the cooling water circuit, the "Specific thermodynamic model for water" is used [HAA84]. To be able to select this model, only water must be present in the calculator's list of compounds. This model is used in the cooling water process feed, V104 three-way valve and the M104 mixer.

[1] *CAS Registry Numbers® are the intellectual property of the American Chemical Society and are used by Fives ProSim SAS with the express permission of ACS. CAS Registry Numbers® have not been verified by ACS and may be inaccurate.*

1.5. Chemical reactions

NO oxidation, NO_2 dimerization and nitric acid oxido-absorption reactions are pre-coded. Thus, they don't have to be described by the user for modules specific to ProSimPlus HNO3. The only reactions to be described are following ones. These reactions have to be described for the calculator using "HNO3 specific" thermodynamic model.

- ✓ Ammonia combustion

$$4\,NH_3 + 5\,O_2 \rightarrow 4\,NO + 6\,H_2O$$

$$4\,NH_3 + 3\,O_2 \rightarrow 2\,N_2 + 6\,H_2O$$

$$2\,NH_3 + 2\,O_2 \rightarrow N_2O + 3\,H_2O$$

- ✓ NOx reduction

$$4\,NH_3 + 6\,NO \rightarrow 5\,N_2 + 6\,H_2O$$

$$8\,NH_3 + 6\,NO_2 \rightarrow 7\,N_2 + 12\,H_2O$$

These different reactions are defined as:

- ✓ Reaction type: Controlled
- ✓ Kinetic model: Instantaneous
- ✓ Heat of reaction: Computed from the standard enthalpies of formation at 25°C.

The instantaneous kinetic model is chosen because conversion ratios are specified for each reaction in the reactors R101 and R102 (§ 1.6.2).

Two reaction sets must be created:

- ✓ One with the ammonia combustion reactions only,
- ✓ One with the NOx reduction reactions only.

The NO_2 dimerization equilibrium in the gas phase is taken into account in the bleaching column. Indeed, this column is modelled by a non-specific module of ProSimPlus HNO3 (§ 1.6.8). This reaction must be described for the calculator using the "Engels (strong acids)" thermodynamic model.

$$2\,NO_2 \leftrightarrow N_2O_4$$

The equilibrium constant used is the one proposed by [KOU68]:

$$Ln(K_3) = -21.24366 + \frac{6891.64}{T}$$

	The partial orders are 2 for the NO_2 and 1 for the N_2O_4.

The heat of reaction is computed from the standard enthalpies of formation at 25°C.

1.6. Operating conditions

1.6.1. Process feeds

	Ammonia	Process water	Condensates return	Cooling water
Partial mass flow rate (kg/h)				
Ammonia	11 874	0	0	0
Water	24	3 555	12 520	2 000 000
Temperature (°C)	10	25	25	22
Pressure (bar)	14	6.5	6.6	4.2

	Air
Mole fraction (-)	
Oxygen	0.29
Nitrogen	0.71
Total flow rate (Nm^3/h)	165 178
Relative humidity (%)	46
Temperature (°C)	25
Pressure (bar)	1

1.6.2. Reactors

✓ R101 ammonia burner

Operating parameters	Value
Reactor type	Simple
Reaction set	Ammonia combustion
Ammonia conversion ratio (%)	
$4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$	96.2 of NH_3
$4\ NH_3 + 3\ O_2 \rightarrow 2\ N_2 + 6\ H_2O$	3.7 of NH_3
$2\ NH_3 + 2\ O_2 \rightarrow N_2O + 3\ H_2O$	0.1 of NH_3
Thermal behavior	Adiabatic
Pressure drop (bar)	0.05

✓ R102 NOx reduction catalytic reactor

Operating parameters	Value
Reactor type	Simple
Reaction set	NOx reduction
Conversion ratio	
$4\ NH_3 + 6\ NO \rightarrow 5\ N_2 + 6\ H_2O$	90.0% of NO
$8\ NH_3 + 6\ NO_2 \rightarrow 7\ N_2 + 12\ H_2O$	28.5% of NO_2
Thermal behavior	Adiabatic
Pressure drop (bar)	0.1

✓ Oxidation reactors

These modules model the oxidation of the NO and the dimerization of the NO_2 in the gas volumes of pipes.

	O101	O102	O103	O104
Operating parameters	**Value**			
Reactor type	Simplified plug flow			
Oxidation volume (m^3)	9	28	6	2
Calculation of the exchanged heat duty	Adiabatic			
Oxidation efficiency	1			
Reactions				
Oxidation reaction rate constant	Koukolik			
Dimerization equilibrium constant	Koukolik			
Pressure drop (bar)	0.01			

1.6.3. Heat exchangers

✓ Generalized heat exchangers.

	E101	E105	E108	E110
Operating parameters	**Value**			
Hot stream				
Outlet temperature (°C)	-	250	100	102
Pressure drop (bar)	0.05			
Cold stream				
Outlet temperature (°C)	34	-		
Pressure drop (bar)	4.80	0.05	0.02	0.05

✓ Generalized heat exchanger HNO3

	E106
Operating parameter	**Value**
Hot stream	
Outlet temperature (°C)	175
Pressure drop (bar)	0.05
Oxidation volume (m^3)	7.4873
Cold stream	
Outlet temperature (°C)	-
Pressure drop (bar)	0.05
Oxidation volume (m^3)	0

The following parameters are used for the heat exchanger for accounting of the chemical reactions:

- Hydrodynamic model: Plug flow
- Oxidation efficiency: 1
- Calculation of the oxidation rate constant: Koukolik
- Calculation of the dimerization equilibrium constant: Koukolik
- Take into account of a maximum temperature for the oxidation: Yes

✓ Cooler/Heater

	E102	E103	E104	E109	E111	E112
Operating parameters	**Value**					
Outlet temperature (°C)	120	450	350	100	45	180
Pressure drop (bar)	1.50	0.05		0.01	0.05	1.15
Oxidation volume (m^3)	0		1.9514	0		

The following parameters are used for the heat exchanger in which the chemical reactions are taken into account (E104, oxidation, volume different from 0):

- Hydrodynamic model: Plug flow
- Oxidation efficiency: 1
- Calculation of the oxidation rate constant: Koukolik
- Calculation of the dimerization equilibrium constant: Koukolik
- Taking into account a maximum temperature for the oxidation: Yes

✓ E107 nitrous vapors condenser

Operating parameters	Value
Tubes length (m)	9
Number of tubes	2 100
Circulation of the vapors	Inside the tubes
Inner diameter of the tubes (mm)	25.40
Equivalent diameter (mm)	25.47
Cooling water	
Flow direction	Counter-current
Heat transfer coefficients (kcal/h/m^2/K)	
Oxido-absorption	290
Oxidation	215
Pressure drop (bar)	0.07
Reactions	
Calculation of the oxidation rate constant	Koukolik
Calculation of the dimerization equilibrium constant	Koukolik
Calculation of the absorption constant of N_2O_4 in water	Miller (bubble caps)
Number of intermediate points for print	21

1.6.4. Three-way valves

	Operating parameters	Value
V101	Mass flow rate of the stream “NH3 S05”	87.4 kg/h
V102	Mass flow rate of the stream “Air S03”	1 006.8 kg/h
V103	Splitting ratio of the stream “Air S06”	79.93111%
V104	Splitting ratio of the stream “CW S03”	80%

1.6.5. Mixers

	M101	M102	M103	M104
Operating parameters	**Value**			
Type	Static mixer		Other mixer	Mixer
Outlet pressure (bar)	7.60	6.35	Equal to the lowest of the feeds	

1.6.6. Compressor, turbine and pump

✓ K101 air compressor

Operating parameters	Value
Type	Compressor
Discharge pressure (bar)	7.8
Isentropic efficiency (-)	0.845
Mechanical efficiency (-)	1
Chemical reactions	Not taken into account

✓ T101 tail gas expander

Operating parameters	Value
Type	Turbine
Discharge pressure (bar)	1.03
Isentropic efficiency (-)	0.83
Mechanical efficiency (-)	1
Electrical efficiency (-)	1

It’s possible to model a turbo-expander by sending the power available at the turbine to the compressor using an information stream. This is detailed in the example “PSPH_EX_EN – dual-pressure process”.

✓ P101 centrifugal pump

Operating parameters	Value
Type	Centrifugal pump
Discharge pressure (bar)	7.5
Volumetric efficiency (-)	0.65
Mechanical efficiency (-)	1
Electrical efficiency (-)	1

1.6.7. Oxido-absorption column

✓ C101 oxido-absorption column

Operating parameters	Value
Type	Plate oxido-absorption column
Number of plates	35
Column diameter (m)	6.1
Holes diameter (mm)	2
Fraction free area (%)	2.60
Column temperature profile	Calculated from the temperatures
Intermediate feeds	
Return condensates	Plate 2
Weak acid from the nitrous vapors condenser	Plate 32
NOx in the liquid phase	
NO oxidized (%)	0
NOx solubility in the liquid phase	Taken into account
Henry constant	Calculated from the internal model
Total pressure drop (bar)	0.77
Correlations	
Calculation of the oxidation rate constant	Koukolik
Calculation of the dimerization equilibrium constant	Koukolik
Equilibrium of the NOx – water – nitric acid system	Zhidkov
Print profiles	Complete

The column stages are numbered from top to bottom (plate 1: top plate; plate 35: bottom plate).

The following table presents the parameters of the plates.

Plate	Oxidation efficiency	Oxidation volume (m^3)	Hydrodynamic model	Absorption efficiency	Tray spacing (m)	Temperature (°C)
1	1	65.8	Plug flow reactor	Atroschenko 2	2.25	29.4
2	1	65.8	Plug flow reactor	Atroschenko 2	2.25	29.6
3	1	65.8	Plug flow reactor	Atroschenko 2	2.25	30.0
4	1	58.4	Plug flow reactor	Atroschenko 2	2.25	30.6
5	1	58.4	Plug flow reactor	Atroschenko 2	2.00	31.4
6	1	58.4	Plug flow reactor	Atroschenko 2	2.00	-
7	1	58.4	Plug flow reactor	Atroschenko 2	2.00	-
8	1	58.4	Plug flow reactor	Atroschenko 2	2.00	-
9	1	51.1	Plug flow reactor	Atroschenko 2	2.00	-
10	1	51.1	Plug flow reactor	Atroschenko 2	1.75	-
11	1	51.1	Plug flow reactor	Atroschenko 2	1.75	-
12	1	51.1	Plug flow reactor	Atroschenko 2	1.75	-
13	1	51.1	Plug flow reactor	Atroschenko 2	1.75	-
14	1	35.4	Plug flow reactor	Atroschenko 2	1.75	-
15	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
16	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
17	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
18	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
19	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
20	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
21	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
22	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
23	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
24	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
25	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
26	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
27	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
28	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
29	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
30	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
31	1	35.4	Plug flow reactor	Atroschenko 2	1.21	-
32	1	78.9	Plug flow reactor	Atroschenko 2	1.21	52.0
33	1	58.4	Plug flow reactor	Atroschenko 2	2.70	52.9
34	1	58.4	Plug flow reactor	Atroschenko 2	2.00	54.5
35	1	58.4	Plug flow reactor	Atroschenko 2	2.00	57.0

1.6.8. Bleaching column

✓ Calculator switch

These modules are used to change the thermodynamic model between the section of the process which uses the “HNO3 specific” model and the section which uses the “Engels (strong acids)” model. The calculation of the liquid enthalpies being not rigorously the same between these two models, the use of a “Calculator switch” unit is necessary in order not to distort the enthalpy balance. The “Engels (strong acids)” model is used in the C102 bleaching column and the E111 product acid cooler. The “HNO3 specific” model is used in the rest of the process.

Unit operation	Thermodynamic model	Outlet physical stage
Calculator Switch	Engels (strong acids)	Calculated
Calculator Switch 1		
Calculator Switch 2	HNO3 specific	

✓ C102 Bleaching column

Operating parameters	Value
Column type	Absorber
Thermodynamic model	Engels
Number of theoretical stages	8
Pressure drop (bar)	0.41
Stage efficiency	1 for each stage
Reactive column	NO_2/N_2O_4 equilibrium in gas phase
Print profiles	Complete

1.7. Initializations

The calculation sequence is automatically determined by ProSimPlus HNO3. Two tear streams are identified: “Air S09” (outlet gas stream of the bleaching column) and “PG S07” (stream between the modules “O102” and “E106”). The following initializations of these streams are used in the simulation.

Stream	Air S09	PG S07
Mass fraction (-)		
Oxygen	0.22	0.03
Nitrogen	0.74	0.71
Nitric oxide	0	0.04
Nitrogen dioxide	0	0.10
Nitric acid	0.03	0
Water	0.01	0.12
Mass flow rate (kg/h)	44 000	180 000
Temperature (°C)	Dew point	300
Pressure (bar)	7.24	7.38

2. RESULTS

2.1. Mass and Energy Balance

This document presents only the most relevant stream results. In ProSimPlus HNO3, mass and energy balances are provided for all streams. Results are also available at the unit operation level (“Report” tab in the configuration window).

Streams		Acid produc...	Acid S01	Acid S03	Air LP	Air S04	Air S06	Air S08
From		E111	E107	C101	Air feed	V102	V103	E108
Total flow (mass)	t/d	1725.6	792.28	1731.5	5074.8	5050.6	4037	1013.6
Total flow (molar)	Nm3/h	52321	27132	52212	1.6518E005	1.6439E005	1.314E005	32992
Mass fractions								
AMMONIA		0	0	0	0	0	0	0
OXYGEN		0.00019363	0	0	0.23078	0.23078	0.23078	0.23078
NITROGEN		0.00010932	0	0	0.76006	0.76006	0.76006	0.76006
NITRIC OXIDE		0	0	0	0	0	0	0
NITROGEN DIOXIDE		3.2354E-010	0	0.00010018	0	0	0	0
NITROGEN TETROXIDE		0	0	0.0041807	0	0	0	0
NITROUS OXIDE		0	0	0	0	0	0	0
NITRIC ACID		0.58112	0.47529	0.58102	0	0	0	0
WATER		0.41857	0.52471	0.4147	0.0091548	0.0091548	0.0091548	0.0091548
Mole fractions								
AMMONIA		0	0	0	0	0	0	0
OXYGEN		0.00018638	0	0	0.20694	0.20694	0.20694	0.20694
NITROGEN		0.0001202	0	0	0.77848	0.77848	0.77848	0.77848
NITRIC OXIDE		0	0	0	0	0	0	0
NITROGEN DIOXIDE		2.1661E-010	0	6.7444E-005	0	0	0	0
NITROGEN TETROXIDE		0	0	0.0014073	0	0	0	0
NITROUS OXIDE		0	0	0	0	0	0	0
NITRIC ACID		0.28406	0.2057	0.28558	0	0	0	0
WATER		0.71564	0.7943	0.71295	0.014581	0.014581	0.014581	0.014581
Physical state		Liquid	Liquid	Liquid	Vapor	Vapor	Vapor	Vapor
Temperature	°C	45	49.426	57	25	102	236.18	100
Pressure	bar	7.6	7.25	7.24	1	7.75	7.7	7.65
Enthalpic flow	kW	-1.6669E005	-89450	-1.6632E005	-7217.6	-2584.8	4421	-542.8
Molar vapor fraction		0	0	0	1	1	1	1

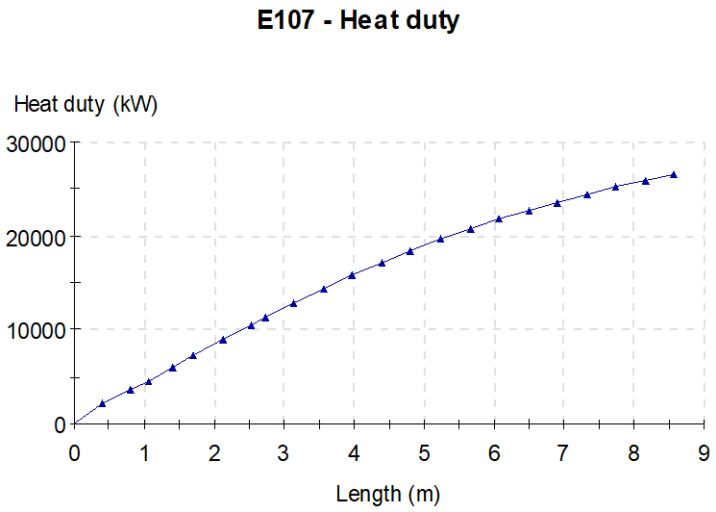
Streams		CW S01	CW S02	CW S06	NH3 S01	NH3 S04	PG S02	PG S09
From		Cooling w ater	E107	M104	NH3 feed	V101	R101	O103
Total flow (mass)	t/d	48000	48000	48000	285.55	283.45	4320.4	4320.4
Total flow (molar)	Nm3/h	2.4883E006	2.4883E006	2.4883E006	15657	15542	1.5082E005	1.4557E005
Mass fractions								
AMMONIA		0	0	0	0.99798	0.99798	0	0
OXYGEN		0	0	0	0	0	0.064173	0.02267
NITROGEN		0	0	0	0	0	0.71219	0.71219
NITRIC OXIDE		0	0	0	0	0	0.11098	0.03314
NITROGEN DIOXIDE		0	0	0	0	0	0	0.11907
NITROGEN TETROXIDE		0	0	0	0	0	0	0.00027466
NITROUS OXIDE		0	0	0	0	0	8.4605E-005	8.4605E-005
NITRIC ACID		0	0	0	0	0	0	0
WATER		1	1	1	0.0020171	0.0020171	0.11258	0.11258
Mole fractions								
AMMONIA		0	0	0	0.99809	0.99809	0	0
OXYGEN		0	0	0	0	0	0.053654	0.019637
NITROGEN		0	0	0	0	0	0.68016	0.70467
NITRIC OXIDE		0	0	0	0	0	0.098948	0.030613
NITROGEN DIOXIDE		0	0	0	0	0	0	0.071735
NITROGEN TETROXIDE		0	0	0	0	0	0	8.274E-005
NITROUS OXIDE		0	0	0	0	0	5.1428E-005	5.3282E-005
NITRIC ACID		0	0	0	0	0	0	0
WATER		1	1	1	0.0019071	0.0019071	0.16719	0.17321
Physical state		Liquid	Liquid	Liquid	Liquid	Vapor	Vapor	Vapor
Temperature	°C	22	38.857	37.071	10	120	929.25	182.21
Pressure	bar	4.2	4.15	4.1	14	7.7	7.55	7.32
Enthalpic flow	kW	-1.3638E006	-1.3246E006	-1.3288E006	-13071	-8235.2	-3814.2	-57528
Molar vapor fraction		0	0	0	0	1	1	1

Streams		PG S12	TG S05	TG S07	Water S01	Water S02
From		M103	M102	T101	Process w a...	Condensate...
Total flow (mass)	t/d	4547.7	3996.4	3996.4	85.32	300.48
Total flow (molar)	Nm3/h	1.463E005	1.3302E005	1.3303E005	4423	15577
Mass fractions						
AMMONIA		0	0.00052382	0.0003661	0	0
OXYGEN		0.060346	0.032221	0.032221	0	0
NITROGEN		0.84595	0.96267	0.96298	0	0
NITRIC OXIDE		0.027653	0.00041465	4.1465E-005	0	0
NITROGEN DIOXIDE		0.046412	0.00011735	8.3908E-005	0	0
NITROGEN TETROXIDE		0.014013	1.9983E-011	7.5964E-010	0	0
NITROUS OXIDE		8.0377E-005	9.1466E-005	9.1466E-005	0	0
NITRIC ACID		0.00072183	3.8672E-007	3.8672E-007	0	0
WATER		0.0048189	0.0039655	0.0042158	1	1
Mole fractions						
AMMONIA		0	0.00086299	0.00060311	0	0
OXYGEN		0.054747	0.028253	0.028251	0	0
NITROGEN		0.87664	0.96419	0.96443	0	0
NITRIC OXIDE		0.026753	0.00038773	3.877E-005	0	0
NITROGEN DIOXIDE		0.029286	7.1572E-005	5.117E-005	0	0
NITROGEN TETROXIDE		0.0044212	6.0937E-012	2.3163E-010	0	0
NITROUS OXIDE		5.3014E-005	5.8309E-005	5.8305E-005	0	0
NITRIC ACID		0.00033254	1.7219E-007	1.7218E-007	0	0
WATER		0.0077652	0.0061761	0.0065653	1	1
Physical state		Vapor	Vapor	Vapor	Liquid	Liquid
Temperature	°C	56.324	270.6	93.386	25	25
Pressure	bar	7.24	6.35	1.03	6.5	6.6
Enthalpic flow	kW	4421.4	9456.6	645.53	-15660	-55150
Molar vapor fraction		1	1	1	0	0

2.2. Process Performance

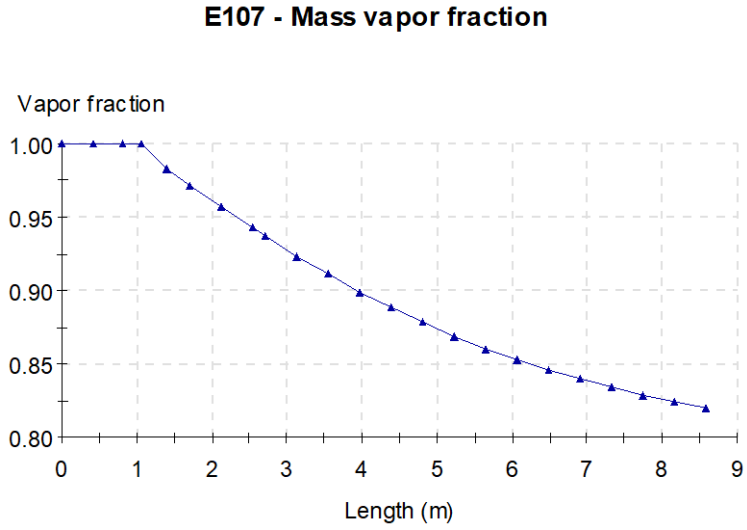
This process produces 1 003 t/d of nitric acid (eq. 100%) at a purity of 58.1% wt. The NOx content at the outlet of the oxido-absorption column is 460 ppmv eq. NO. After the NOx abbatment reactor, the NOx content is 90 ppmv eq. NO.

2.3. Nitrous vapors condenser profiles



Heat duty

The following curve shows that 8% of the length of the heat exchanger is used to cool the inlet process gas down to its dew point, only gas phase reactions are occuring in this section while the oxido-absorption phenomena is occuring in the remaing part of the condenser.

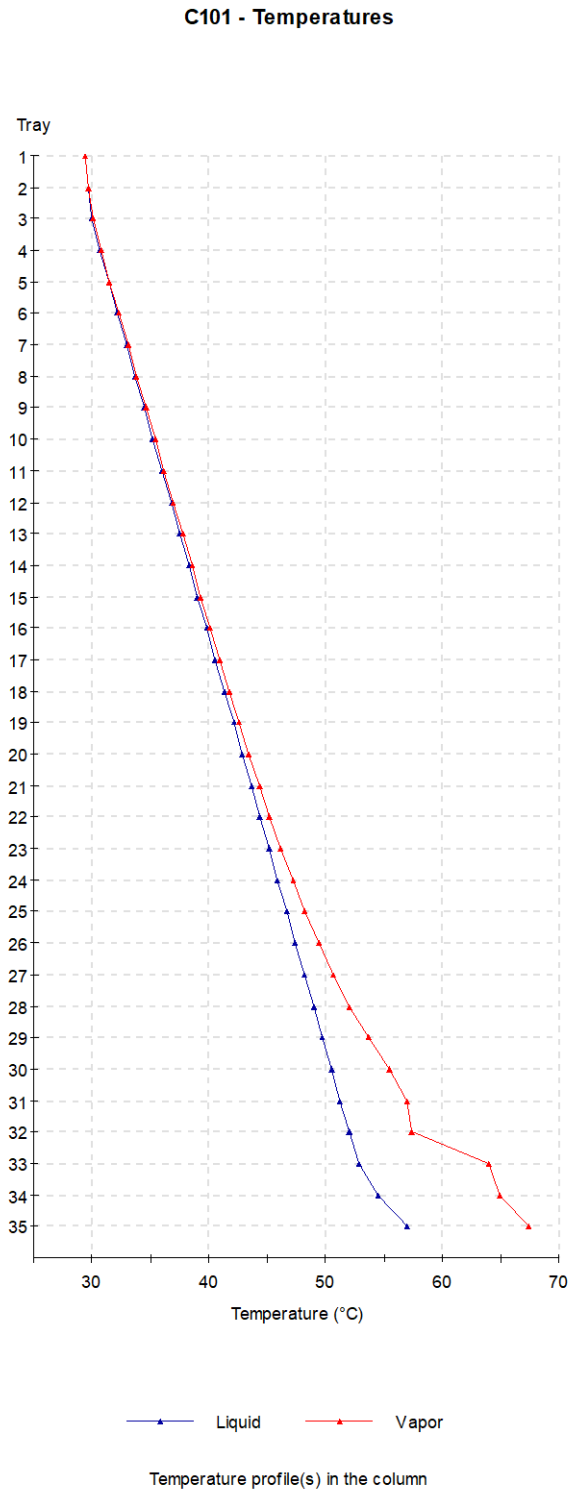


Mass vapor fraction profiles along the condenser

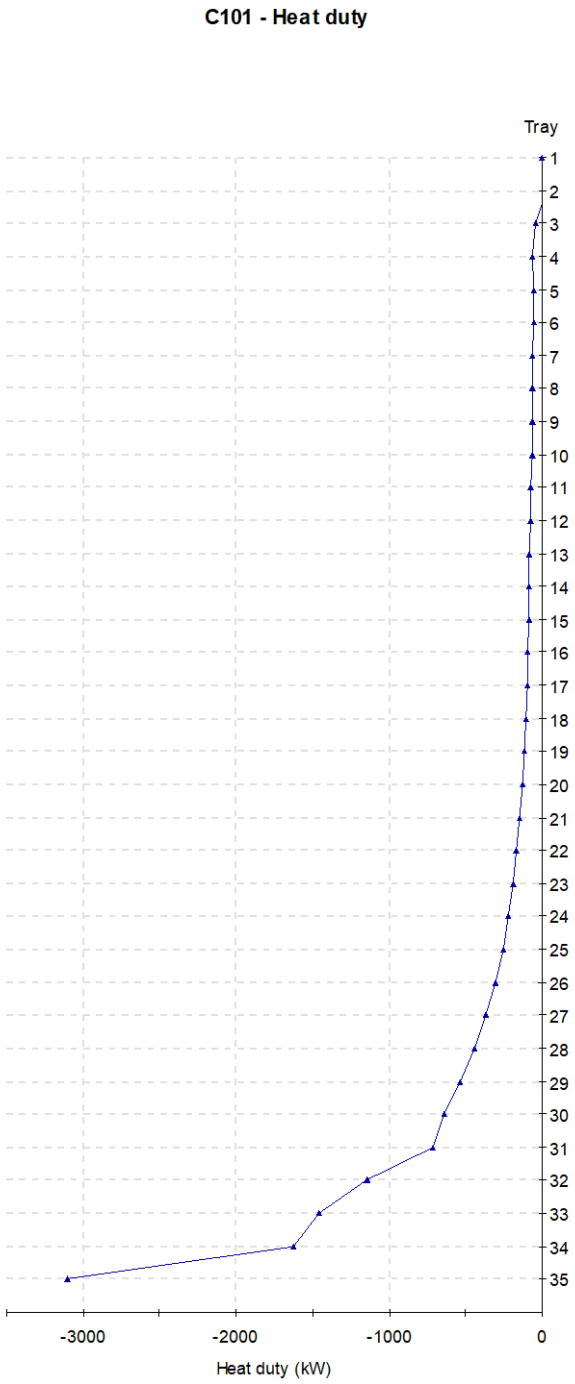
2.4. Columns profiles

2.4.1. C101 oxido-absorption column

The column stages are numbered from top to bottom (plate 1: top plate; plate 35: bottom plate).

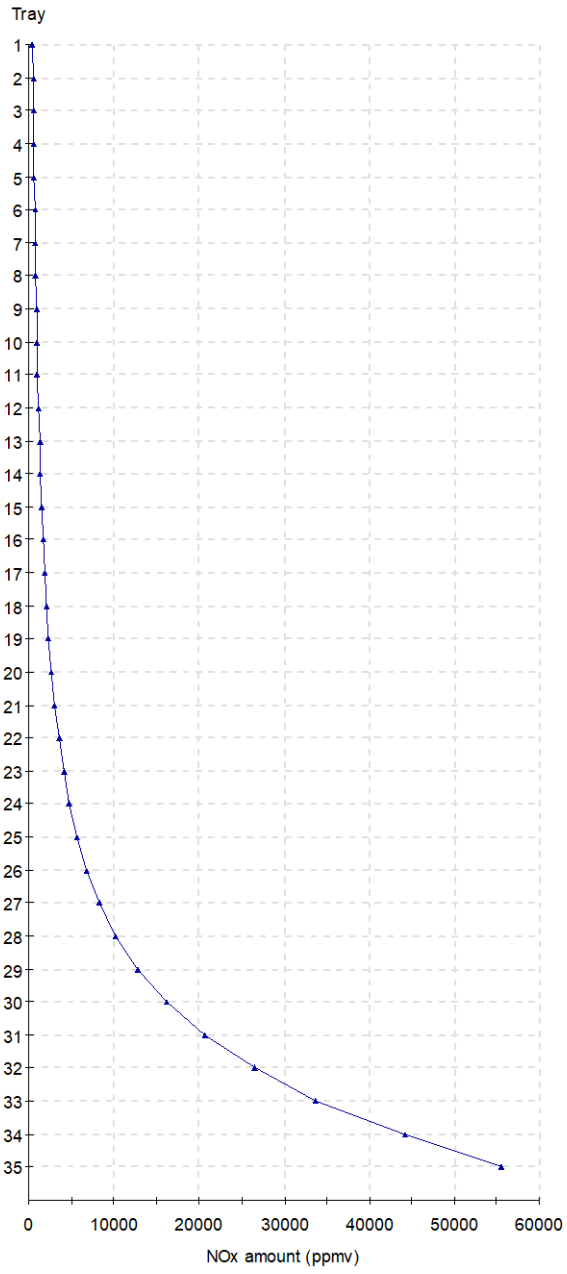


Temperature profile(s) in the column



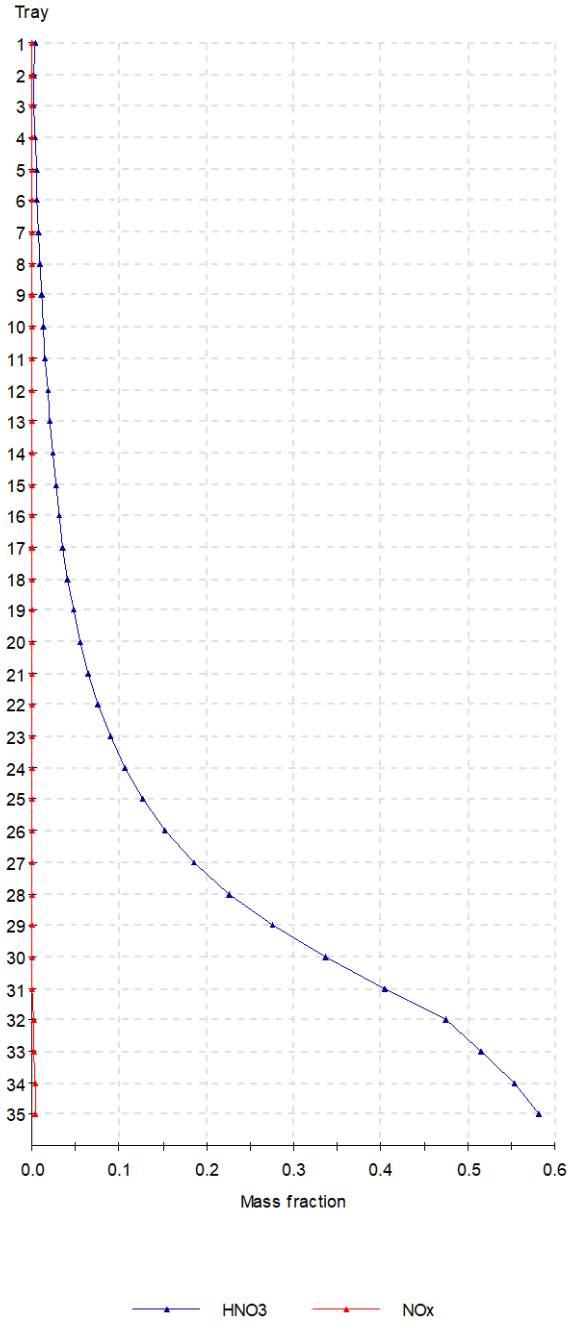
Heat duty profile in the column

C101 - Amount of NOx (ppmv)



Amount of NOx profile in the column

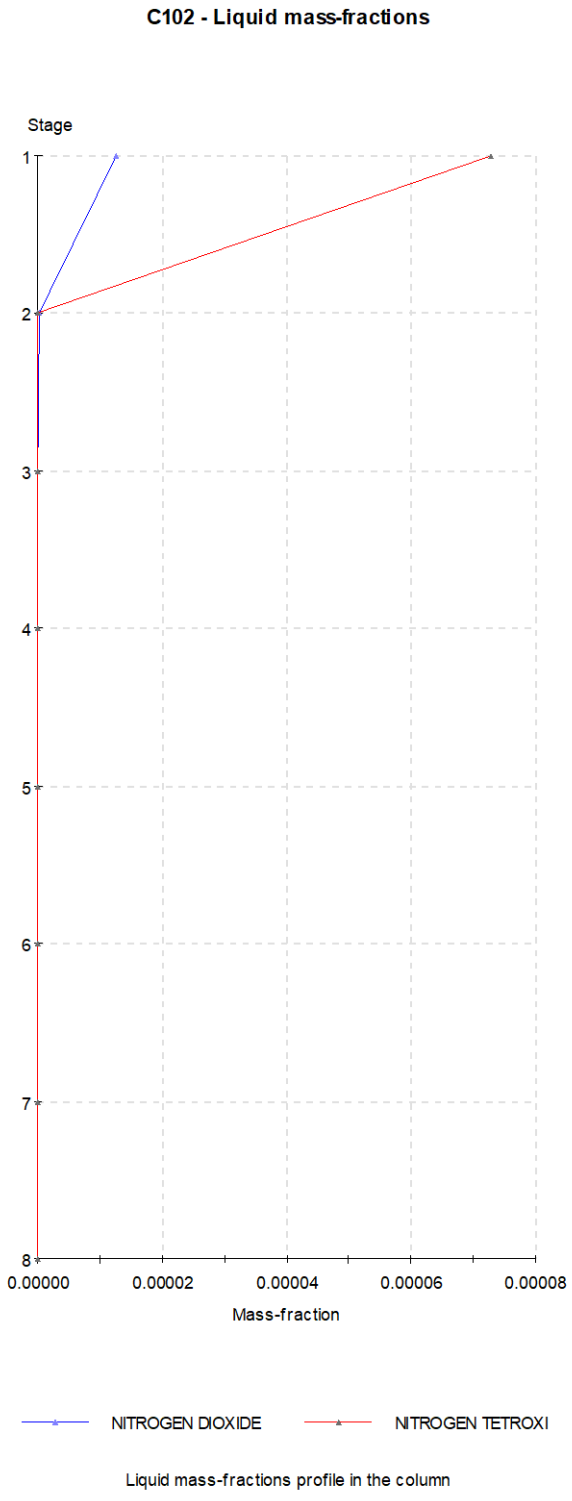
C101 - Liquid mass fractions



Liquid mass fractions profiles in the column

2.4.2. C102 bleaching column

The column stages are numbered from top to bottom (plate 1: top plate; plate 8: bottom plate).



Liquid mass-fractions profile in the column

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