ProSim

PROSIMPLUS APPLICATION EXAMPLE

SIMULATION OF AN ATMOSPHERIC DISTILLATION UNIT WITH A PREFLASH COLUMN

EXAMPLE PURPOSE
This example illustrates the simulation of a crude oil atmospheric distillation unit with a preflash column with ProSimPlus.

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CORRESPONDING PROSIMPLUS FILE	*PSPS_E21_EN - Atmospheric Distillation with Preflash.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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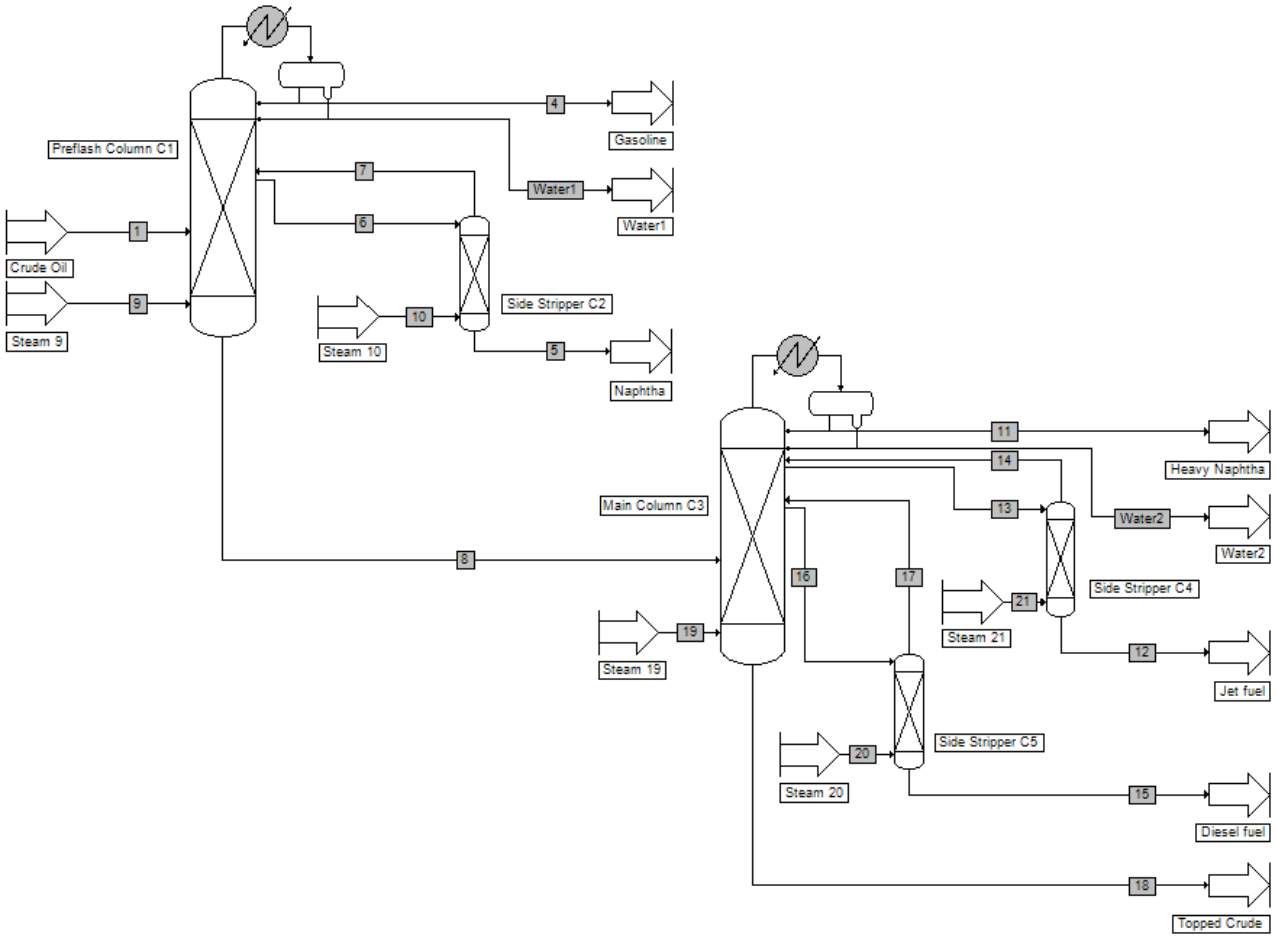
1. PROCESS MODELING

1.1. Process presentation

The distillation system consists of a preflash column coupled with a side stripper and of a main column coupled with two side strippers. These columns have got a decanter and a total condenser. The liquid streams that feed this two main columns are pre-heated with furnaces: these furnaces are simulated by a heating on the column feed stages.

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

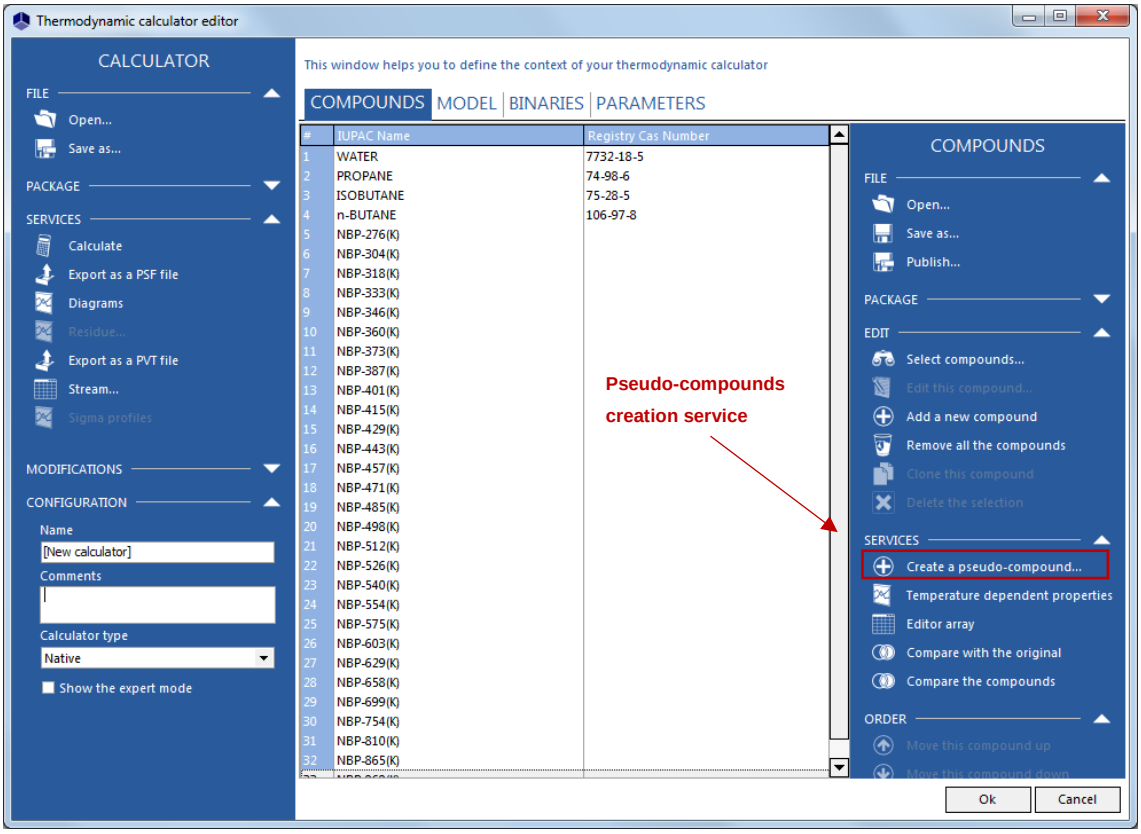
1.2. Process flowsheet



1.3. Compounds

The crude oil to be processed is made of 32 compounds: 3 light-ends (propane, isobutane, n-butane) and 29 pseudo-compounds. Water is also used for the stripping vapor in this process.

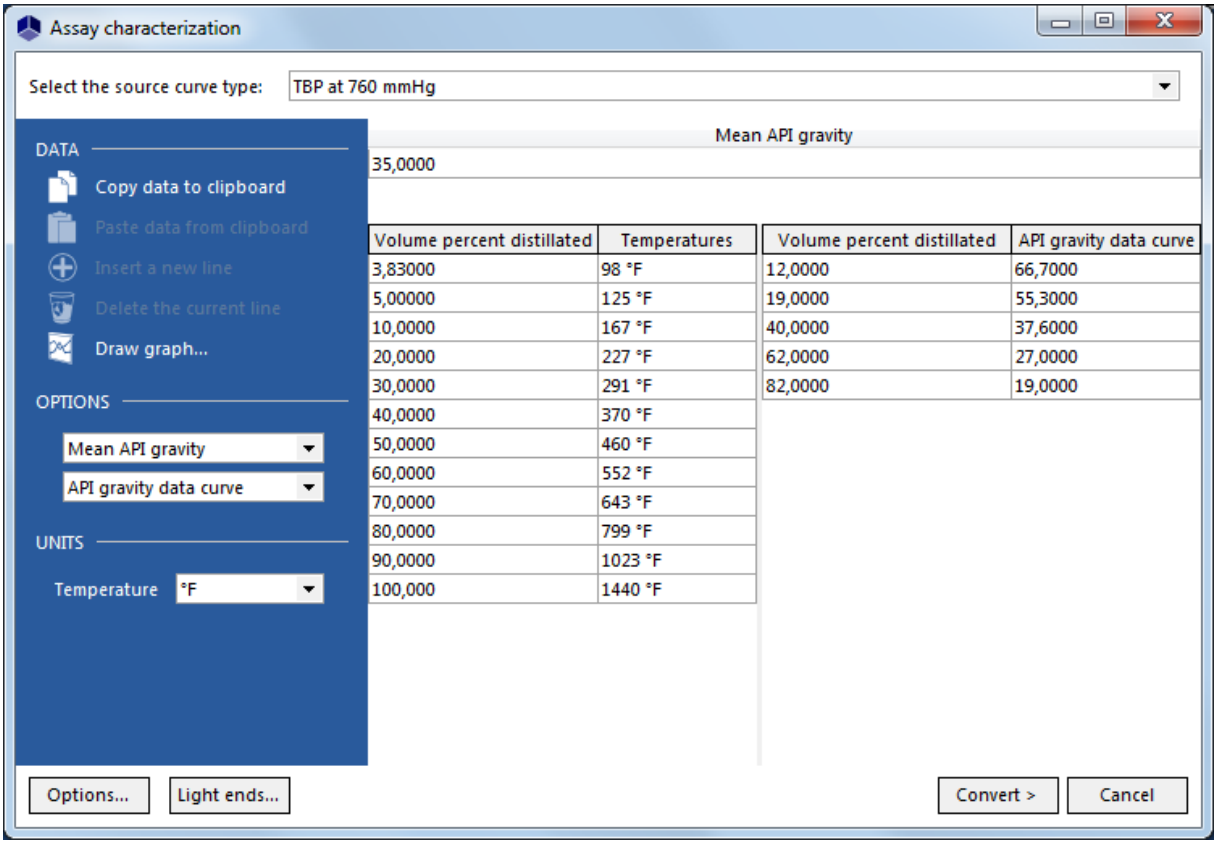
The pseudo-compounds creation service is available in the thermodynamic calculator editor as illustrated below.

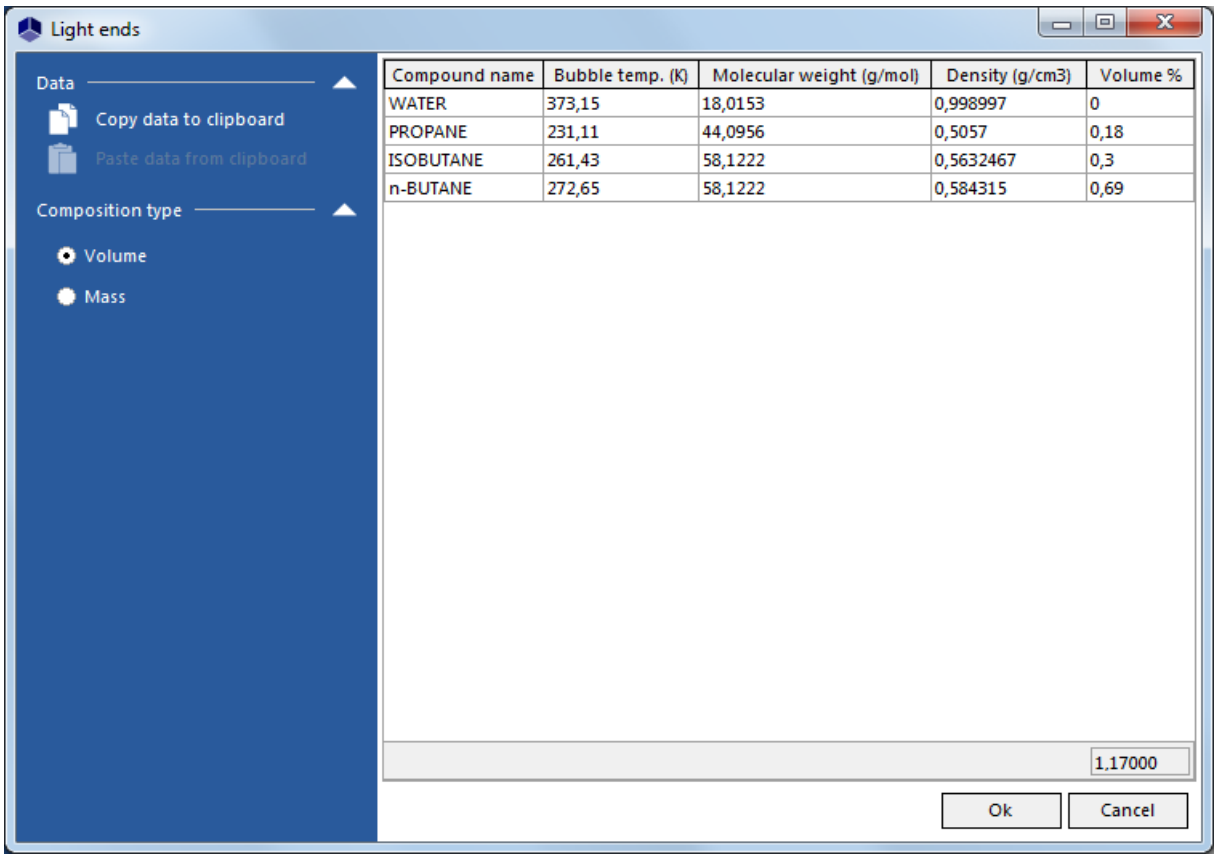


The pseudo-compounds are generated using the following crude oil properties:

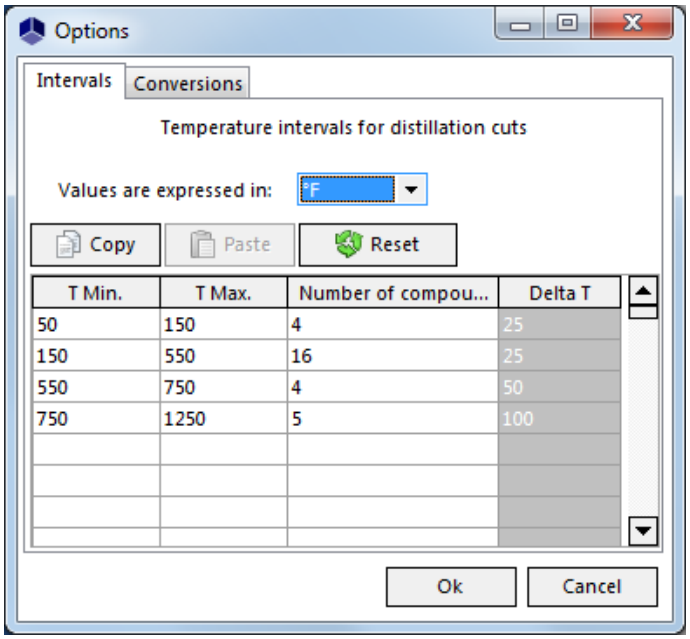
- the mean API gravity,
- the TPB at 760 mmHg,
- the API gravity curve,
- the lights volume composition.

The required data are provided in the following screen shot:





The distillation curve is cut as follows: 4 compounds between 50 and 150 °F, 16 compounds between 150 and 550 °F, 4 compounds between 550 and 750 °F and 5 compounds between 750 and 1250 °F.



The normal boiling points of the compounds generated with Simulis are gathered in the following table. The minimal temperature of the first interval is taken equal to the heaviest light normal boiling point (here 31 °F for the n-butane).

Compound	Normal boiling point (°F)
NBP-276(K)	37
NBP-304(K)	88
NBP-318(K)	114
NBP-333(K)	139
NBP-346(K)	163
NBP-360(K)	187
NBP-373(K)	212
NBP-387(K)	237
NBP-401(K)	262
NBP-415(K)	287
NBP-429(K)	312
NBP-443(K)	337
NBP-457(K)	362
NBP-471(K)	387
NBP-485(K)	412
NBP-498(K)	437
NBP-512(K)	462
NBP-526(K)	487
NBP-540(K)	513
NBP-554(K)	538
NBP-575(K)	575
NBP-603(K)	625
NBP-629(K)	673
NBP-658(K)	725
NBP-699(K)	799
NBP-754(K)	898
NBP-810(K)	999
NBP-865(K)	1098
NBP-969(K)	1284

The obtained molar composition of the crude oil is presented in the table below. The molar mass calculated is equal to 163.42 g/mol.

Compound	Molar composition
WATER	0
PROPANE	0.00397
ISOBUTANE	0.00560
n-BUTANE	0.01335
NBP-276(K)	0.03596
NBP-304(K)	0.01465
NBP-318(K)	0.01788
NBP-333(K)	0.04094
NBP-346(K)	0.05631
NBP-360(K)	0.06382
NBP-373(K)	0.06105
NBP-387(K)	0.05699
NBP-401(K)	0.05380
NBP-415(K)	0.04910
NBP-429(K)	0.04272
NBP-443(K)	0.03763
NBP-457(K)	0.03378
NBP-471(K)	0.03159
NBP-485(K)	0.03000
NBP-498(K)	0.02840
NBP-512(K)	0.02679
NBP-526(K)	0.02583
NBP-540(K)	0.02479
NBP-554(K)	0.02383
NBP-575(K)	0.04544
NBP-603(K)	0.04160
NBP-629(K)	0.02584
NBP-658(K)	0.01881
NBP-699(K)	0.03108
NBP-754(K)	0.02114
NBP-810(K)	0.01463
NBP-865(K)	0.00962
NBP-969(K)	0.01282

1.4. Thermodynamic model

The studied process deals with mixtures of water (with molar ratio less than 50% when not pure) and hydrocarbons. Thus, a Peng-Robinson (PR) equation of state with the Water-Hydrocarbons model has been chosen. The liquid molar volume calculation uses the “Ideal mixture” model.

1.5. Operating conditions

1.5.1. Feeds

The aim is to process 25 000 bbl/d of crude oil at standard conditions (60 °F and 1 bar). This corresponds to 28 510 bbld/d (1 187.9 bbl/h) in the process operating conditions. The crude oil is at 300 °F and 54.636 psi.

The vapor flowrates that feed the main columns and side strippers are the following:

- Stream “Steam 9”: 3 000 lb/h (T = 314.3074 °F ; P = 55 psi)
- Stream “Steam 10”: 900 lb/h (T = 313.8679 °F ; P = 54 psi)
- Stream “Steam 19”: 1 500 lb/h (T = 300.5648 °F ; P = 25 psi)
- Stream “Steam 20”: 650 lb/h (T = 300.0882 °F ; P = 24 psi)
- Stream “Steam 21”: 600 lb/h (T = 300.0879 °F ; P = 24 psi)

1.5.2. Preflash column C1

1.5.2.1. Parameters

- Characteristics:
  - Stripper with decanter and total condenser subcooled to 100 °F
  - Number of theoretical stages: 13
  - Operating mode specification: reflux flowrate, initial value: 3 000 lbmol/h
  - Intermediate reboiler at stage 11 (in order to simulate the feed heating in the furnace), initial value: 30 MBtu/h
  - Pressure profile: 48 psi at the condenser, 53 psi at stage 2, 55 psi at the bottom
- Feeds:
  - “Crude oil” at stage 11
  - Stream 7 at stage 7 (C2 side stripper head stream)
- Sidestream:
  - Stream 6 at stage 8 (stream feeding the side stripper C2) , initial value: 100 lbmol/h
- Pumparound:
  - From stage 8 to stage 6 (liquid phase)
  - Flowrate: 5 200 bbl/d (216.667 bbl/h, standard conditions)
  - Power: - 5 MBtu/h (cooling)

1.5.2.2. Objectives / Constraints

- Bottom liquid product flowrate: 16 800 bbl/d (700 bbl/h, standard conditions)

  Adjusted variable: reflux flowrate
- Overflash: 400 bbl/d (16.667 bbl/h, standard conditions)

  In ProSimPlus, the overflash is not specified in flowrate but in flowrate ratio (the liquid flowrate arriving at the feed stage divided by the flashed feed flowrate at the column pressure) at the feed stage. The fixed constraint in the simulation is here the liquid flowrate at stage 10 and is equal to 16.667 bbl/h (standard conditions).

  Adjusted variable: stage 11 intermediate heat duty

1.5.2.3. Initializations

- Head composition in molar fraction: 0.1 for the 10 lightest hydrocarbons
- Bottom composition in molar fraction: 0.05 for the 20 heaviest hydrocarbons

1.5.3. Side stripper C2

1.5.3.1. Parameters

- Characteristics:
  - Absorber
  - Number of theoretical stages: 2
  - Pressure: 54 psi

1.5.3.2. Objectives / Constraints

- Bottom liquid product flowrate (Naphtha): 5 420 bbl/d (225.833 bbl/h, standard conditions)

  Adjusted variable: feed flowrate (stream 6)

1.5.4. Main column C3

1.5.4.1. Parameters

- Characteristics:
  - Stripper with decanter and total condenser subcooled to 100 °F
  - Number of theoretical stages: 16
  - Operating mode specification: reflux flowrate
  - Stage 14 intermediate reboiler (to simulate the heating of the feed in the furnace)
  - Pressure profile: 20 psi at the condenser, 23 psi at stage 2, 25 psi at the bottom

- Feeds:
  - Stream 8 at stage 14 (bottom liquid product stream of the preflash column)
  - Stream 14 at stage 7 (head stream of the side stripper C4)
  - Stream 17 at stage 11 (head stream of the side stripper C5)

- Sidestreams:
    - Stream 13 at stage 8 (stream feeding the side stripper C4)
    - Stream 16 at stage 12 (stream feeding the side stripper C5)
- Pumparound:
    - From stage 12 to stage 10 (liquid phase)
    - Flowrate: 4 700 bbl/d (195.833 bbl/h, standard conditions)
    - Power: - 5 MBtu/h (cooling)

1.5.4.2. Objectives / Constraints

- Bottom liquid product flowrate: 7 335 bbl/d (305.625 bbl/h, standard conditions)

  Adjusted variable: reflux flowrate
- Overflash of 0.05 (standard conditions)

  Adjusted variable: stage 4 intermediate heating

  The overflash in volume is defined as the liquid volume flowrate entering the feed stage divided by the feed volume flowrate (standard conditions).
- Stage 9 liquid flowrate: 200.2 bbl/h (standard conditions)

  Adjusted variable: pumparound reboiler heat duty

1.5.4.3. Initializations

- Stage 8 sidestream liquid flowrate: 100 lbmol/h (this flowrate is adjusted by a specification of the side stripper C4).
- Stage 12 sidestream liquid flowrate: 100 lbmol/h (this flowrate is adjusted by a specification of the side stripper C5).
- Reflux flowrate: 1 000 lbmol/h
- Stage 14 intermediate reboiler heat duty: 40 MBtu/h (this heat duty is adjusted by the overflash specification)
- Head composition in molar fraction: 0.1 for the 11^{th} to the 20^{th} lightest hydrocarbons
- Bottom composition in molar fraction: 0.1 for the heaviest 10 hydrocarbons

1.5.5. Side stripper C4

1.5.5.1. Parameters

- Characteristics:
  - Absorber
  - Number of theoretical stages: 2
  - Pressure: 24 psi

1.5.5.2. Objectives / Constraints

- Bottom liquid product flowrate (Jet fuel): 3 780 bbl/d (157.5 bbl/h, standard conditions)

  Adjusted variable: feed flowrate (stream 13)

1.5.6. Side stripper C5

1.5.6.1. Parameters

- Characteristics:
  - Absorber
  - Number of theoretical stages: 2
  - Pressure: 24 psi

1.5.6.2. Objectives / Constraints

- Bottom liquid product flowrate (Diesel fuel): 3 765 bbl/d (156.875 bbl/h, standard conditions

  Adjusted variable: feed flowrate (stream 16)

1.5.7. Numerical parameters

The default numerical parameters are used for all the unit operations.

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).

Inlet streams:

Streams		1	9	10	19	20	21
From		Crude Oil	Steam 9	Steam 10	Steam 19	Steam 20	Steam 21
To		Preflash Column C1	Preflash Column C1	Side Stripper C2	Main Column C3	Side Stripper C5	Side Stripper C4
Total flow	lbmol/h	1850.8	166.5	50.0	83.3	36.1	33.3
Mole fractions		0	0	0	0	0	0
WATER		0	1	1	1	1	1
PROPANE		0.00397	0	0	0	0	0
ISOBUTANE		0.00560	0	0	0	0	0
n-BUTANE		0.01335	0	0	0	0	0
NBP-276(K)		0.03596	0	0	0	0	0
NBP-304(K)		0.01465	0	0	0	0	0
NBP-318(K)		0.01788	0	0	0	0	0
NBP-333(K)		0.04094	0	0	0	0	0
NBP-346(K)		0.05631	0	0	0	0	0
NBP-360(K)		0.06382	0	0	0	0	0
NBP-373(K)		0.06105	0	0	0	0	0
NBP-387(K)		0.05699	0	0	0	0	0
NBP-401(K)		0.05380	0	0	0	0	0
NBP-415(K)		0.04910	0	0	0	0	0
NBP-429(K)		0.04272	0	0	0	0	0
NBP-443(K)		0.03763	0	0	0	0	0
NBP-457(K)		0.03378	0	0	0	0	0
NBP-471(K)		0.03159	0	0	0	0	0
NBP-485(K)		0.03000	0	0	0	0	0
NBP-498(K)		0.02844	0	0	0	0	0
NBP-512(K)		0.02698	0	0	0	0	0
NBP-526(K)		0.02583	0	0	0	0	0
NBP-540(K)		0.02479	0	0	0	0	0
NBP-554(K)		0.02383	0	0	0	0	0
NBP-575(K)		0.04544	0	0	0	0	0
NBP-603(K)		0.04160	0	0	0	0	0
NBP-629(K)		0.02584	0	0	0	0	0
NBP-658(K)		0.01881	0	0	0	0	0
NBP-699(K)		0.03108	0	0	0	0	0
NBP-754(K)		0.02114	0	0	0	0	0
NBP-810(K)		0.01463	0	0	0	0	0
NBP-865(K)		0.00962	0	0	0	0	0
NBP-969(K)		0.01282	0	0	0	0	0
Physical state		Liquid	Vapor	Vapor	Vapor	Vapor	Vapor
Temperature	°F	300.0	314.3	313.9	300.6	300.1	300.1
Pressure	psi	54.6	55.0	54.0	25.0	24.0	24.0
Molar weight	g/mol	163.42	18.02	18.02	18.02	18.02	18.02

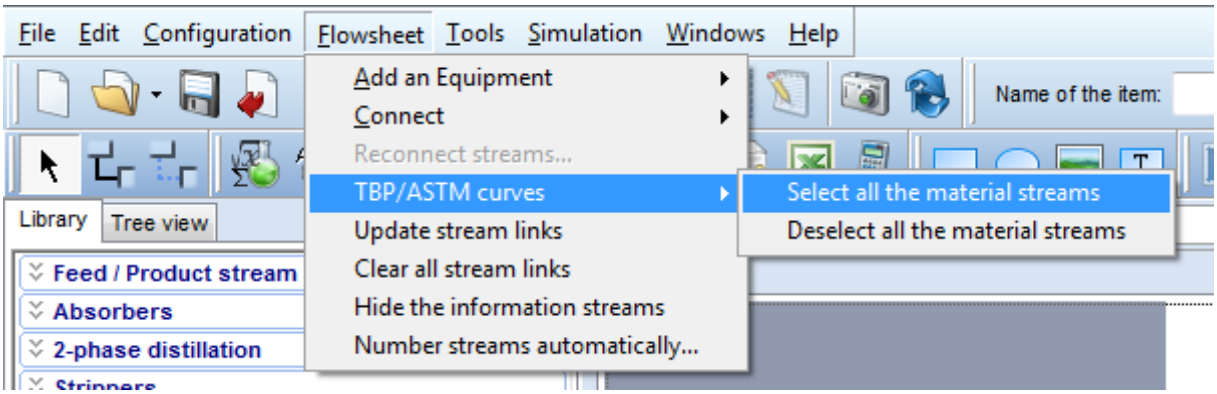
Outlet streams:

Streams		4	5	11	12	15	18	Water1	Water2
From		Preflash Column C1	Side Stripper C2	Main Column C3	Side Stripper C4	Side Stripper C5	Main Column C3	Preflash Column C1	Main Column C3
To		Gasoline	Naphtha	Heavy Naphtha	Jet fuel	Diesel fuel	Topped Crude	Water1	Water2
Total flow	lbmol/h	300.0	568.2	196.3	300.3	231.9	268.2	191.1	163.9
Mole fractions		0	0	0	0	0	0	0	0
WATER		0.00128	0.01533	0.00128	0.00589	0.00545	0.00659	1	1
PROPANE		0.02440	0.00004	0.00004	1E-09	3E-10	2E-10	0	0
ISOBUTANE		0.03398	0.00022	0.00020	2E-08	4E-09	2E-09	0	0
n-BUTANE		0.08034	0.00082	0.00071	9E-08	2E-08	7E-09	0	0
NBP-276(K)		0.21554	0.00257	0.00218	3E-07	7E-08	3E-08	0	0
NBP-304(K)		0.08339	0.00291	0.00229	1E-06	2E-07	5E-08	0	0
NBP-318(K)		0.09572	0.00610	0.00463	4E-06	5E-07	2E-07	0	0
NBP-333(K)		0.19101	0.02614	0.01838	0.00003	4E-06	1E-06	0	0
NBP-346(K)		0.18266	0.07227	0.04234	0.00013	0.00002	4E-06	0	0
NBP-360(K)		0.07692	0.14117	0.07471	0.00044	0.00005	0.00001	0	0
NBP-373(K)		0.01301	0.15560	0.10339	0.00110	0.00012	0.00003	0	0
NBP-387(K)		0.00155	0.13800	0.13130	0.00244	0.00026	0.00006	0	0
NBP-401(K)		0.00017	0.11704	0.15934	0.00524	0.00054	0.00012	0	0
NBP-415(K)		0.00002	0.09322	0.17475	0.01097	0.00103	0.00021	0	0
NBP-429(K)		0.00000	0.06887	0.16138	0.02575	0.00179	0.00036	0	0
NBP-443(K)		2E-07	0.05006	0.09774	0.07045	0.00301	0.00060	0	0
NBP-457(K)		1E-08	0.03597	0.02237	0.12076	0.00500	0.00098	0	0
NBP-471(K)		1E-09	0.02607	0.00268	0.13570	0.00836	0.00163	0	0
NBP-485(K)		1E-10	0.01847	0.00026	0.13666	0.01389	0.00266	0	0
NBP-498(K)		0	0.01246	0.00002	0.13036	0.02277	0.00421	0	0
NBP-512(K)		0	0.00788	2E-06	0.11702	0.03700	0.00648	0	0
NBP-526(K)		0	0.00461	1E-07	0.09631	0.05888	0.00973	0	0
NBP-540(K)		0	0.00243	6E-09	0.06854	0.08683	0.01413	0	0
NBP-554(K)		0	0.00113	2E-10	0.04042	0.11221	0.01981	0	0
NBP-575(K)		0	0.00057	0	0.02683	0.25482	0.06205	0	0
NBP-603(K)		0	0.00006	0	0.00444	0.21349	0.09741	0	0
NBP-629(K)		0	4E-06	0	0.00047	0.10096	0.09053	0	0
NBP-658(K)		0	2E-07	0	0.00004	0.04556	0.09037	0	0
NBP-699(K)		0	6E-09	0	2E-06	0.02576	0.19221	0	0
NBP-754(K)		0	0	0	6E-09	0.00209	0.14412	0	0
NBP-810(K)		0	0	0	0	0.00009	0.10088	0	0
NBP-865(K)		0	0	0	0	3E-06	0.06639	0	0
NBP-969(K)		0	0	0	0	1E-08	0.08846	0	0
Physical state		Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid
Temperature	°F	100.0	268.7	100.0	382.3	509.4	601.3	100.0	100.0
Pressure	psi	48.0	54.0	20.0	24.0	24.0	25.0	48.0	20.0
Molar weight	g/mol	73.88	107.82	110.97	156.96	212.48	376.96	18.02	18.02

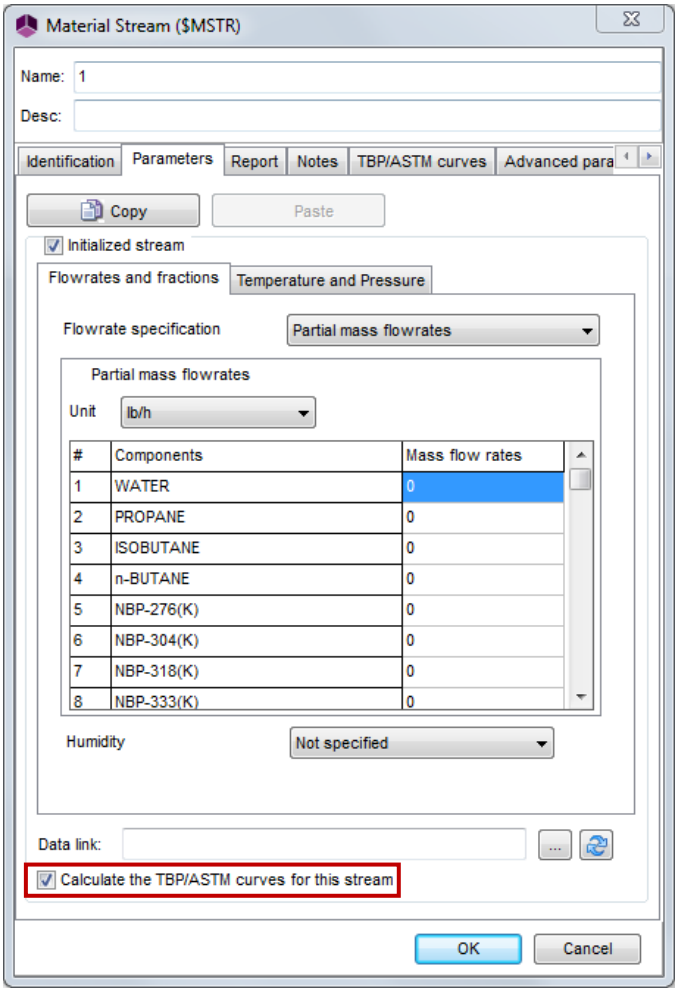
2.2. Process Performances

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:

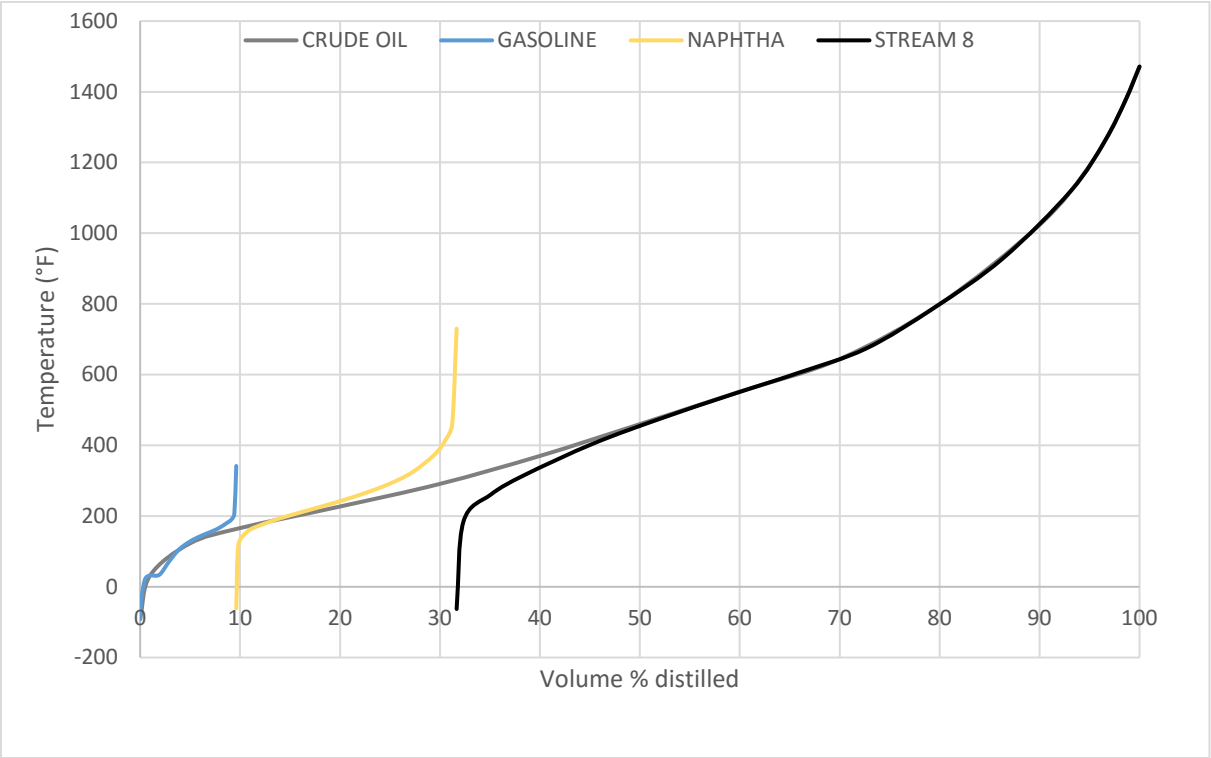


- Tick the “Calculate the TBP/ASTM curves for this stream” box in the configuration window of the material stream which TBP/ASTM curves have to be plotted during the next simulation as illustrated below:

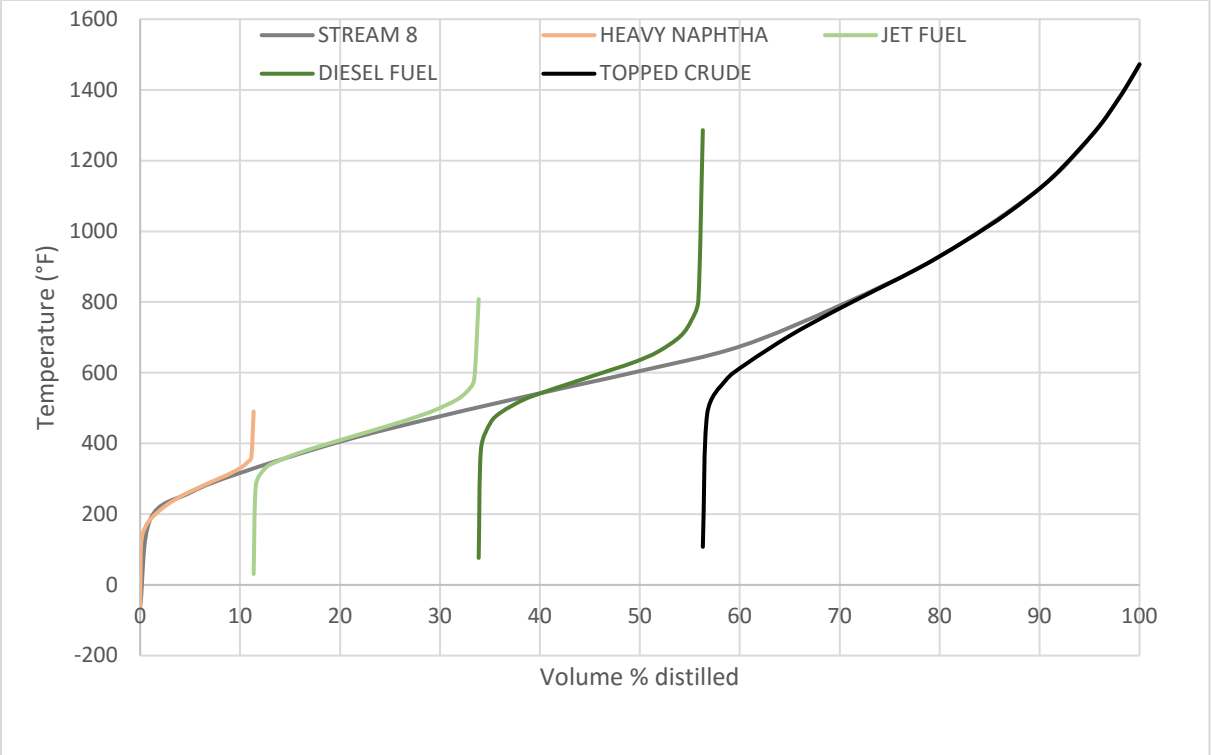


To reach this option the “Initialized stream” box has to be ticked and then unticked once the “Calculate the TBP/ASTM curves for this stream” box has been ticked.

The following figure shows on a same graph the TBP at 760 mmHg curve of the crude oil entering the preflash C1 column and the ones of the cuts obtained at the outlet of this column:

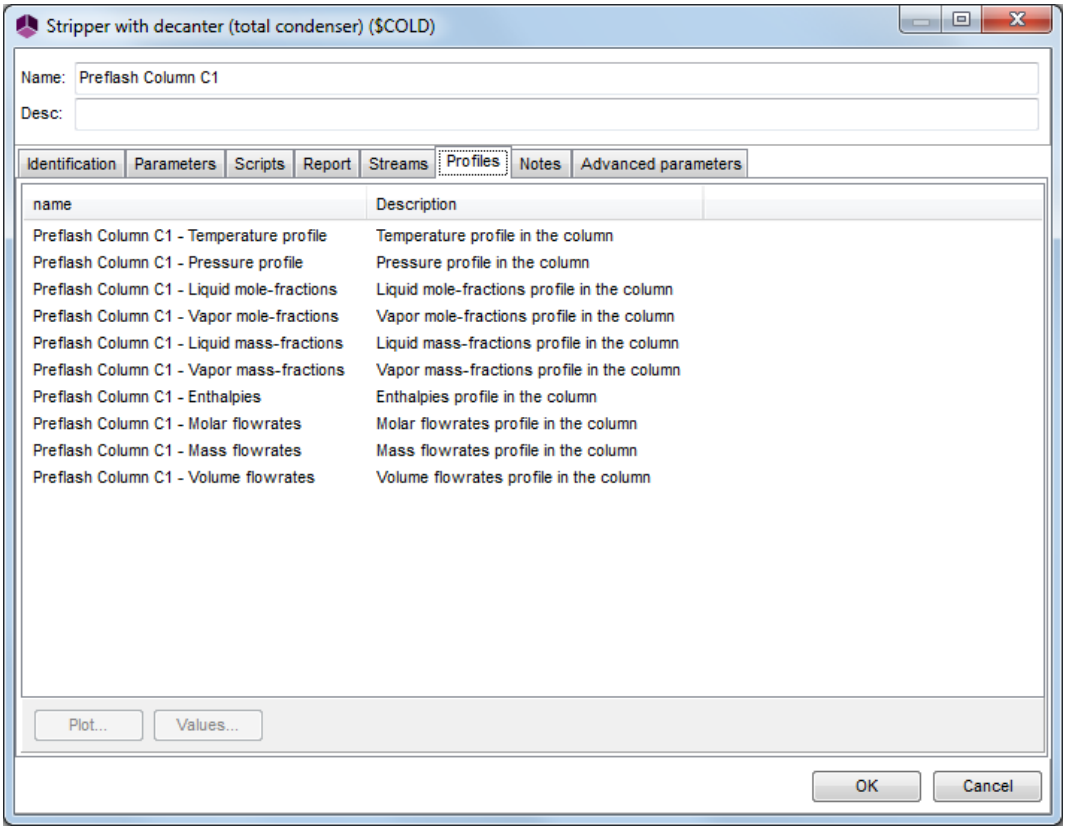


The following figure shows on a same graph the TBP at 760 mmHg curve of the stream 8 entering the main column C3 and the ones of the cuts obtained at the outlet of this column:

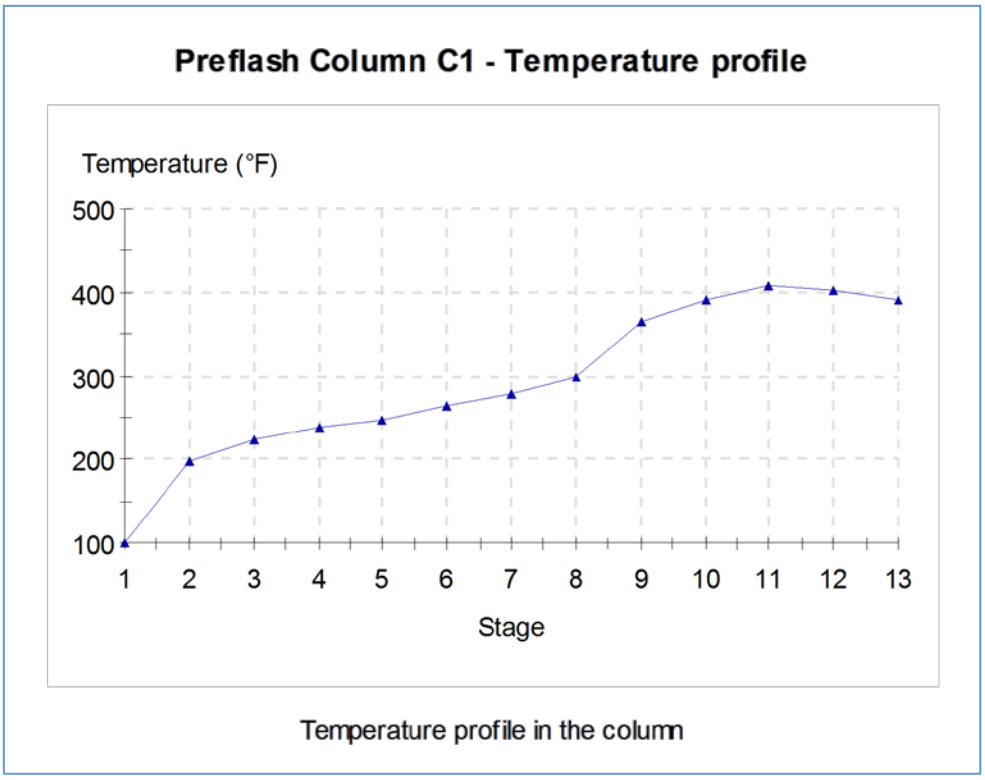


2.3. Column profiles

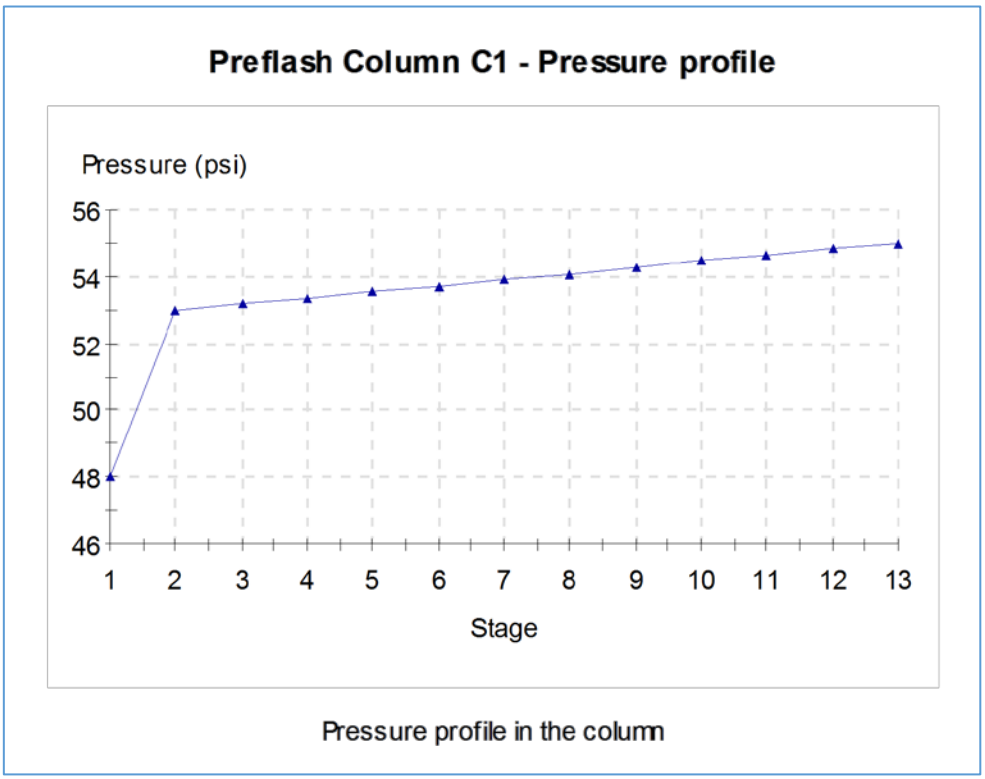
Profiles can be accessed after the simulation in each column configuration window, in the “Profiles” tab. Double clicking on the profile will generate the corresponding graph. It is important to note that, in ProSimPlus, the first stage corresponds to the top stage and the last stage to the bottom stage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



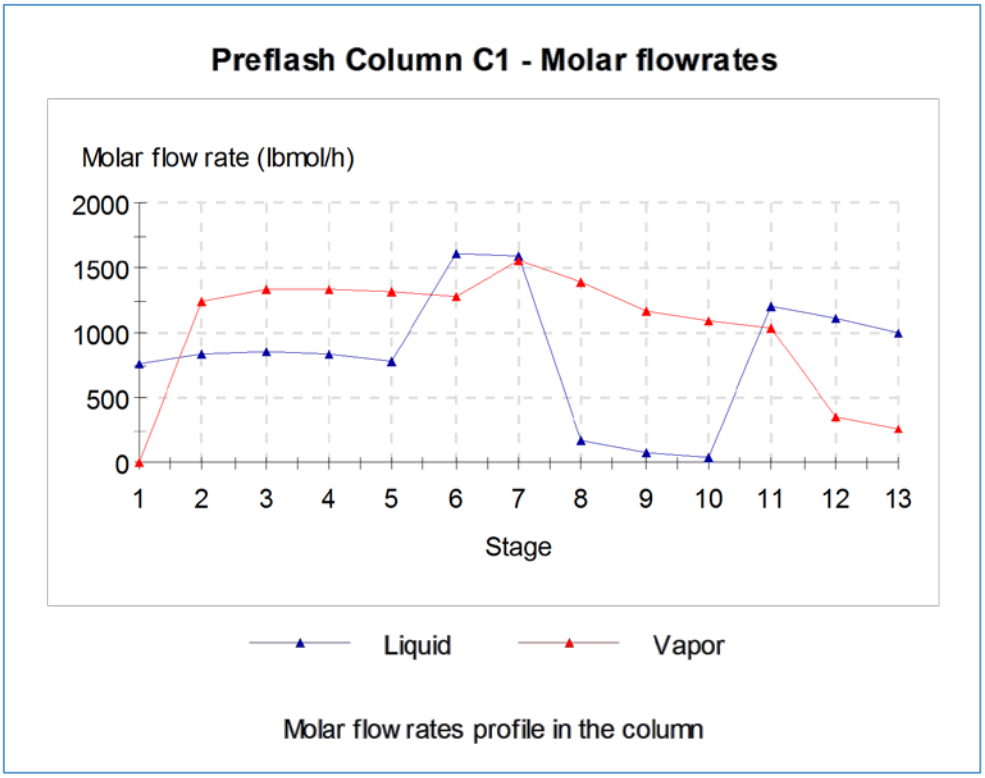
Preflash column C1:



Temperature profile in the column

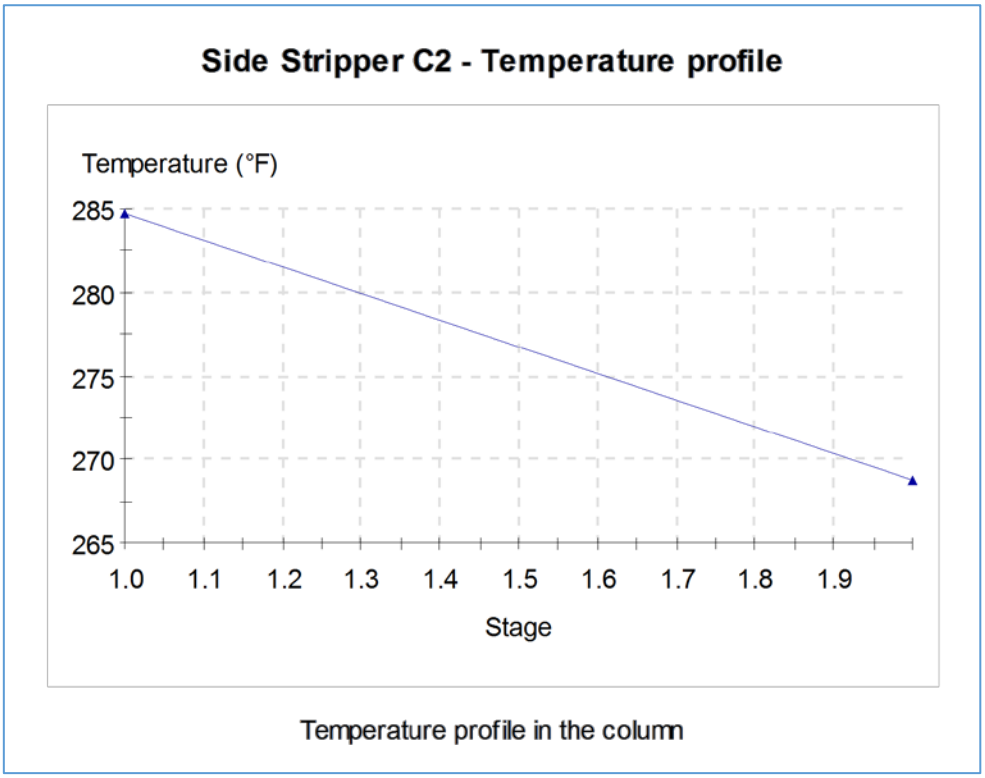


Pressure profile in the column

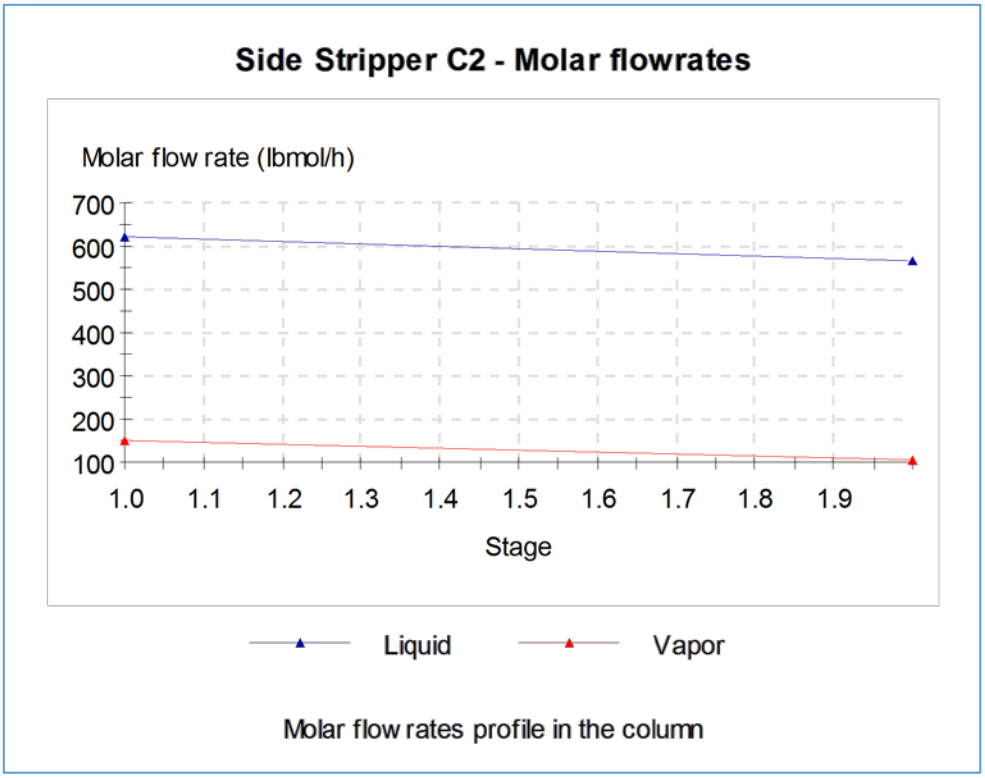


Molar flow rates profile in the column

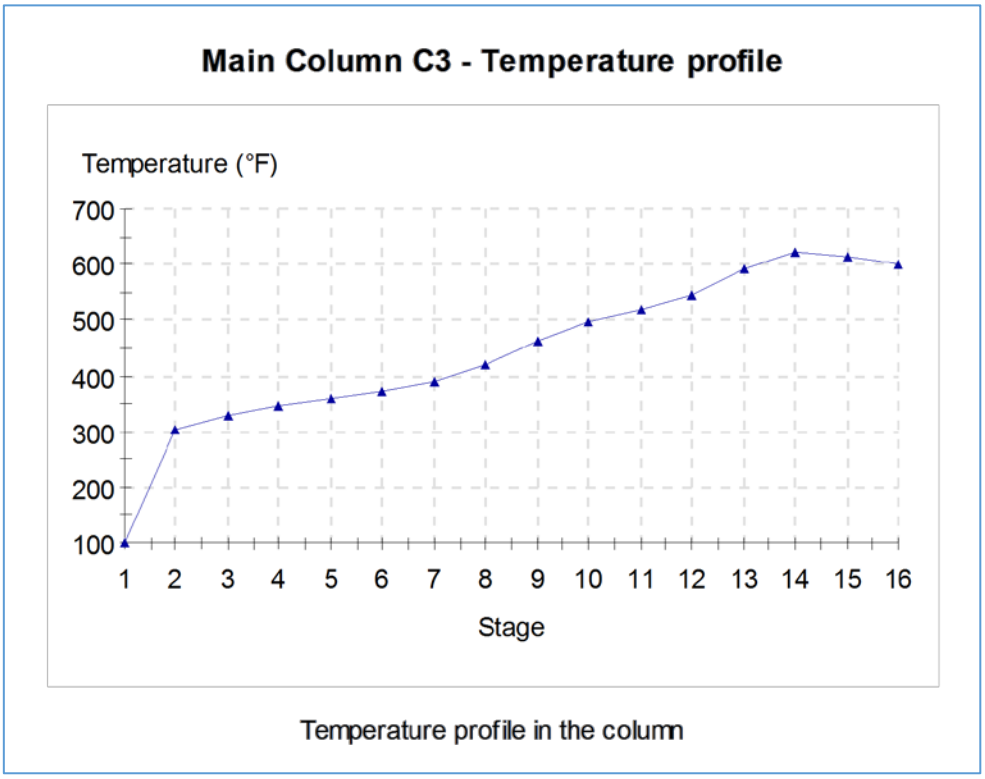
Side stripper C2:

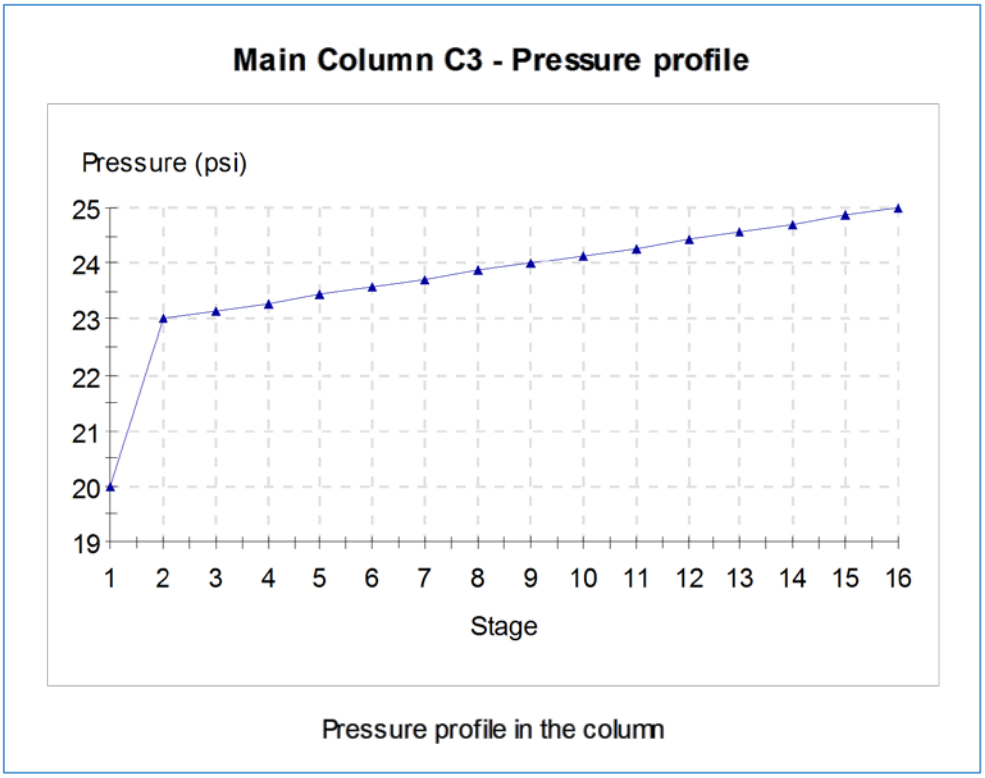


Temperature profile in the column

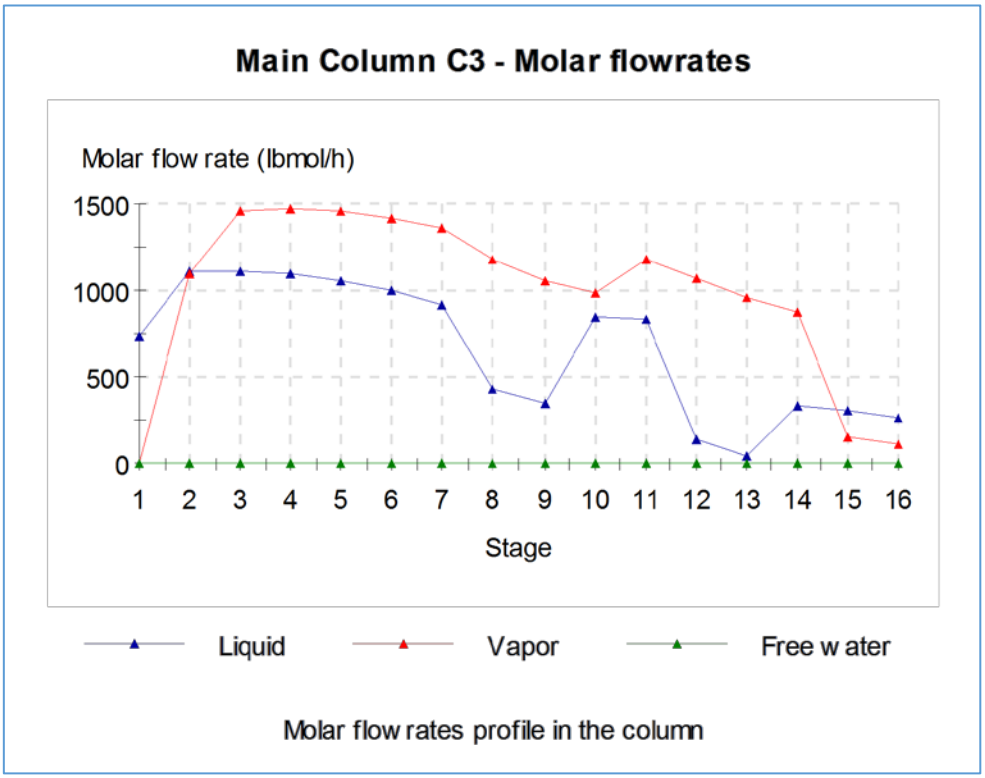


Main column C3:



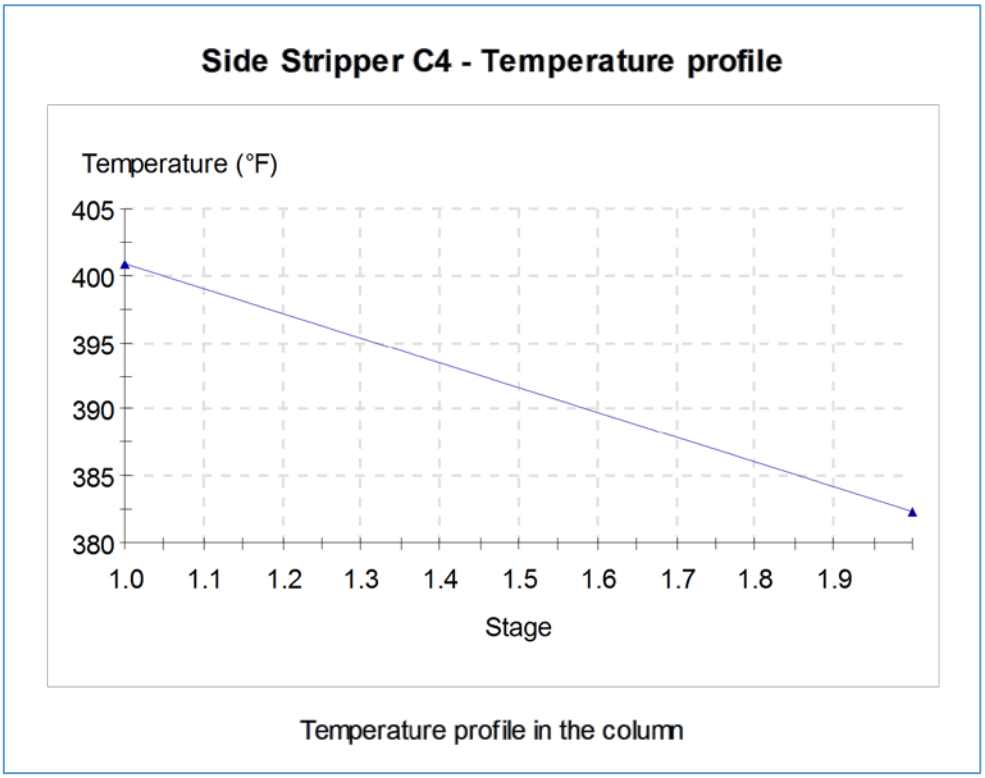


Pressure profile in the column

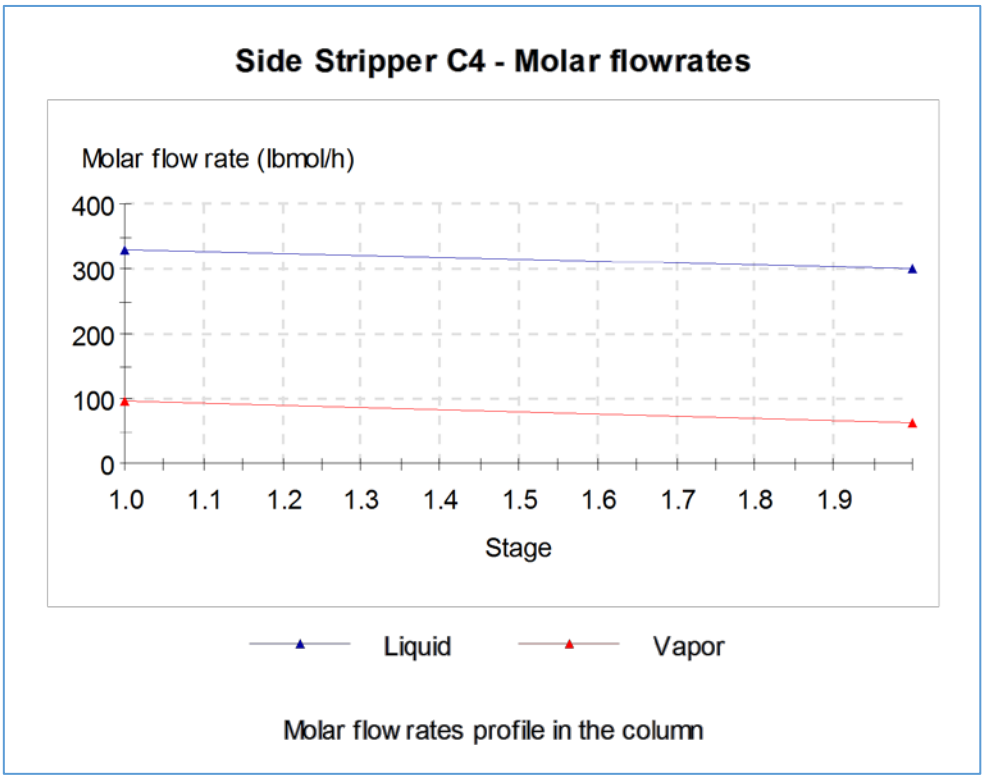


Molar flow rates profile in the column

Side stripper C4:

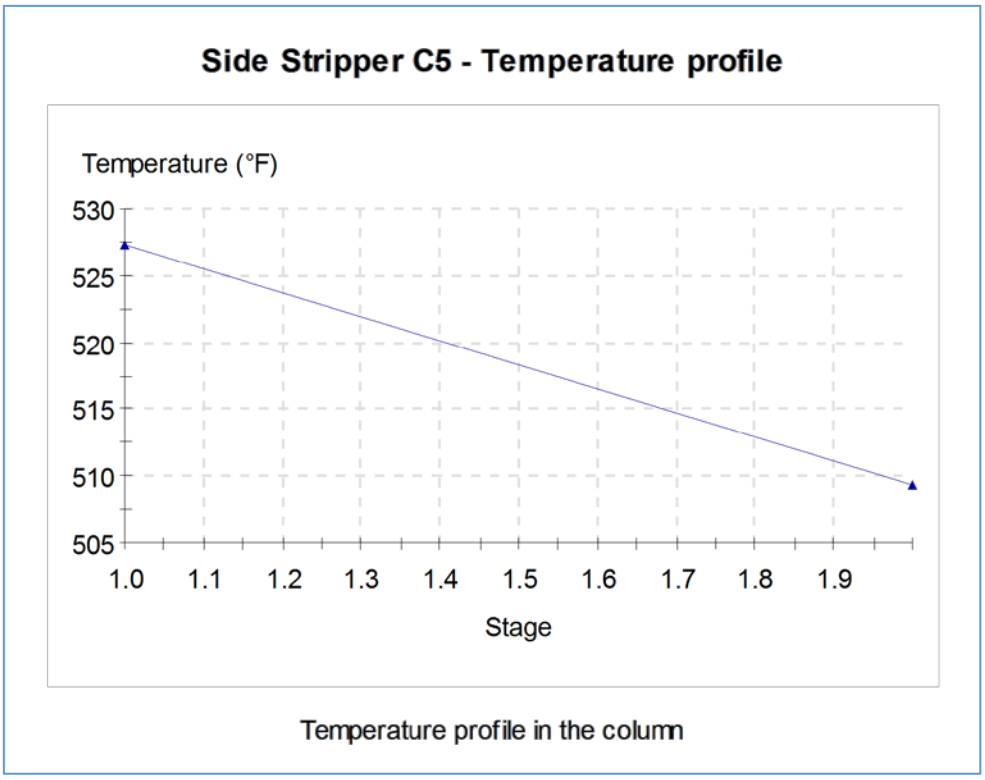


Temperature profile in the column

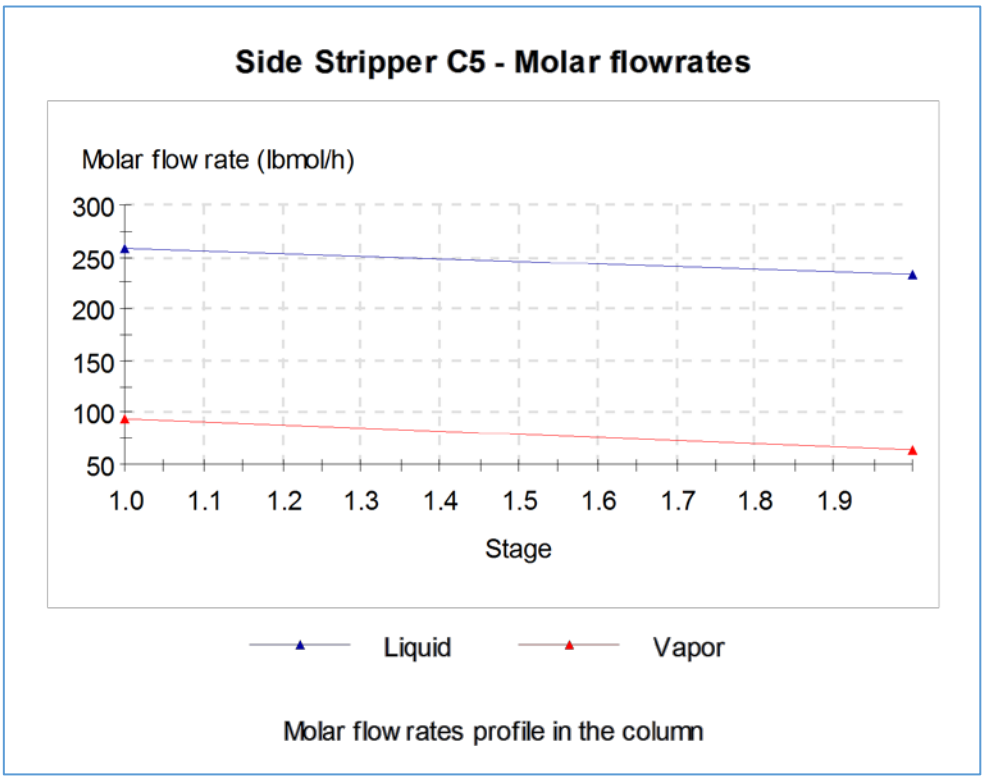


Molar flow rates profile in the column

Side stripper C5:



Temperature profile in the column



Molar flow rates profile in the column

REFERENCES

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

