PROSIMPLUS APPLICATION EXAMPLE

NATURAL GAS DEHYDRATION UNIT

WITH TRIETHYLENE GLYCOL

EXAMPLE PURPOSE
This example illustrates a process to remove water from natural gas using Triethylene Glycol (TEG) as dehydration solvent. The interesting points of this example lie in the use of the "absorption" module for the contactor model and in the representation of two columns connected in series (the TEG regenerator and the TEG stripper) by a single ProSimPlus "stripper" module. Additionally, the Windows Script module is used in different parts of the flowsheet to perform specific calculations (gas water dew point, TEG losses for make-up calculation).

ACCESS	☑ **Free Internet**	☐ **Restricted to ProSim clients**	☐ **Restricted**	☐ **Confidential**

CORRESPONDING PROSIMPLUS FILES	*E12_TEG_Dehydration.pmp3*

TABLE OF CONTENTS

1. PROCESS MODELING

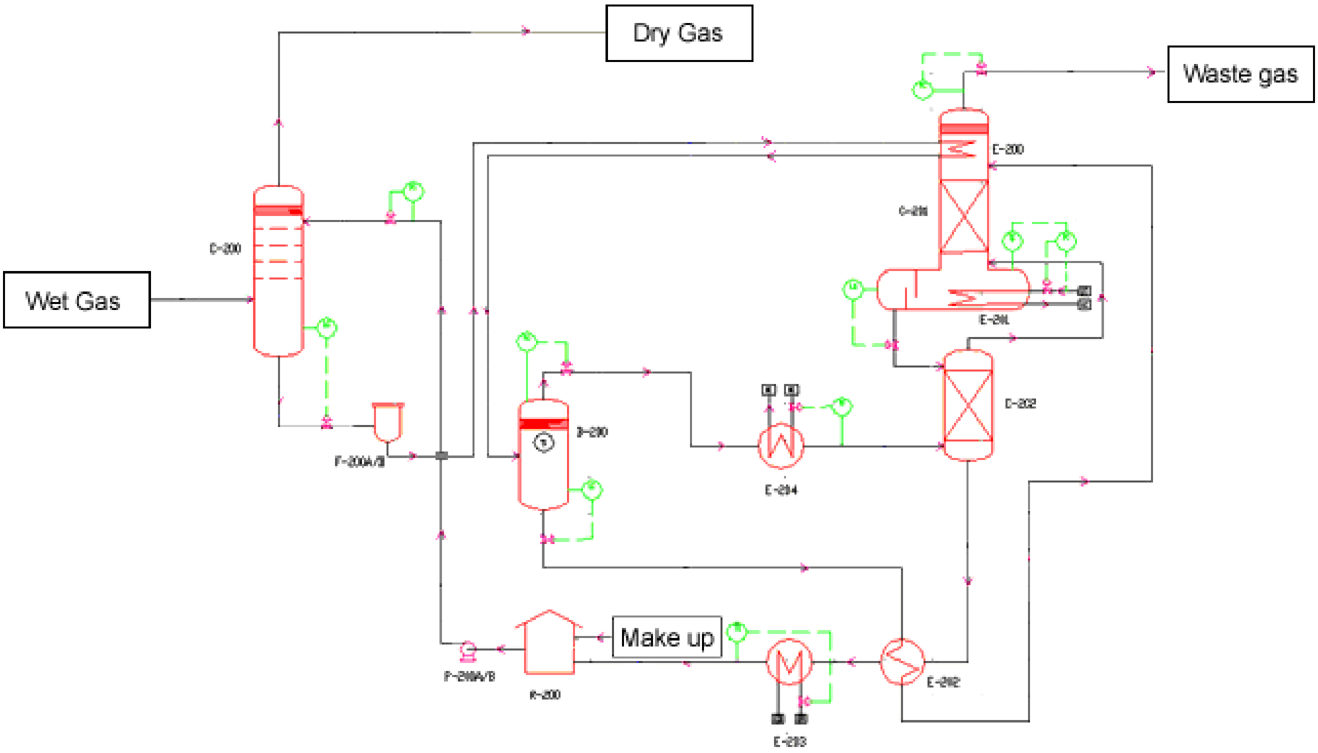
1.1. Process description

This process is the “traditional” Triethylene Glycol (TEG) based dehydration process and represent a unit with gas absorption and extraction solvent regeneration. The objective is to reduce the amount of water in the natural gas with TEG, used as the extraction solvent. This process is required to prevent hydrates formation at low temperatures or corrosion problems due to the presence of carbon dioxide or hydrogen sulfide (regularly found in natural gas).

The wet gas feeds the contactor D200 (stream 1) at 71 bar gage. This column absorbs a part of the water in the gas in the Triethylene Glycol (TEG) mixture. At the end of the regeneration loop, the lean TEG feeds the top part of the contactor (stream 16) and absorbs water. Rich TEG leaves the bottom (stream 3) by level control and is depressurized to 5 bar gage (valve V200). The rich stream flows through a cartridge filter (F200 A/B) to remove solid particles coming from corrosion or TEG degradation. These solid particles and degradation are not taken into account in this model and consequently, the filtration does not have any impact in terms of simulation and is not represented. Once filtered, this flow is used as cold fluid of the condenser (E200) of the TEG regeneration column (C201). It is to be noted that in the simulation this condenser is represented separately from the column. The amount of heat to be removed in the C201 column condenser is transferred through an information stream in the heat exchanger module E200.

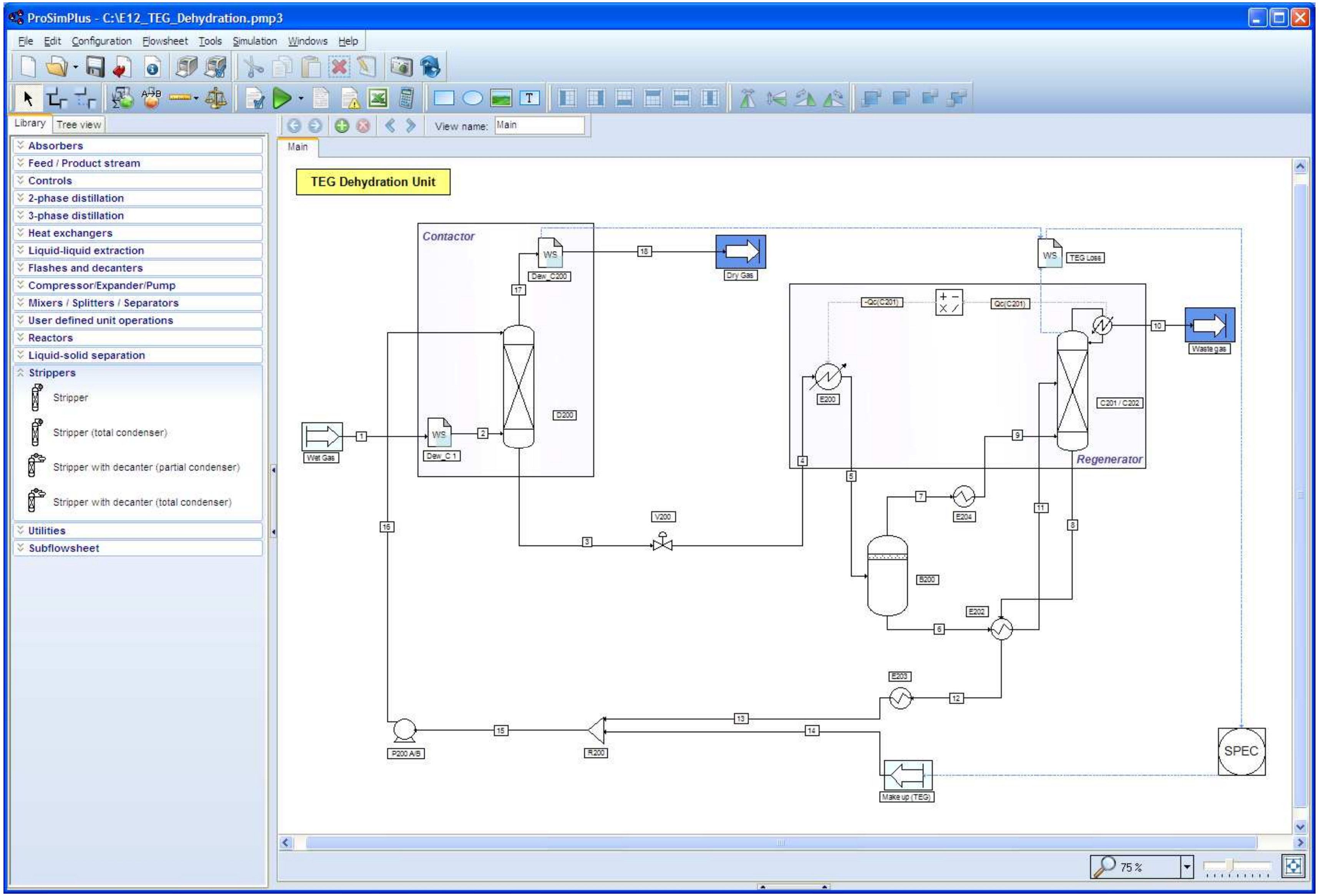
The wet TEG then enters a flash tank B200 (stream 5) in which gaseous hydrocarbons that were absorbed along with the water in the contactor are vaporized. These hydrocarbons are heated in heat exchanger E204 (stream 7) and used as stripping fluid in the stripper C202 (stream 9). The liquid phase heated in the heat exchanger E202 (stream 6) then feeds the regenerator C201 head (stream 11). This column is used to strip water from the TEG and operates at atmospheric pressure. Waste gases consisting of water and the hydrocarbons dissolved in the TEG, leave the regenerator at the top. The liquid bottom stream feeds the stripping column C202. This column decreases of the TEG water concentration by stripping using hydrocarbons vapors from B200. Lean TEG (stream 8) is then sent from the bottom of the column to storage tank R200. This storage tank has no meaning in terms of steady-state simulation but allows the regulation of the TEG flow. Consequently, it is represented by a mixer module. The TEG make-up (stream 14) is required to compensate the losses due to gas entrainment or degradation. Lean TEG is then pumped in P200 A/B and feed the contactor D200 head (stream 16).

1.2. Process flowsheet



Process flowsheet of a TEG natural gas dehydration unit

1.3. Simulation flowsheet



1.4. Components

Components taken into account in the simulation, chemical formula and CAS number are presented in the following table. Pure components physical properties are extracted from the ProSimPlus standard database.

Component name	**Chemical formula**	**CAS number**
Methane	CH_4	74-82-8
Ethane	C_2H_6	74-84-0
Propane	C_3H_8	74-98-6
n-butane	C_4H_{10}	106-97-8
Isobutane	C_4H_{10}	75-28-5
n-pentane	C_5H_{12}	109-66-0
Isopentane	C_5H_{12}	78-78-4
n-hexane	C_6H_{14}	110-54-3
n-heptane	C_7H_{16}	142-82-5
n-octane	C_8H_{18}	111-65-9
n-nonane	C_9H_{20}	111-84-2
n-decane	$C_{10}H_{22}$	124-18-5
n-undecane	$C_{11}H_{24}$	1120-21-4
n-dodecane	$C_{12}H_{26}$	112-40-3
Nitrogen	N_2	7727-37-9
Carbon dioxide	CO_2	124-38-9
Water	H_2O	7732-18-5
Triethylene glycol	$C_6H_{14}O_4$	112-27-6

1.5. Thermodynamic model

Considering the temperatures and pressures of the contactor, an equation of state approach has been chosen, allowing the accurate calculation of the thermodynamics functions (fugacities, enthalpies, entropies….) at conditions close to critical conditions. As polar components are also present (water and TEG in particular), a complex mixing rule has been used in order to use an equation of state approach with this type of components. The equation of state selected is the **Peng-Robinson** equation of state [PEN76] with the mixing rule **MHV2** proposed by Michelsen *and al.* [MIC90b], [DAH90]. The model for the excess enthalpy calculation is **UNIQUAC** [ABR75], [AND78].

The binaries interaction parameters have been regressed in MS-Excel using Simulis Thermodynamics.

1.6. Operating conditions

✓ Process feed (Wet gas)

Temperature (℃)	25
Pressure (barg)	71
Total mass flowrate (t/h)	37.2080
Mass fraction	
Methane	0.8227
Ethane	0.0592
Propane	0.0476
n-butane	0.0188
Isobutane	0.0109
n-pentane	0.0063
Isopentane	0.0074
n-hexane	0.0065
n-heptane	0.0042
n-octane	0.0014
n-nonane	0.000217
n-decane	4.27E-005
n-undecane	3.8E-006
n-dodecane	1.01E-006
Nitrogen	0.0045
Carbon dioxide	0.0095
Water	0.000622
Triethylene glycol	0

✓ Absorber - Contactor D200

Operating parameters	*Value*
Type of column	Absorber
Number of theoretical tray	4
Feed tray	1
Outlet pressure (barg)	70.75

- ✓ Valve V200

Operating parameters	*Value*
Type of valve	Expansion valve
Pressure (barg)	5

- ✓ Heat exchanger E200

Operating parameters	*Value*
Type of exchanger	Simple heat exchanger
Information stream specification	-

- ✓ Liquid-vapor separator B200

Operating parameters	*Value*
Type of separator	Diphasic L-V separator
Type of flash	Pressure and heat duty fixed
Heat duty exchanged	Adiabatic
Pressure	The lowest of the feed streams

- ✓ Heat exchanger E204

Operating parameters	*Value*
Type of exchanger	Cooler / heater
Outlet temperature (℃)	175

- ✓ Columns C201/ C202

Operating parameters	*Value*
Type of column	Stripper
Number of theoretical trays	7
Feed tray	2
Heat duty to be removed from the condenser (kW)	3
Outlet pressure (bar)	1.05

Additional specifications

Tray N°1 temperature (°C)	100
Tray N°4 temperature (°C)	204
Intermediate boiler	At tray 4, with 10 kW heat input
Initialization : top temperature (°C)	100
Initialization : bottom temperature (°C)	194

- ✓ Heat exchanger E202

Operating parameters	*Value*
Type of exchanger	Counter current or multipasses
Specification	Cold stream
Outlet temperature (°C)	150

- ✓ Heat exchanger E203

Operating parameters	*Value*
Type of exchanger	Cooler / heater
Outlet temperature (°C)	28.7

- ✓ Mixer R200

Operating parameters	*Value*
Type of mixer	Other mixer
Pressure	The lowest of the feed streams

- ✓ Pump P200 A/B

Operating parameters	*Value*
Type of mixer	Centrifugal pump
Outlet pressure (barg)	70.75
Volumetric efficiency	0.65

1.7. Initialization

The TEG flowrate in the loop is fixed by initializing the flash drum B200 inlet stream (stream 5). From the knowledge of this flowrate, it is possible to calculate B200, C201 / C202 and the TEG feed to contactor D200. Initialization is set in order to obtain a dry gas dew point at -40°C .

1.8. "Tips and tricks"

Windows Script modules (Dew C_1 and Dew C_17) located on the wet gas stream and on the dry gas stream calculate the water dew point of their respective streams. The calculation is performed using data from McKetta and Wehe [MKW58].

Another Windows Script module ("TEG loss") is used to calculate the required TEG make-up from the TEG losses in the dry gas and the waste gas.

Additionally, the top column C201 condenser has been separated in the simulation flowsheet: the heat duty removed from the condenser is transferred through an information stream to the heat exchanger module E200. The required conversion is made by information stream handler.

C201 and C202 columns are represented with a unique column module as they are installed in series. C201 reboiler is set in this module as an intermediate tray boiler. This simplifies the simulation flow scheme but it's not mandatory. Using s distillation column module for C201 and a stripper module for C202 connected in series would have provided the same results.

2. RESULTS

2.1. Mass and energy balance

This table presents only the most relevant stream results. In ProSimPlus, mass and energy balances are provided for every stream. Results are also available at the unit operation level (result tab in the configuration window).

Streams		**1**	**3**	**5**	**8**	**9**
From		Wet Gas	D200	E200	C201 / C202	E204
To		Dew_C 1	V200	B200	E202	C201 / C202
Partial flows		t/h	t/h	t/h	t/h	t/h
METHANE		30.614496	0.00892193	0.008922	0.00019248	0.00785102
ETHANE		2.20296361	0.00031979	0.00031979	7.04E-06	0.00029981
PROPANE		1.77130183	0.00039308	0.00039308	9.61E-06	0.00034463
n-BUTANE		0.6995898	0.00047217	0.00047217	8.69E-06	0.00029736
ISOBUTANE		0.40561323	0.00021306	0.00021306	3.74E-06	0.00014873
n-PENTANE		0.23443701	0.00016836	0.00016836	3.61E-06	9.56E-05
ISOPENTANE		0.27537045	0.00016215	0.00016215	3.42E-06	0.00010174
n-HEXANE		0.24187945	0.00017607	0.00017607	4.40E-06	9.11E-05
n-HEPTANE		0.15629134	0.00011506	0.00011506	3.18E-06	5.36E-05
n-OCTANE		0.05209711	3.87E-05	3.87E-05	1.18E-06	1.61E-05
n-NONANE		0.00807505	6.14E-06	6.14E-06	2.00E-07	2.23E-06
n-DECANE		0.00158896	1.25E-06	1.25E-06	4.30E-08	3.88E-07
n-UNDECANE		0.00014141	1.21E-07	1.21E-07	4.07E-09	3.02E-08
n-DODECANE		3.76E-05	3.32E-08	3.32E-08	1.14E-09	6.91E-09
NITROGEN		0.167455	6.48E-05	6.48E-05	6.74E-07	5.62E-05
CARBON DIOXIDE		0.35351612	0.00020549	0.00020549	4.13E-06	0.00016576
WATER		0.023146	0.02315561	0.02315563	0.00027511	1.12E-05
TRIETHYLENE GLYCOL		0	0.56314148	0.56314742	0.56308308	1.48E-08
Total flow	t/h	37.208	0.59755524	0.59756128	0.5636006	0.00953553
Total flow	m3(n)/h	46352.7933	126.367223	126.368238	84.6751459	11.783692
Mass fractions						
METHANE		0.82279338	0.01493071	0.01493069	0.00034152	0.82334371
ETHANE		0.05920672	0.00053516	0.00053516	1.25E-05	0.03144177
PROPANE		0.0476054	0.00065782	0.00065781	1.71E-05	0.03614116
n-BUTANE		0.01880213	0.00079016	0.00079016	1.54E-05	0.03118463
ISOBUTANE		0.01090124	0.00035656	0.00035656	6.63E-06	0.01559709
n-PENTANE		0.00630072	0.00028175	0.00028175	6.41E-06	0.01002903
ISOPENTANE		0.00740084	0.00027136	0.00027136	6.07E-06	0.01066959
n-HEXANE		0.00650074	0.00029464	0.00029464	7.80E-06	0.0095507
n-HEPTANE		0.00420048	0.00019255	0.00019254	5.64E-06	0.00562361
n-OCTANE		0.00140016	6.47E-05	6.47E-05	2.10E-06	0.00168666
n-NONANE		0.00021702	1.03E-05	1.03E-05	3.55E-07	0.00023372
n-DECANE		4.27E-05	2.10E-06	2.10E-06	7.63E-08	4.07E-05
n-UNDECANE		3.80E-06	2.02E-07	2.02E-07	7.23E-09	3.17E-06
n-DODECANE		1.01E-06	5.56E-08	5.56E-08	2.01E-09	7.24E-07
NITROGEN		0.00450051	0.00010837	0.00010837	1.20E-06	0.00589571
CARBON DIOXIDE		0.00950108	0.00034388	0.00034388	7.33E-06	0.01738332
WATER		0.00062207	0.03875058	0.03875021	0.00048814	0.00117321
TRIETHYLENE GLYCOL		0	0.94240908	0.94240948	0.99908177	1.55E-06
Physical state		Vapor	Liquid	Liq./Vap.	Liquid	Vapor
Temperature	℃	25	25.2382295	25.8503908	195.744508	175
Pressure	barr	70.9999805	70.7499806	4.99999837	0.03674972	4.99999837
Enthalpy	kW	-933.947796	-105.15569	-103.83171	-26.6041535	0.92407112
Vapor fraction		1		0.09324884		1

Streams		**10**	**13**	**14**	**12**	**16**	**18**
From		C201 / C202	E203	Make up (TEG	E202	P200 A/B	Dew_C200
To		Waste gas	R200	R200	E203	D200	Dry Gas
Partial flows		t/h	t/h	t/h	t/h	t/h	t/h
METHANE		0.0087295	0.00019248	0	0.00019248	0.00019248	30.6057666
ETHANE		0.00031275	7.04E-06	0	7.04E-06	7.04E-06	2.20265086
PROPANE		0.00038347	9.61E-06	0	9.61E-06	9.61E-06	1.77091835
n-BUTANE		0.00046348	8.69E-06	0	8.69E-06	8.69E-06	0.69912632
ISOBUTANE		0.00020933	3.74E-06	0	3.74E-06	3.74E-06	0.40540391
n-PENTANE		0.00016475	3.61E-06	0	3.61E-06	3.61E-06	0.23427225
ISOPENTANE		0.00015873	3.42E-06	0	3.42E-06	3.42E-06	0.27521172
n-HEXANE		0.00017167	4.40E-06	0	4.40E-06	4.40E-06	0.24170778
n-HEPTANE		0.00011188	3.18E-06	0	3.18E-06	3.18E-06	0.15617946
n-OCTANE		3.75E-05	1.18E-06	0	1.18E-06	1.18E-06	0.05205961
n-NONANE		5.94E-06	2.00E-07	0	2.00E-07	2.00E-07	0.00806911
n-DECANE		1.21E-06	4.30E-08	0	4.30E-08	4.30E-08	0.00158775
n-UNDECANE		1.17E-07	4.07E-09	0	4.07E-09	4.07E-09	0.00014129
n-DODECANE		3.21E-08	1.14E-09	0	1.14E-09	1.14E-09	3.76E-05
NITROGEN		6.41E-05	6.74E-07	0	6.74E-07	6.74E-07	0.16739092
CARBON DIOXIDE		0.00020136	4.13E-06	0	4.13E-06	4.13E-06	0.35331476
WATER		0.02288049	0.00027511	0	0.00027511	0.00027511	0.0002655
TRIETHYLENE GLYCOL		5.84E-05	0.56308308	8.83E-05	0.56308308	0.56317139	2.99E-05
Total flow	t/h	0.0339547	0.5636006	8.83E-05	0.5636006	0.56368891	37.1741337
Total flow	m3(n)/h	41.6921514	84.6751459	0.01318003	84.6751459	84.6883259	46311.1144
Mass fractions							
METHANE		0.25709263	0.00034152	0	0.00034152	0.00034147	0.82330813
ETHANE		0.00921083	1.25E-05	0	1.25E-05	1.25E-05	0.05925224
PROPANE		0.01129369	1.71E-05	0	1.71E-05	1.70E-05	0.04763846
n-BUTANE		0.01364984	1.54E-05	0	1.54E-05	1.54E-05	0.0188068
ISOBUTANE		0.00616491	6.63E-06	0	6.63E-06	6.63E-06	0.01090554
n-PENTANE		0.00485212	6.41E-06	0	6.41E-06	6.40E-06	0.00630202
ISOPENTANE		0.00467473	6.07E-06	0	6.07E-06	6.07E-06	0.00740331
n-HEXANE		0.00505584	7.80E-06	0	7.80E-06	7.80E-06	0.00650204
n-HEPTANE		0.0032949	5.64E-06	0	5.64E-06	5.64E-06	0.00420129
n-OCTANE		0.0011046	2.10E-06	0	2.10E-06	2.10E-06	0.00140043
n-NONANE		0.00017508	3.55E-07	0	3.55E-07	3.55E-07	0.00021706
n-DECANE		3.57E-05	7.63E-08	0	7.63E-08	7.63E-08	4.27E-05
n-UNDECANE		3.44E-06	7.23E-09	0	7.23E-09	7.23E-09	3.80E-06
n-DODECANE		9.45E-07	2.01E-09	0	2.01E-09	2.01E-09	1.01E-06
NITROGEN		0.00188728	1.20E-06	0	1.20E-06	1.20E-06	0.00450289
CARBON DIOXIDE		0.00593029	7.33E-06	0	7.33E-06	7.32E-06	0.00950432
WATER		0.67385331	0.00048814	0	0.00048814	0.00048806	7.14E-06
TRIETHYLENE GLYCOL		0.00171989	0.99908177	1	0.99908177	0.99908192	8.05E-07
Physical state		Vapor	Liquid	Liquid	Liq./Vap.	Liquid	Vapor
Temperature	°C	100	28.7	28.7	56.424346	30.0329608	25.5282723
Pressure	barr	0.03674972	0.03674972	-2.74E-07	0.03674972	70.7499806	70.7499806
Enthalpy	kW	1.37124506	-85.8591173	-0.01342316	-75.8857401	-84.3434882	-913.135691
Vapor fraction		1		0.00969686	0.00017069		1

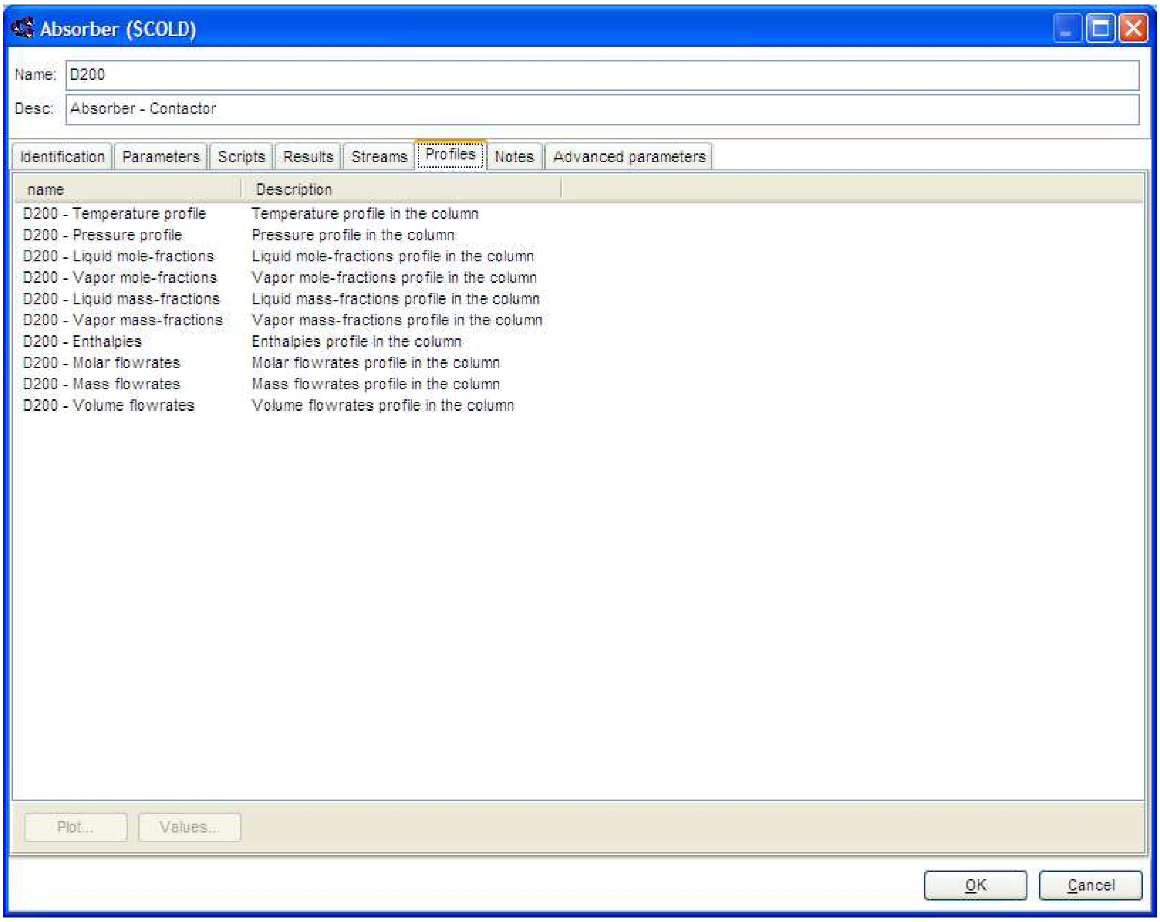
2.2. Dew temperatures

Dew temperatures are calculated by Windows Script modules:

Module	**Inlet stream**	**Result (°C)**
Dew_C 1	1	24.7
Dew C200	17	-40.6

2.3. Columns profiles

Composition profiles can be accessed after the simulation in each column configuration window, in the "Profiles" tab. Double clicking on the profile will generate the corresponding graph.

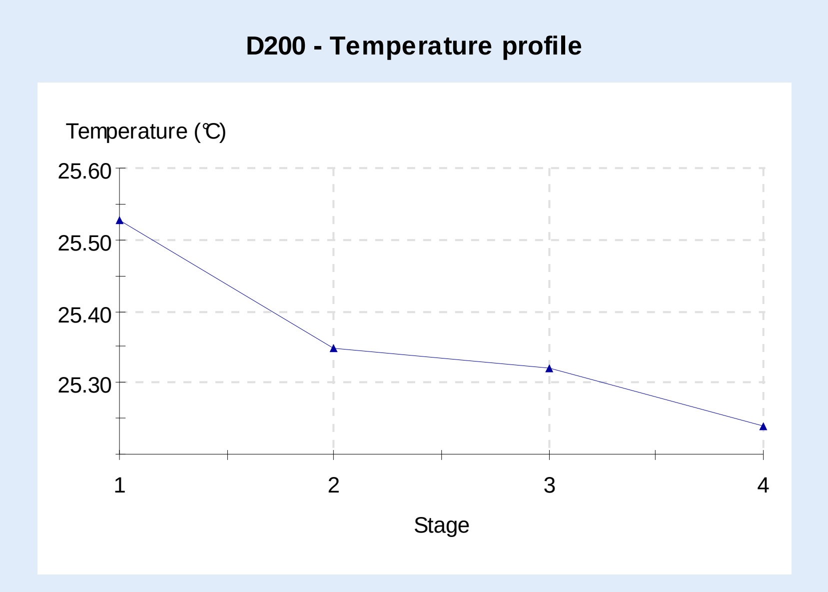


Name: D200
Desc: Absorber - Contactor

name	Description
D200 - Temperature profile	Temperature profile in the column
D200 - Pressure profile	Pressure profile in the column
D200 - Liquid mole-fractions	Liquid mole-fractions profile in the column
D200 - Vapor mole-fractions	Vapor mole-fractions profile in the column
D200 - Liquid mass-fractions	Liquid mass-fractions profile in the column
D200 - Vapor mass-fractions	Vapor mass-fractions profile in the column
D200 - Enthalpies	Enthalpies profile in the column
D200 - Molar flowrates	Molar flowrates profile in the column
D200 - Mass flowrates	Mass flowrates profile in the column
D200 - Volume flowrates	Volume flowrates profile in the column

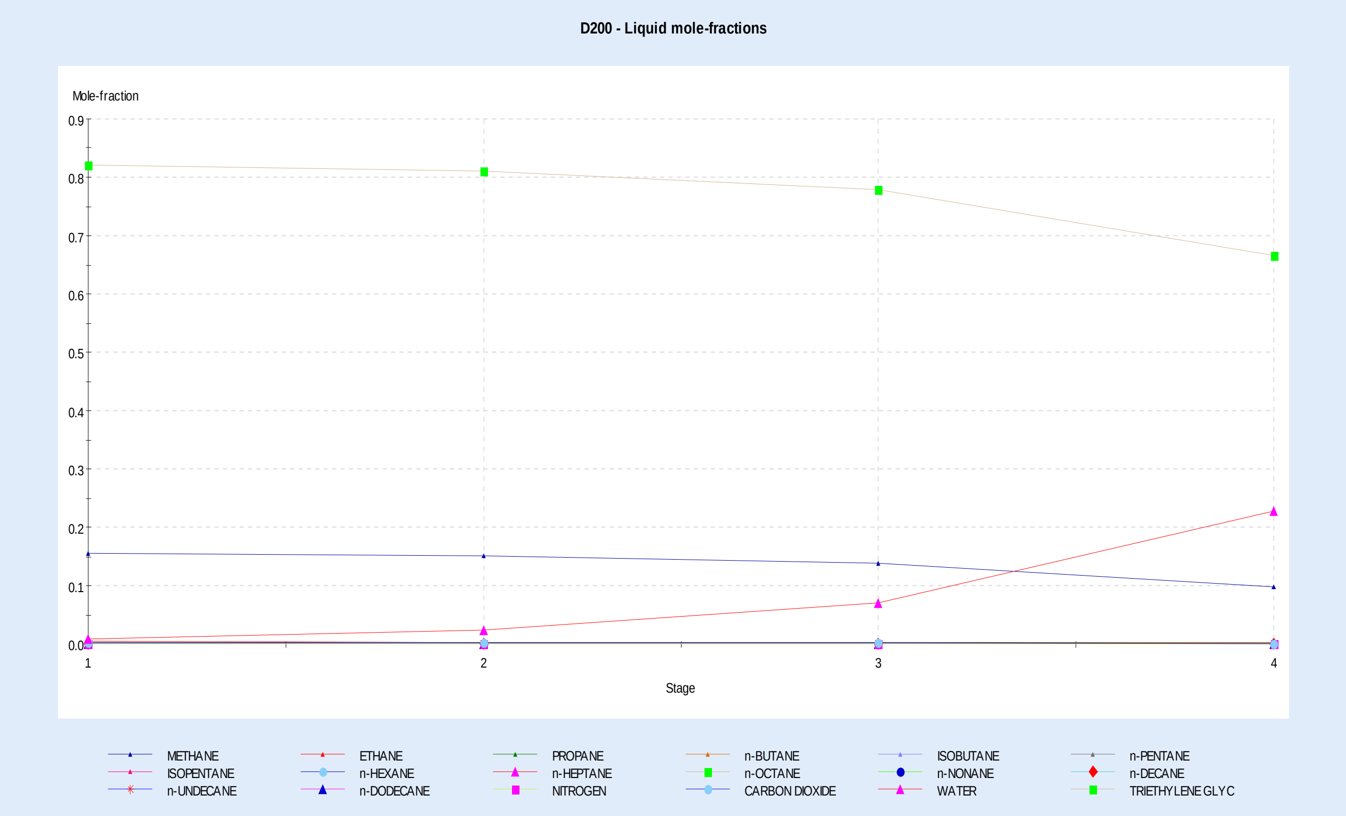
Note that in ProSimPlus the stages are numbered from top to bottom. Stage 1 is the condenser, the last stage is the boiler.

D200 (Absorber – Contactor): temperature profile



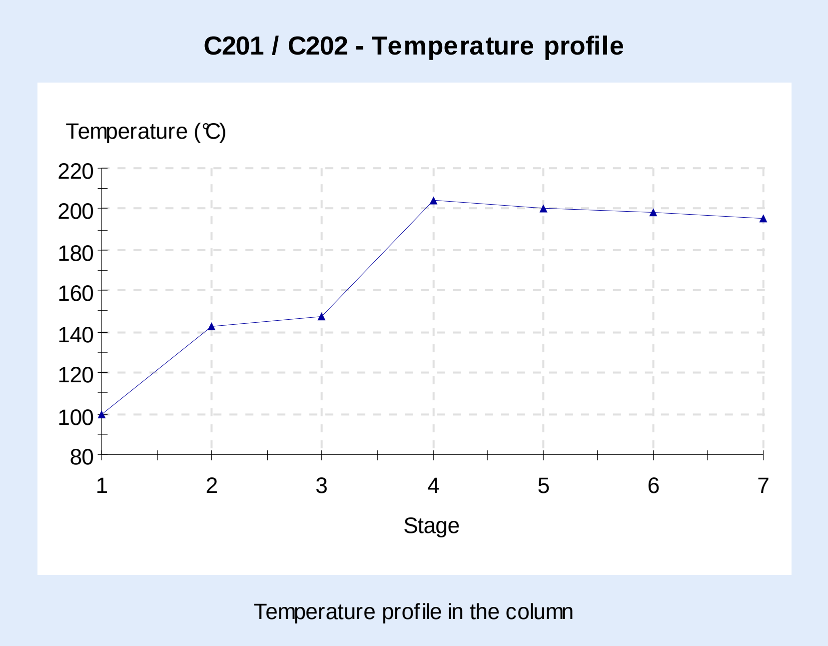
Temperature profile in the column

D200 (Absorber – Contactor): Liquid mole fractions profile



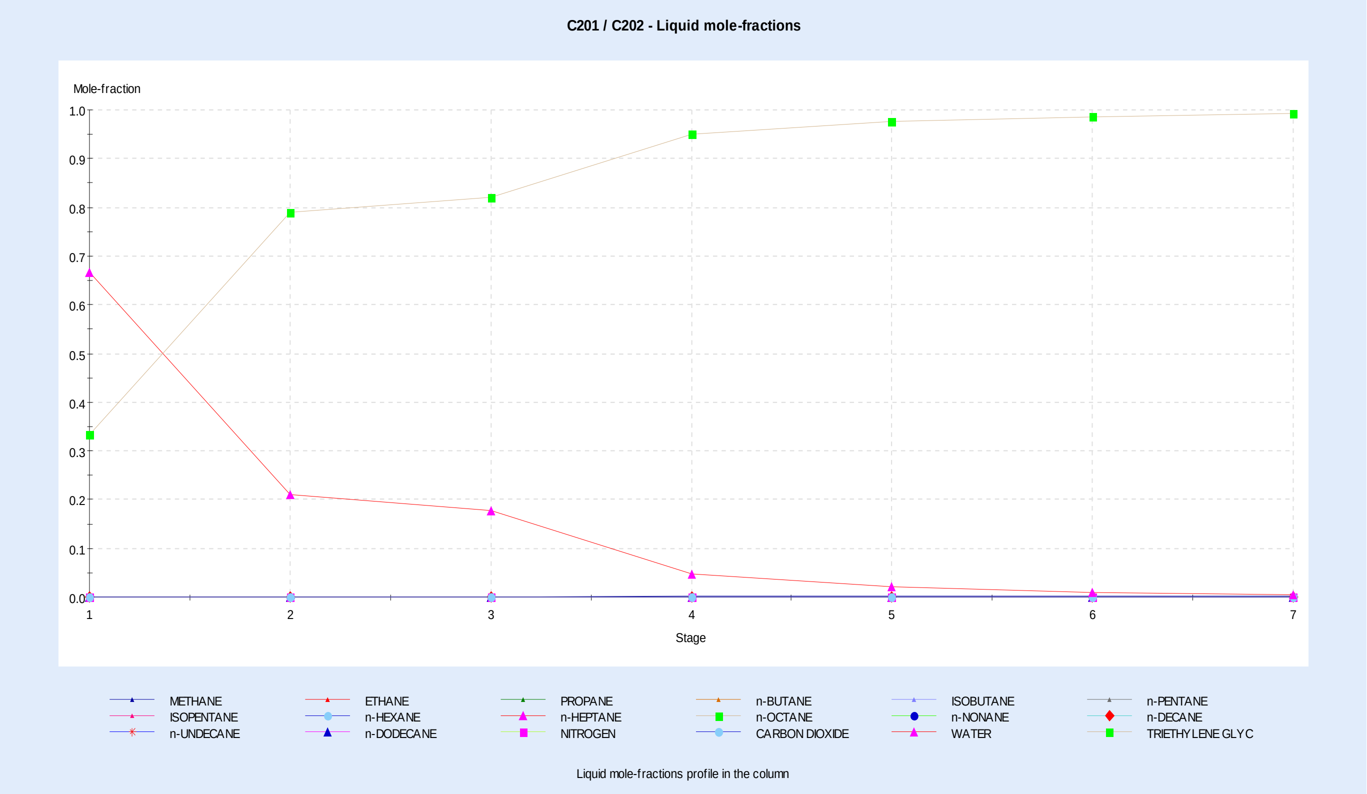
Liquid mole-fractions profile in the column

C201 / C202 (Regenerator and stripper): temperature profile



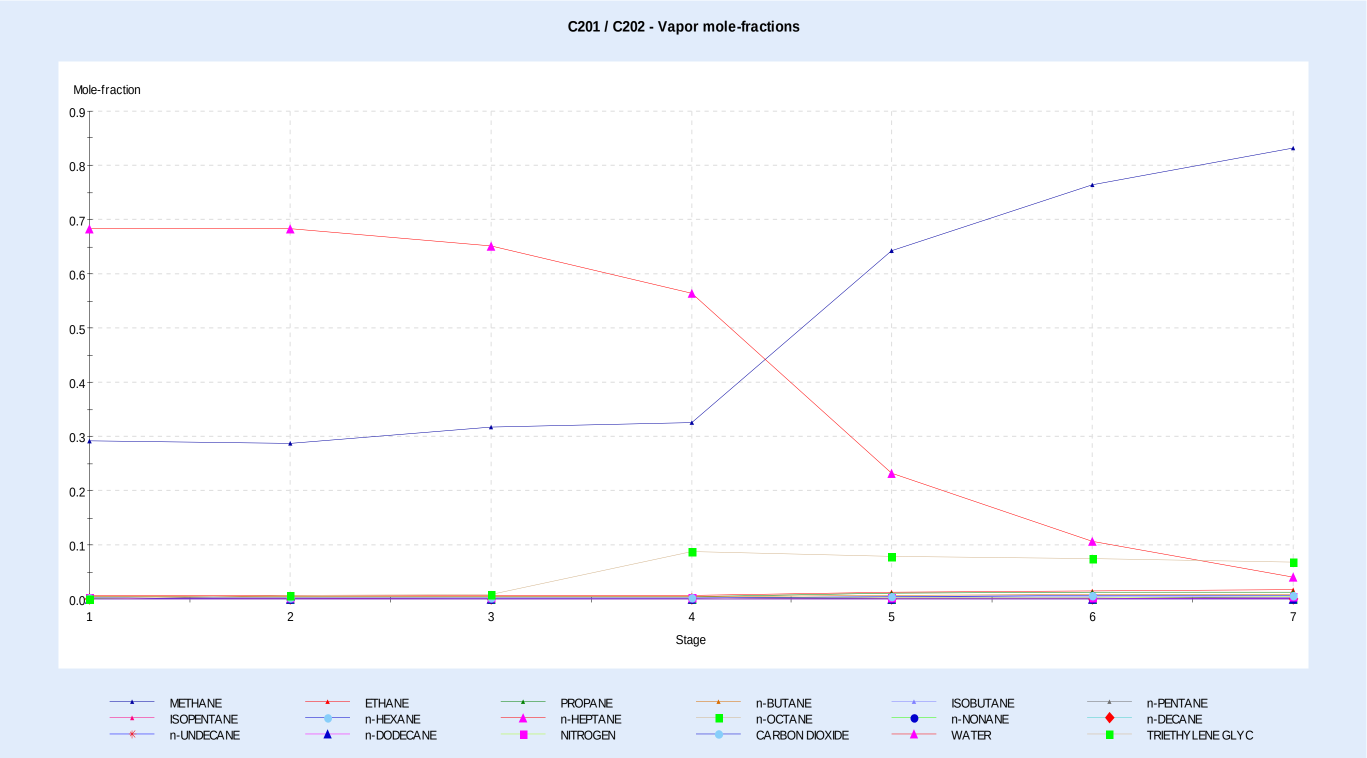
Temperature profile in the column

C201 / C202 (Regenerator and stripper): liquid mole-fractions profile



Liquid mole-fractions profile in the column

C201 / C202 (Regenerator and stripper): vapor mole fractions profile



Vapor mole-fractions profile in the column

3.Process analysis and optimization

When optimizing the design of dehydration unit, the impact of the following parameters can be easily evaluated using the simulation model presented in this document:

- The number of contactor D 200 theoretical trays
- TEG circulation rate
- Temperature of the reboiler in the regenerator
- Pressure of B200 flash drum

In particular, it can be noted that the reboiler TEG temperature is limited by the degradation temperature of the glycol. B200 pressure acts on the stripping gas flow and therefore and on the regenerator performance. These two parameters act on the water content of the lean TEG.

Other parameters may have also a limited impact. The number of theoretical trays of the TEG regenerator has a little impact on lean TEG content. Heat exchanger recovery E 202 outlet temperature has an impact on the reboiler duty.

Lean TEG temperature at the top of the contactor affects the water partial pressure at the top stage. Consequently, lower TEG temperatures will result in reduced amount of water in the overhead lean gas. This will also increase the amount of gas absorbed in the TEG and consequently, increase the gas losses. This temperature is controlled by the temperature controller located at E202 outlet.

4. REFERENCES

[ABR75] D.S. Abrams, J.M. Prausnitz

Statistical thermodynamics of liquid mixtures: A new expression for the excess Gibbs energy of partly or complete miscible systems.

AIChE. Journal, 1975, Vol. 21, No 3, p. 116-128

[AND78] T.F. Anderson, J.M. Prausnitz

Application of the UNIQUAC equation to calculation of multicomponent phase-equilibria. 1-Vapor-liquid equilibria.

Industrial & Engineering Chemistry Process Design & Development, 1978, Vol. 17, No 4, p. 552-560

[DAH 90] Dahl S. Michelsen, M.L,

AIChE Journal, 1990, Vol. 36, p 1829-1836

[MIC 90b] Michelsen M.L.

A modified Huron-Vidal mixing rule for cubic Equation of state

Fluid Phase Equilibria, 60, pp. 213-219 (1990)

[MKW58] MC Ketta and Wehe

Water contents of natural gases with correlations for salinity and relative density

Hydrocarbon Processing, 1958

[PEN76] Y.D. Peng, D.B. Robison

A new two constant equation of state.

Industrial & Engineering Chemistry Fundamentals, 1976, Vol. 15, No 1, p. 59-64