PROSIMPLUS APPLICATION EXAMPLE

SIMULATION OF A VACUUM DISTILLATION UNIT

EXAMPLE PURPOSE
This example illustrates the simulation of a vacuum distillation unit with ProSimPlus.

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CORRESPONDING PROSIMPLUS FILE	*PSPS_E23_EN - Vacuum Distillation.pmp3*

Reader is reminded that this use case is only an example and should not be used for other purposes. Although this example is based on actual case it may not be considered as typical nor are the data used always the most accurate available. ProSim shall have no responsibility or liability for damages arising out of or related to the use of the results of calculations based on this example.

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1. PROCESS MODELING

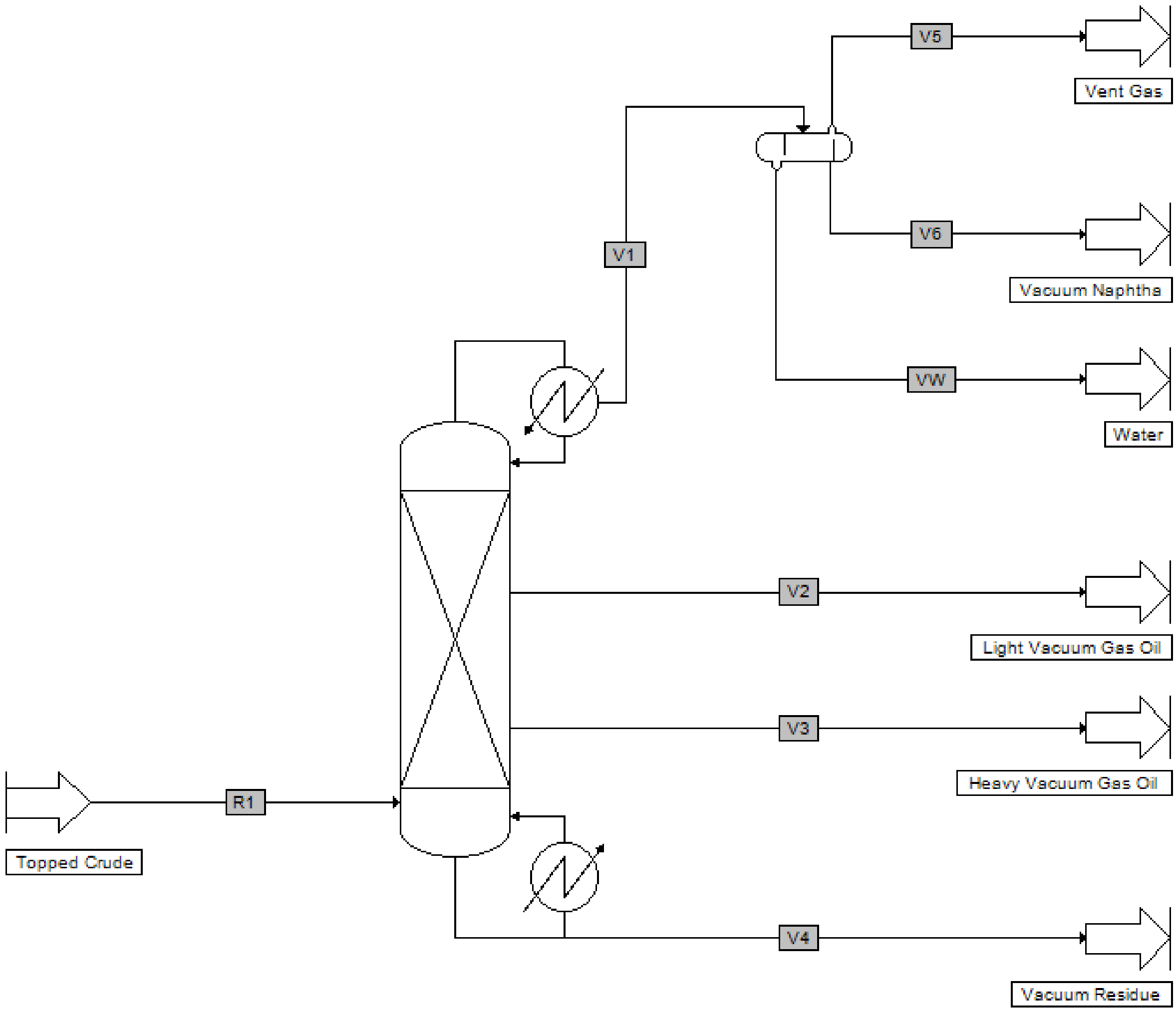
1.1. Process presentation

The vacuum distillation system is used to separate heavy petroleum cuts. It consists of a distillation column with a partial condenser and a null reflux ratio and equipped with two pumparounds. The liquid stream feeding the column is pre-heated in a furnace: this furnace is simulated through the reboiler heating since the feed is connected to the column bottom.

The feed pressure is equal to the column bottom pressure (65 mmHg). The feed temperature is 338°C: the feed stream is vapor/liquid at this temperature (vapor molar fraction of around 0.6). The liquid state is imposed for this stream: the vaporization enthalpy of the feed is taken into account in the heat duty of the reboiler that both simulates the furnace and the reboiler of the column.

The input data of this problem is available in [SIM83].

1.2. Flowsheet

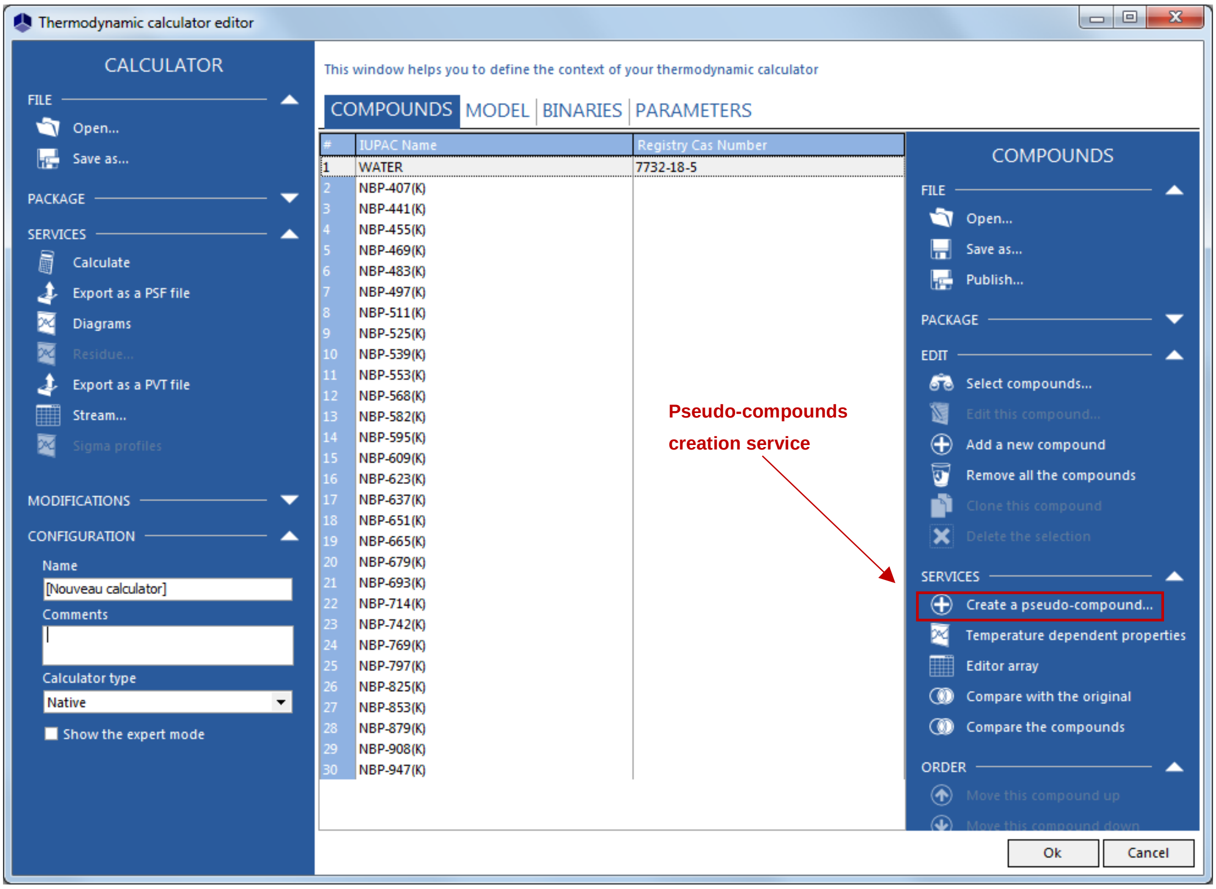


1.3. Compounds

The petroleum cut to be processed has 30 compounds: water and 29 pseudo-compounds.

The pseudo-compounds are generated using the atmospheric TBP. Water is here a light end since it is solubilized in the petroleum cut and it is the lightest compound of the cut.

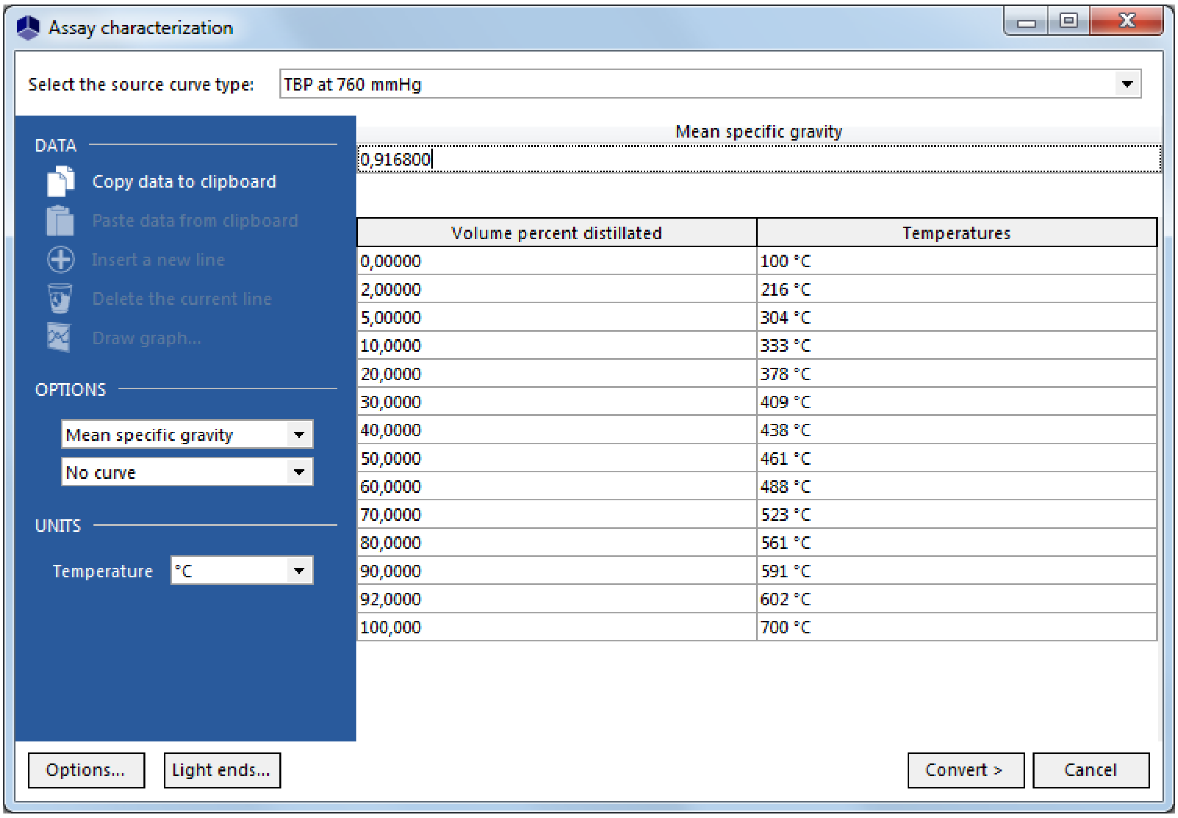
The pseudo-compounds creation service is available in the thermodynamic calculator editor as illustrated below.

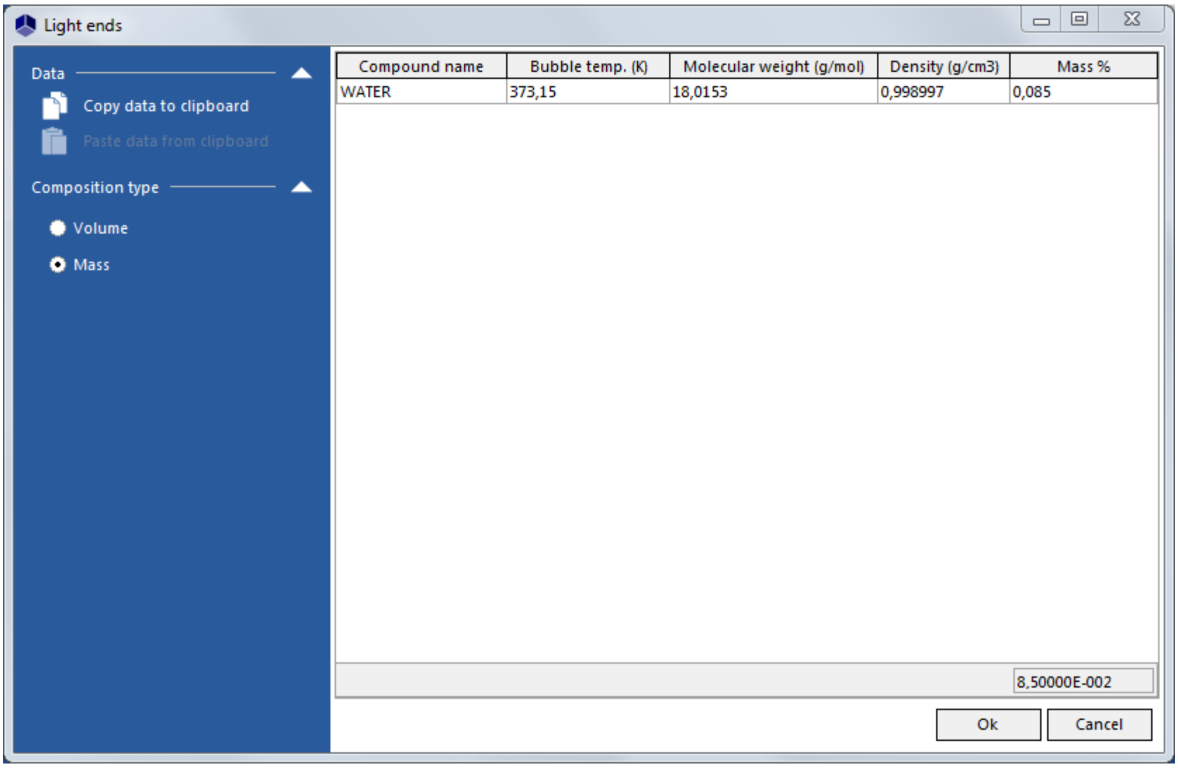


The pseudo-compounds are generated using the following petroleum cut properties:

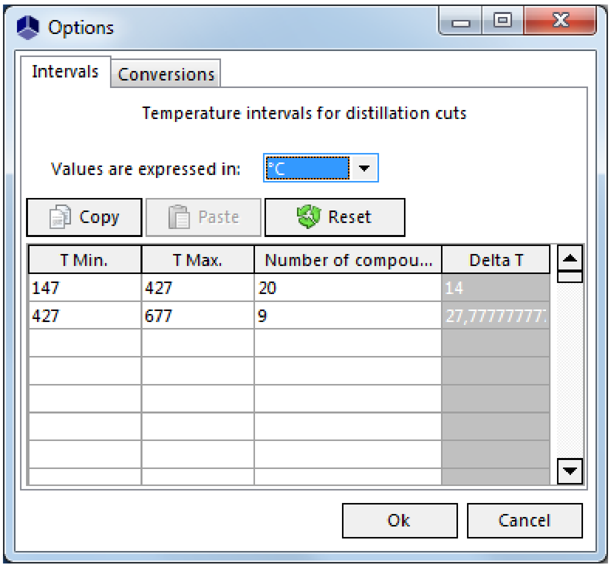
- the normal boiling point
- the specific gravity

The required data can be seen in the following windows:





The distillation curve is cut as follows: 20 compounds between 147 °C and 427 °C, 9 compounds between 427 °C and 677 °C.



The normal boiling point of the compounds generated with Simulis are gathered in the following table.

Compound	Normal boiling point (°C)
NBP-407(K)	134
NBP-441(K)	168
NBP-455(K)	182
NBP-469(K)	196
NBP-483(K)	210
NBP-497(K)	224
NBP-511(K)	238
NBP-525(K)	252
NBP-539(K)	266
NBP-553(K)	280
NBP-568(K)	295
NBP-582(K)	308
NBP-595(K)	322
NBP-609(K)	336
NBP-623(K)	350
NBP-637(K)	364
NBP-651(K)	378
NBP-665(K)	392
NBP-679(K)	406
NBP-693(K)	420
NBP-714(K)	441
NBP-742(K)	469
NBP-769(K)	496
NBP-797(K)	524
NBP-825(K)	552
NBP-853(K)	580
NBP-879(K)	606
NBP-908(K)	635
NBP-947(K)	674

The obtained molar composition of the topped crude is presented in the table below. The molar mass calculated is equal to 358.46 g/mol.

Compound	Molar composition
WATER	0.01691
NBP-407(K)	0.02079
NBP-441(K)	0.00550
NBP-455(K)	0.00567
NBP-469(K)	0.00589
NBP-483(K)	0.00618
NBP-497(K)	0.00625
NBP-511(K)	0.00622
NBP-525(K)	0.00635
NBP-539(K)	0.00673
NBP-553(K)	0.00766
NBP-568(K)	0.01084
NBP-582(K)	0.02879
NBP-595(K)	0.03456
NBP-609(K)	0.03937
NBP-623(K)	0.03699
NBP-637(K)	0.03872
NBP-651(K)	0.04835
NBP-665(K)	0.05164
NBP-679(K)	0.05173
NBP-693(K)	0.05036
NBP-714(K)	0.11251
NBP-742(K)	0.10132
NBP-769(K)	0.07159
NBP-797(K)	0.05951
NBP-825(K)	0.05414
NBP-853(K)	0.06249
NBP-879(K)	0.02188
NBP-908(K)	0.01326
NBP-947(K)	0.01780

1.4. Thermodynamic model

The studied process deals with mixtures of water and hydrocarbons. Thus, a Soave-Redlich-Kwong (SRK) equation of state with the "Water-Hydrocarbons" option has been chosen. The liquid molar volume calculation uses the "Ideal mixture" model.

1.5. Operating conditions

1.5.1. Feed

The aim is to process 329 371 kg/h of topped crude (including 280 kg/h of water). The feed petroleum cut is at 338°C and 65 mmHg. Liquid state has also been imposed.

1.5.2. Vacuum column

1.5.2.1. Parameters

- Characteristics:
    - Distillation column with partial condenser
    - Number of theoretical stages: 9
    - Operating mode specifications: vapor distillated flowrate and reflux flowrate
    - Pressure profile: 30 mmHg at the condenser, 30 mmHg at stage 2, 38 mmHg at stage 4, 50 mmHg at stage 6, 65 mmHg at the bottom
- Feed:
    - Topped Crude at stage 9
- Sidestreams:
    - Light Vacuum Gas Oil at stage 4
    - Heavy Vacuum Gas Oil at stage 6
- Pumparound 1:
    - From stage 4 to stage 2 (liquid phase)
    - Flowrate: 276 220 kg/h
    - Duty: - 7 Gcal/h (cooling)

- Pumparound 2:
  - From stage 6 to stage 5 (liquid phase)
  - Flowrate: 538 150 kg/h
  - Duty: - 30 Gcal/h (cooling)

1.5.2.2. Objectives

- Dry bottom liquid product flowrate: 70 m^3/h (standard conditions)

  Adjusted variable: vapor distillate flowrate
- Dry Light Vacuum Gas Oil flowrate: 72 m^3/h (standard conditions)

  Adjusted variable: Light Vacuum Gas Oil sidestream flowrate
- Dry Heavy Vacuum Gas Oil flowrate: 213 m^3/h (standard conditions)

  Adjusted variable: Heavy Vacuum Gas Oil sidestream flowrate
- Liquid flowrate at stage 4: 1 kmol/h

  Adjusted variable: pumparound 1 reboiler duty
- Liquid flowrate at stage 6: 85 m^3/h (standard conditions)

  Adjusted variable: pumparound 2 reboiler duty

1.5.2.3. Initialization

- Liquid sidestream flowrate at stage 4: 100 kmol/h (this flowrate is adjusted by a specification).
- Liquid sidestream flowrate at stage 6: 100 kmol/h (this flowrate is adjusted by a specification).
- Vapor distillate flowrate: 100 kmol/h (this flowrate is adjusted by a specification)
- Reflux flowrate: 0 kmol/h
- Liquid distillate flowrate: 0 kmol/h

1.5.3. General 3-phase flash

1.5.3.1. Parameters

- Characteristics:
  - Temperature: 28 °C
  - Pressure: 25 mmHg

1.5.4. Numerical parameters

The default numerical parameters are used for all the unit operations excepted for the column which maximum damping factor is fixed to 0.5.

2. RESULTS

2.1. Mass and energy balances

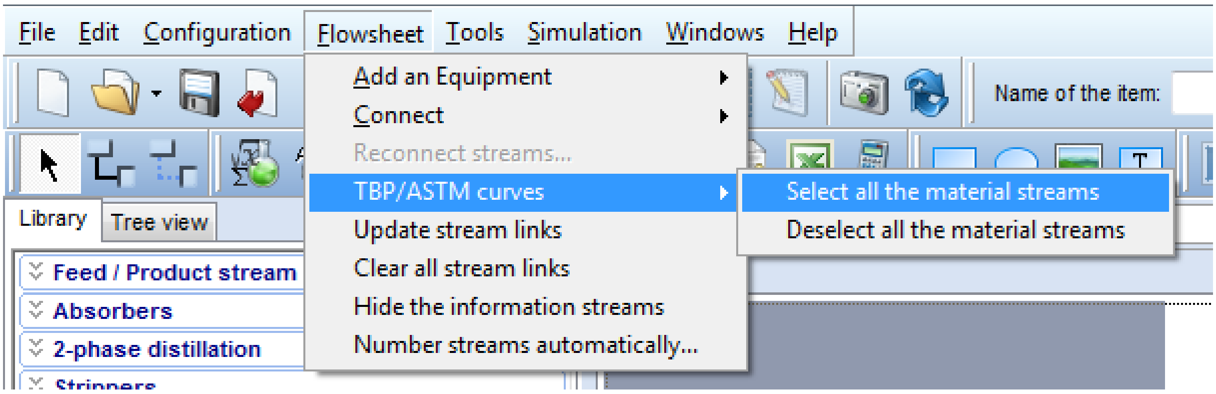
This document only presents the most relevant stream results. In ProSimPlus, mass and energy balances are provided for every stream. Results are also available at the unit operation level (result tab in the configuration window).

Streams		R1	V1	V2	V3	V4	V5	V6
From		Topped Crude	Column	Column	Column	Column	Flash	Flash
To		Column	Flash	Light Vacuum Gas Oil	Heavy Vacuum Gas Oil	Vacuum Residue	Vent Gas	Vacuum Naphtha
Total flow	kmol/h	918.8	41.3	246.2	513.1	118.3	22.3	19.0
Mole fractions								
WATER		0.01691	0.37596	0.00003	0.00001	0.00001	0.69659	0.00052
NBP-407(K)		0.02079	0.41389	0.00795	0.00009	0.00006	0.28022	0.57042
NBP-441(K)		0.00550	0.07029	0.00865	0.00004	0.00002	0.01465	0.13545
NBP-455(K)		0.00567	0.04972	0.01271	0.00005	0.00003	0.00568	0.10129
NBP-469(K)		0.00589	0.03280	0.01634	0.00007	0.00003	0.00195	0.06893
NBP-483(K)		0.00618	0.02121	0.01930	0.00009	0.00004	0.00064	0.04530
NBP-497(K)		0.00625	0.01305	0.02087	0.00012	0.00005	0.00019	0.02812
NBP-511(K)		0.00622	0.00778	0.02155	0.00016	0.00005	0.00005	0.01684
NBP-525(K)		0.00635	0.00468	0.02242	0.00022	0.00007	0.00002	0.01014
NBP-539(K)		0.00673	0.00286	0.02393	0.00032	0.00008	4E-06	0.00621
NBP-553(K)		0.00766	0.00183	0.02714	0.00052	0.00011	1E-06	0.00398
NBP-568(K)		0.01084	0.00138	0.03786	0.00109	0.00019	4E-07	0.00300
NBP-582(K)		0.02879	0.00201	0.09805	0.00420	0.00062	2E-07	0.00436
NBP-595(K)		0.03456	0.00126	0.11270	0.00751	0.00091	6E-08	0.00273
NBP-609(K)		0.03937	0.00071	0.11954	0.01281	0.00127	1E-08	0.00154
NBP-623(K)		0.03699	0.00031	0.10010	0.01785	0.00147	2E-09	0.00067
NBP-637(K)		0.03872	0.00013	0.08764	0.02685	0.00193	3E-10	0.00029
NBP-651(K)		0.04835	0.00006	0.08504	0.04508	0.00302	5E-11	0.00014
NBP-665(K)		0.05164	0.00002	0.06554	0.06009	0.00407	7E-12	0.00005
NBP-679(K)		0.05173	0.00001	0.04401	0.07032	0.00519	7E-13	0.00002
NBP-693(K)		0.05036	2E-06	0.02715	0.07565	0.00651	7E-14	5E-06
NBP-714(K)		0.11251	7E-07	0.02888	0.18264	0.02159	3E-15	1E-06
NBP-742(K)		0.10132	4E-08	0.00946	0.16919	0.03349	0	0
NBP-769(K)		0.07159	2E-09	0.00235	0.11733	0.04232	0	0
NBP-797(K)		0.05951	0	0.00061	0.09061	0.06796	0	0
NBP-825(K)		0.05414	0	0.00015	0.06795	0.12552	0	0
NBP-853(K)		0.06249	0	0.00003	0.04448	0.29242	0	0
NBP-879(K)		0.02188	0	1E-06	0.00437	0.15098	0	0
NBP-908(K)		0.01326	0	2E-08	0.00028	0.10181	0	0
NBP-947(K)		0.01780	0	0E+00	0.00001	0.13819	0	0
Physical state		Liquid	Vapor	Liquid	Liquid	Liquid	Vapor	Liquid
Temperature	°C	338.0	107.1	155.3	294.7	396.3	28.0	28.0
Pressure	mmHg	65	30	38	50	65	25	25
Molar weight	g/mol	358.46	87.14	252.73	381.63	572.72	48.63	132.24

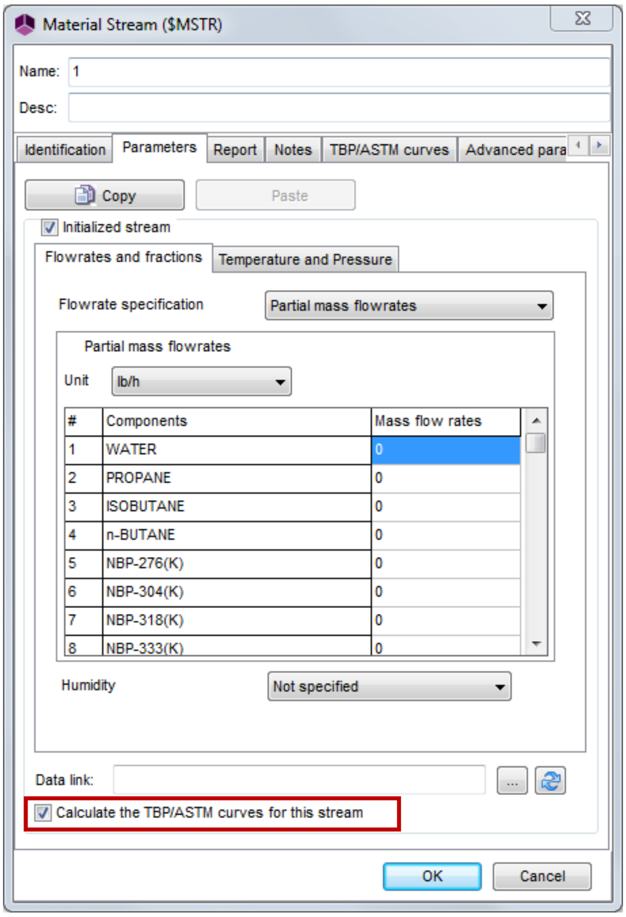
2.2. Process Performances

With ProSimPlus, it is possible to generate the TBP/ASTM curves of material streams. To do so, two ways are available:

- Select the option to plot the TBP/ASTM curves of all the material streams of the process during the next simulation in the tab "Flowsheet" as shown in the following figure:

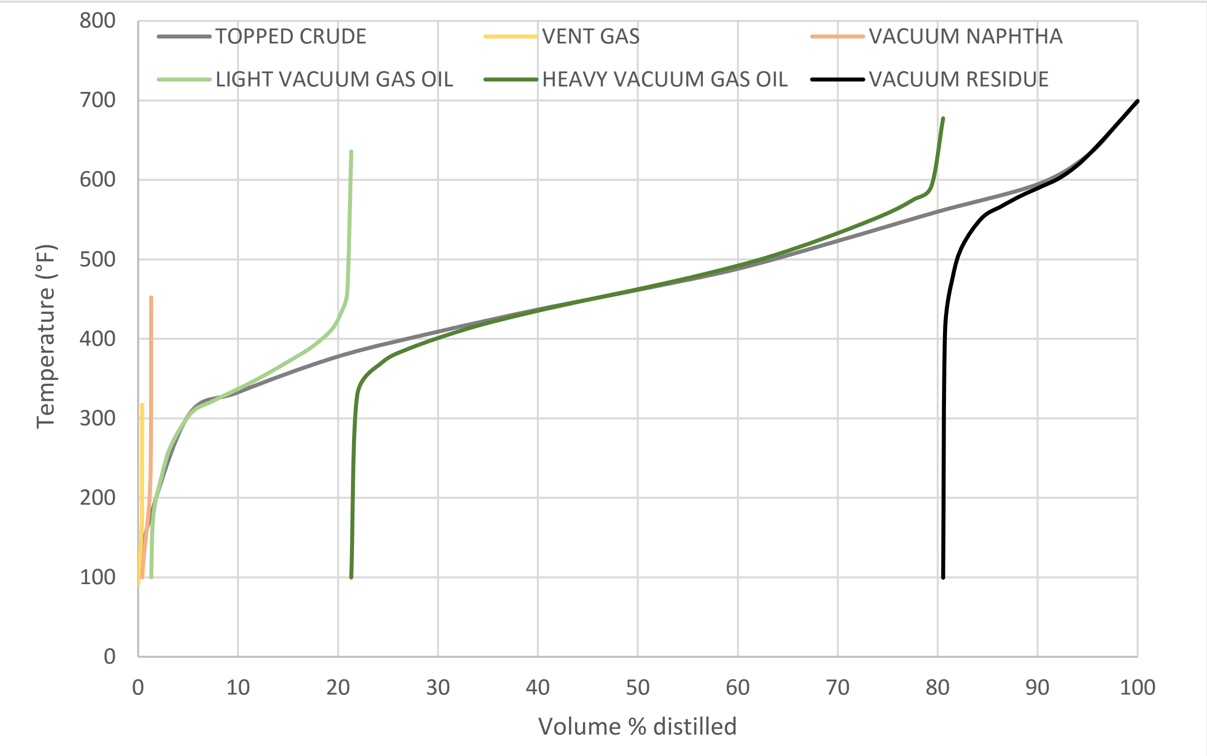


- Tick the "Calculate the TBP/ASTM curves for this stream" box in the configuration window of the material stream which TBP/ASTM curves have to be plotted during the next simulation as illustrated below:



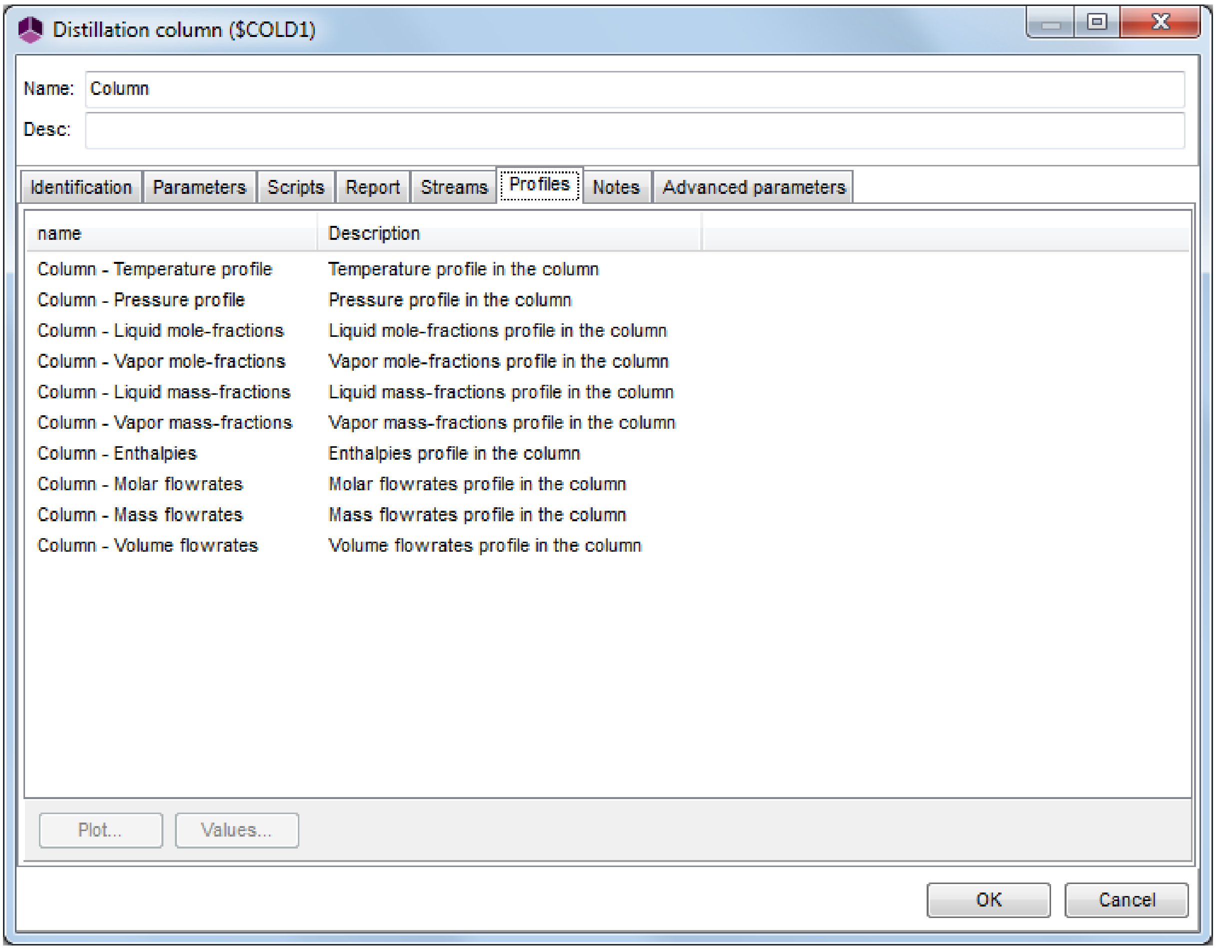
To reach this option the “Initialized stream” box has to be ticked and then unticked once the “Calculate the TBP/ASTM curves for this stream” box has been ticked.

The following figure shows on a same graph the TBP at 760 mmHg curve of the topped crude entering the vacuum column and the ones of the obtained cuts:

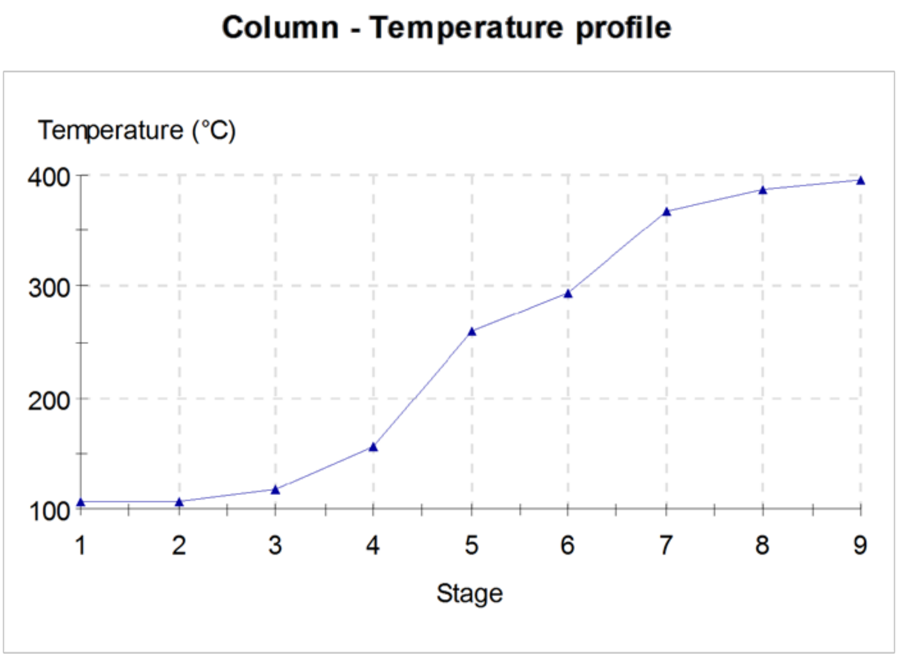


2.3. Column profiles

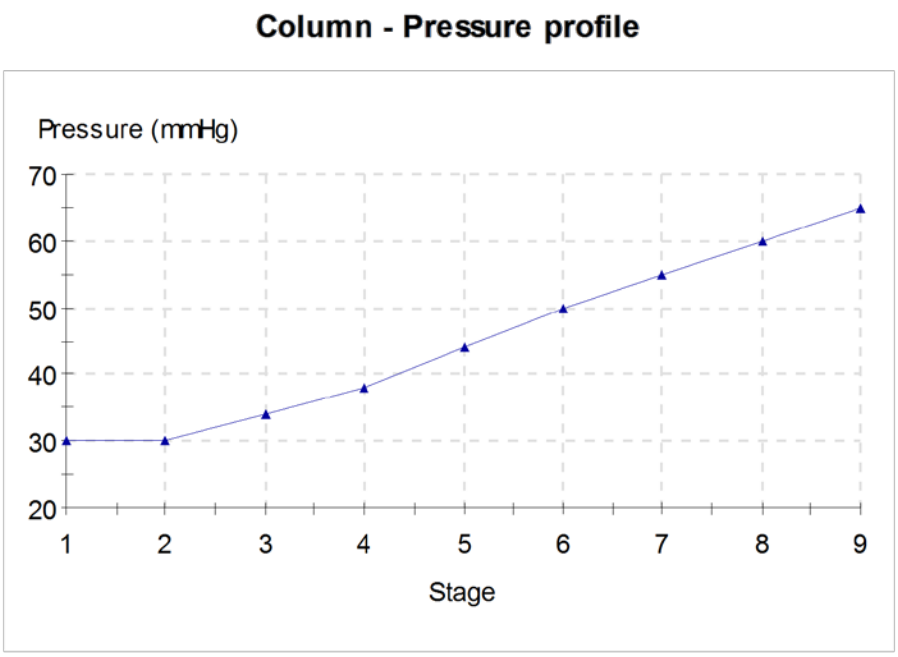
Profiles can be accessed after the simulation in each column configuration window, in the "Profiles" tab. Double clicking on the profile will generate the corresponding graph. It is important to note that, in ProSimPlus, the first stage corresponds to the top stage and the last stage to the bottom stage (respectively the condenser and the reboiler in the case of a distillation column).



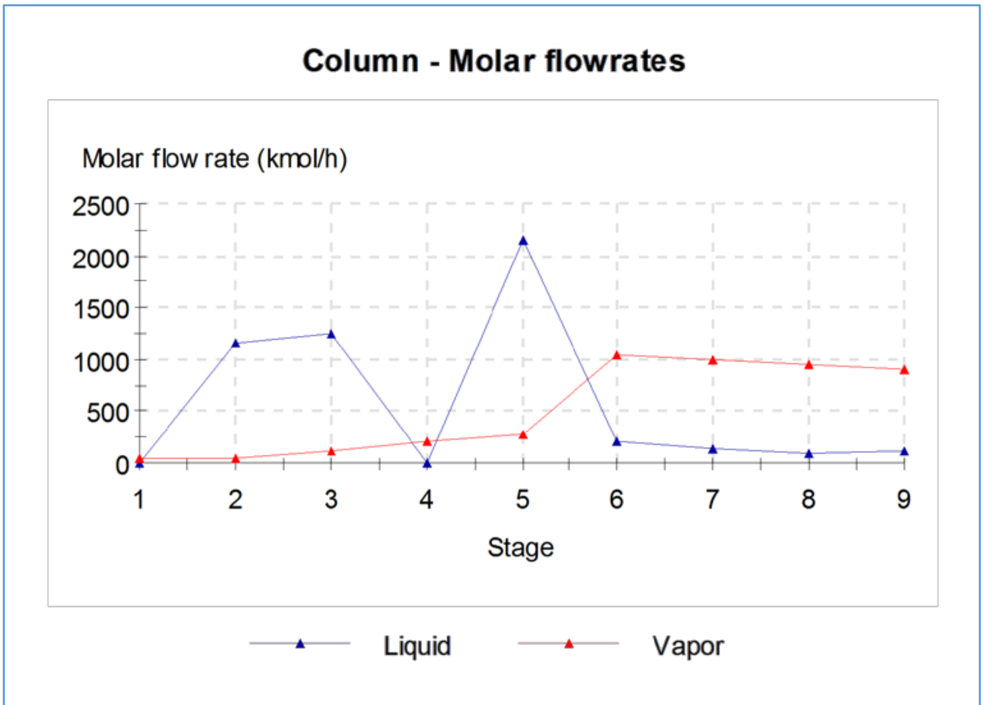
Column:



Temperature profile in the column



Pressure profile in the column



Molar flow rates profile in the column

REFERENCES

[SIM83] Simulation Sciences Inc., SimSci Manual, Revision 1 (1983)

