PROSIMPLUS APPLICATION EXAMPLE

SIMULATION OF AN ATMOSPHERIC DISTILLATION UNIT

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

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CORRESPONDING PROSIMPLUS FILE	*PSPS_EX_EN-Atmospheric-Distillation.pmp3*

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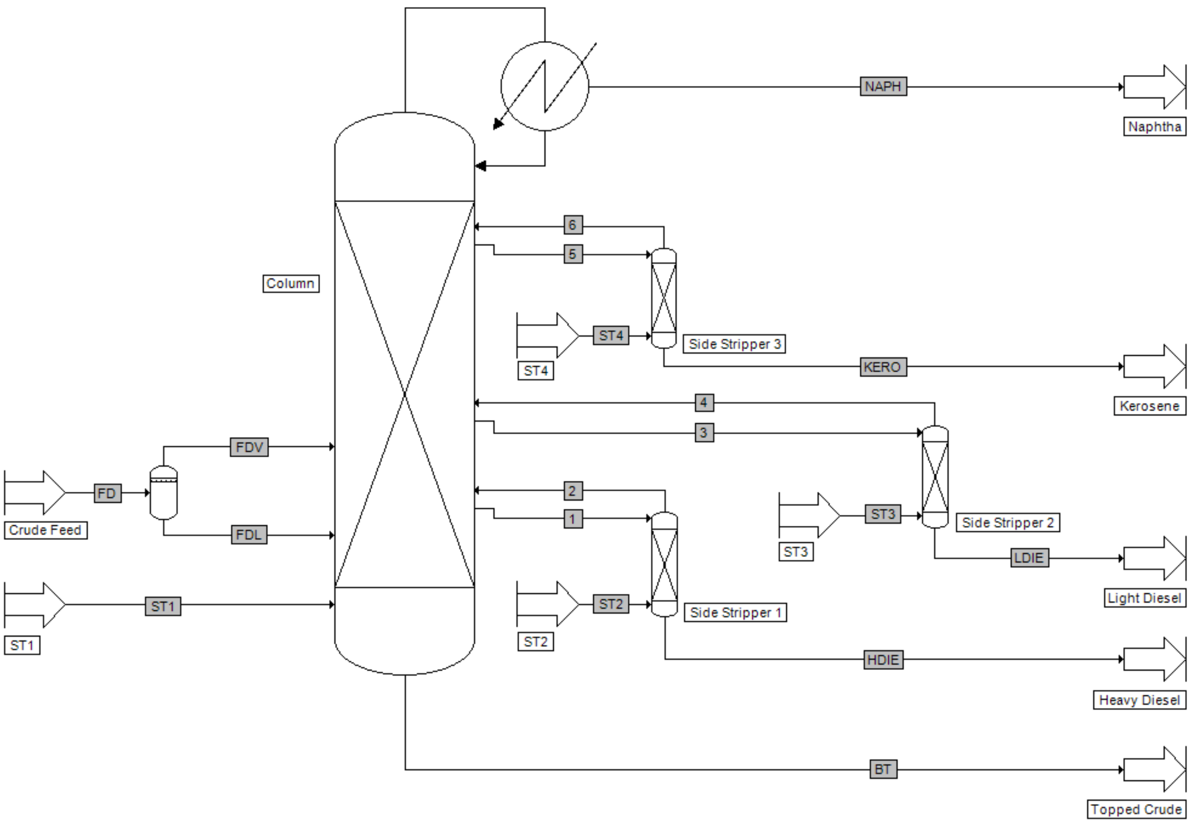
1. PROCESS MODELING

1.1. Process presentation

The distillation system consists of a main column coupled with 3 side strippers. This main column is a stripper with a partial condenser.

The input data of this problem is available in [SIM84].

1.2. Process flowsheet

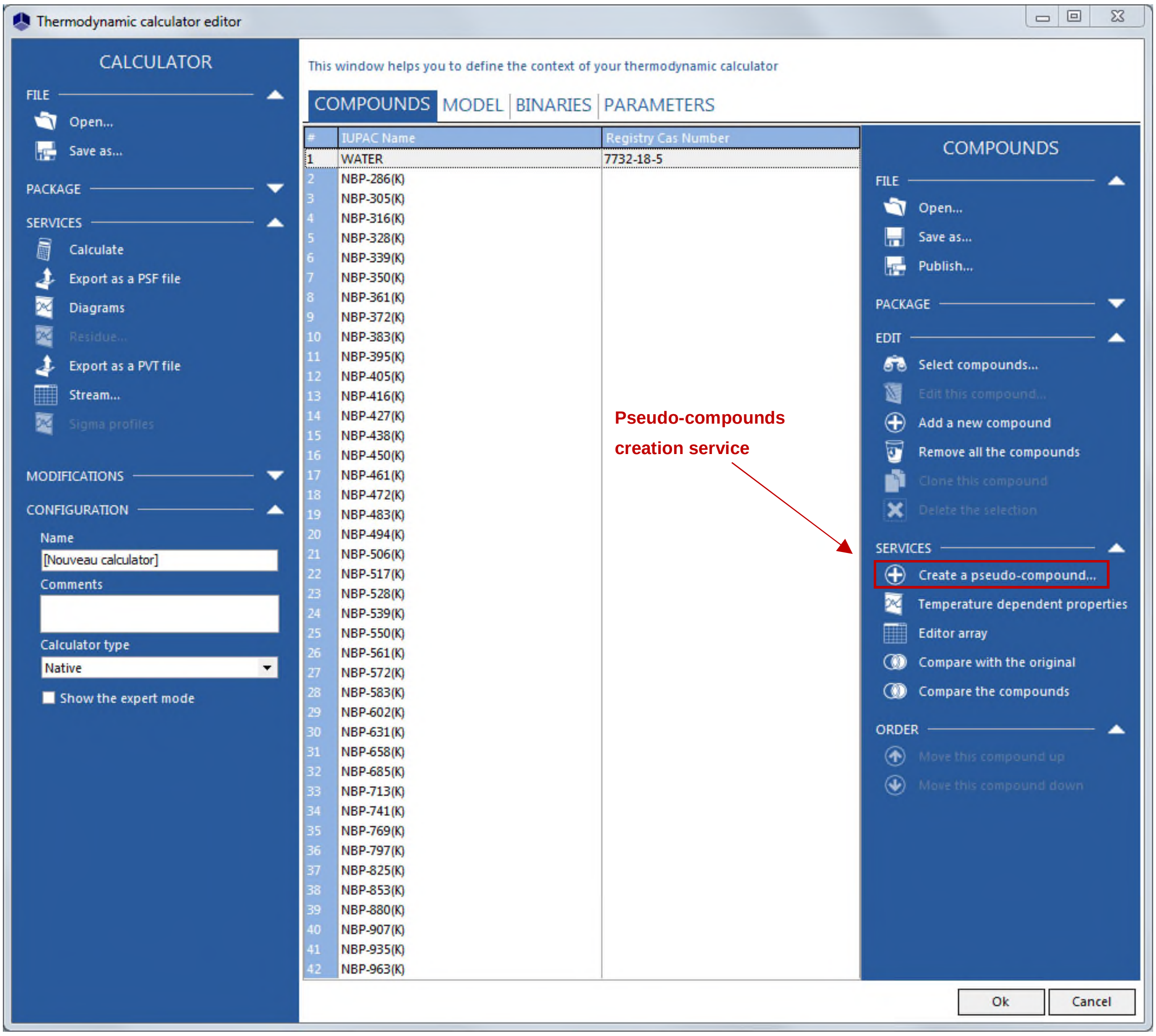


1.3. Compounds

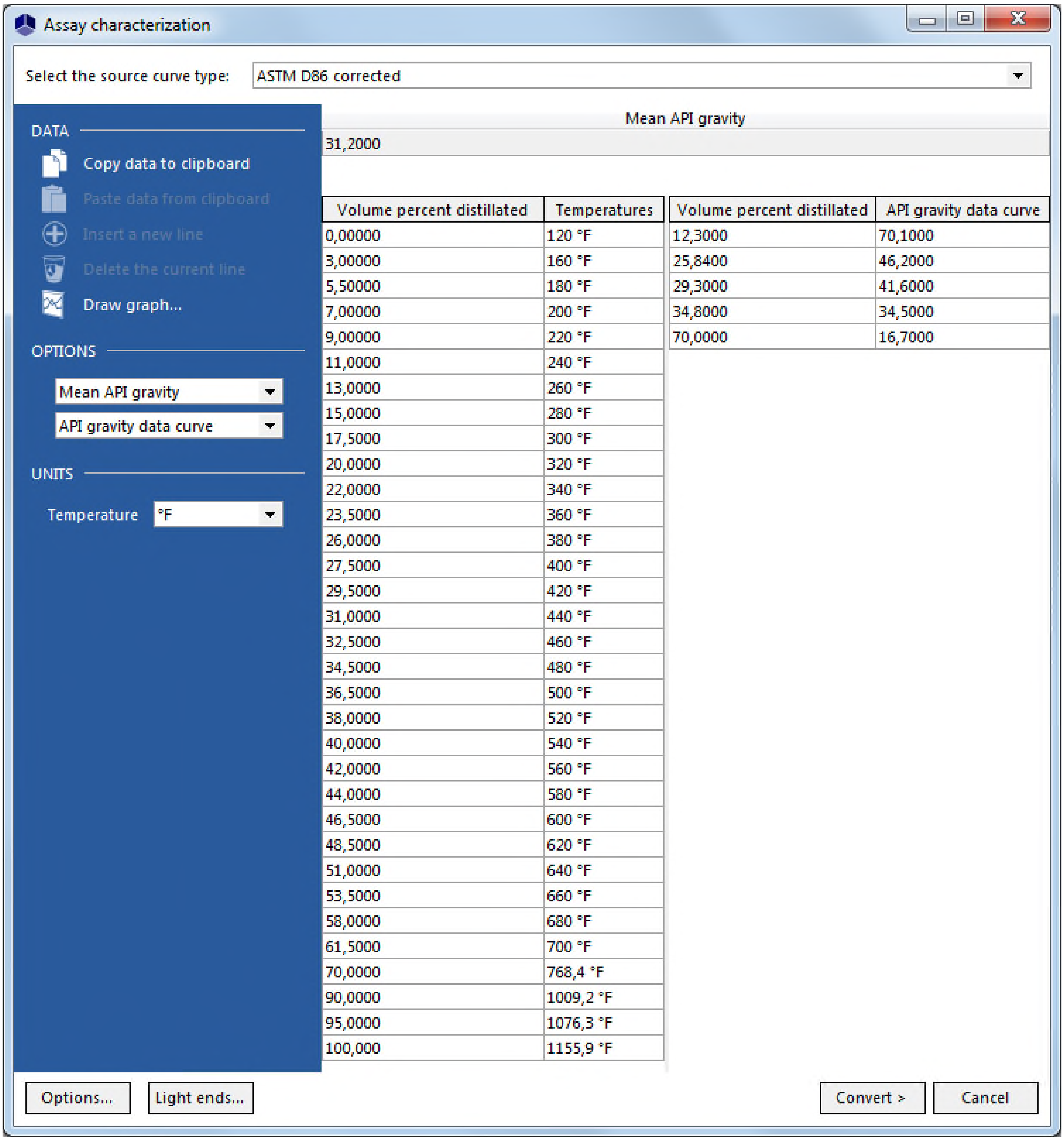
The crude oil to be processed is made of 41 pseudo-compounds. Water is also present in this process. The pseudo-compounds are generated with the following crude oil properties:

- the corrected ASTM D86,
- the mean API gravity,
- the API gravity curve.

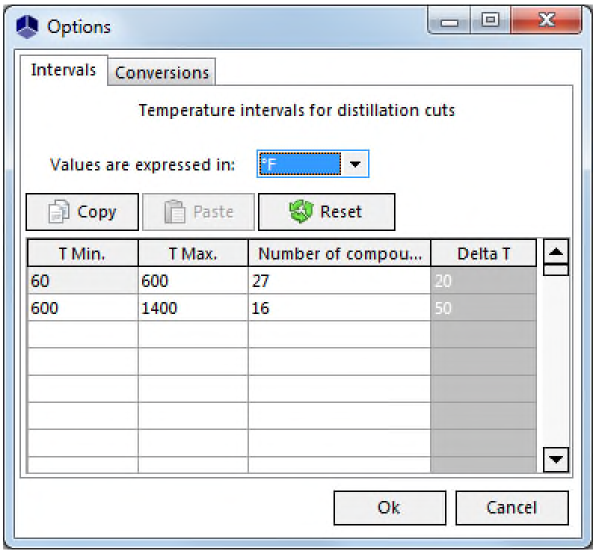
The pseudo-compounds creation service is available in the thermodynamic calculator editor as illustrated below.

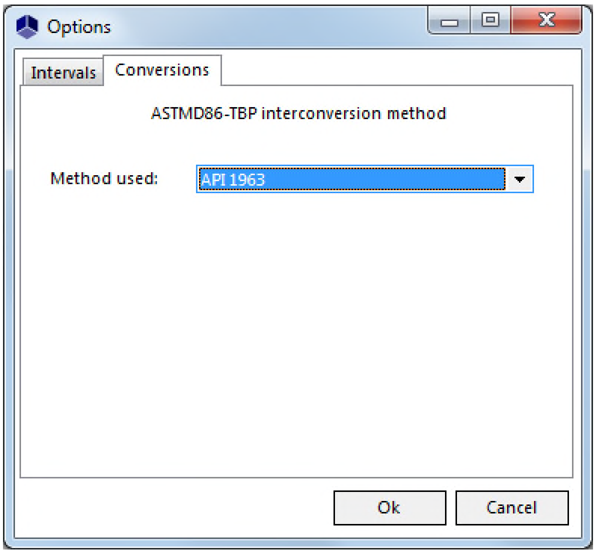


The required data are provided on the following screen shot:



The distillation curve is cut as follows (API 1963 conversion method): 27 compounds between 60 °F and 600 °F, and 16 compounds between 600 °F and 1400 °F.





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 87 890 bbl/d (3662.08 bbl/h) of crude oil (standard conditions). The crude oil at the column feed conditions is vapor/liquid (T = 617 °F; P = 25 psi), the corresponding molar flowrate is 5 360.5 lbmol/h.

The vapor flowrates feeding the column and the side strippers are the following ones:

- Stream "ST1": 4 870 lb/h (T = 792 °F ; P = 77.3 psi)
- Stream "ST2": 558 lb/h (T = 792 °F ; P = 77.3 psi)
- Stream "ST3": 540 lb/h (T = 792 °F ; P = 77.3 psi)
- Stream "ST4": 550 lb/h (T = 792 °F ; P = 77.3 psi)

1.5.2. Main Column

1.5.2.1. Parameters

- Characteristics:
    - Stripper with partial condenser
    - Number of theoretical stages: 19
    - Operating mode specifications: reflux flowrate
    - Reflux flowrate: 0 lbmol/h
    - Liquid distillate flowrate: 0 lbmol/h
    - Pressure profile: 28.7 psi at the condenser, 28.7 psi at stage 2, 32.7 at stage 17 and 33 psi at the bottom
- Feeds:
    - Stream "FDV" at stage 17 (vapor fraction of the feed flashed at the stage 18 pressure: 32.85 psi)

    - Stream "FDL" at stage 18 (liquid fraction of the flashed feed)
    - Stream 2 at stage 15 (head stream of the side stripper 1)
    - Stream 4 at stage 12 (head stream of the side stripper 2)
    - Stream 6 at stage 7 (head stream of the side stripper 3)
- Side stream:
    - Stream 1 at stage 16 (stream feeding the side stripper 1)
    - Stream 3 at stage 13 (stream feeding the side stripper 2)
    - Stream 5 at stage 8 (stream feeding the side stripper 3)
- Pumparound 1:
    - From stage 4 to stage 2 (liquid phase)
    - Flowrate: 4 019.4 bbl/h
    - Duty : - 80 MBtu/h (cooling, initial value)
- Pumparound 2:
    - From stage 10 to stage 9 (liquid phase)
    - Flowrate: 2 728.2 bbl/h
    - Duty: - 7 MBtu/h (cooling)
- Pumparound 3:
    - From stage 15 to stage 14 (liquid phase)
    - Flowrate: 1 037.8 bbl/h
    - Duty: - 8.7 MBtu/h (cooling)

1.5.2.2. Objectives

- Bottom liquid product flowrate: 52 696 bbl/d (2195.7 bbl/h, standard conditions)

  Adjusted variable: pumparound 1 duty

1.5.2.3. Initialization

- Liquid sidestream flowrate at stage 8: 100 lbmol/h (this flowrate is adjusted by a specification on the side stripper 3).
- Liquid sidestream flowrate at stage 13: 100 lbmol/h (this flowrate is adjusted by a specification on the side stripper 2).

- Liquid sidestream flowrate at stage 16: 100 lbmol/h (this flowrate is adjusted by a specification on the side stripper 1).
- Pumparound 1 reboiler duty: - 80 MBtu/h (cooling)

1.5.3. Side stripper 1

1.5.3.1. Parameters

- Characteristics:
  - Absorber
  - Number of theoretical stages: 2
  - Pressure: 32.3 psi at the head, pressure loss in the remaining part of the column: 0.2 psi

1.5.3.2. Objectives

- Bottom liquid product flowrate ("HDIE"): 5 751 bbl/d (239.625 bbl/h, standard conditions

  Adjusted variable: feed flowrate (stream 1)

1.5.4. Side-stripper 2

1.5.4.1. Parameters

- Characteristics:
  - Absorber
  - Number of theoretical stages: 2
  - Pressure: 31.4 psi at the head, pressure loss in the remaining part of the column: 0.2 psi

1.5.4.2. Objectives

- Bottom liquid product flowrate ("LDIE"): 5 756 bbl/d (239.83 bbl/h, standard conditions)

  Adjusted variable: feed flowrate (stream 3)

1.5.5. Side-stripper 3

1.5.5.1. Parameters

- Characteristics:
    - Absorber
    - Number of theoretical stages: 2
    - Pressure: 30 psi at the head, pressure loss in the remaining part of the column: 0.2 psi

1.5.5.2. Objectives

- Bottom liquid product flowrate ("KERO"): 2 005 bbl/d (83.54 bbl/h, standard conditions)

  Adjusted variable: feed flowrate (stream 5)

1.5.6. 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		FD	ST1	ST2	ST3	ST4
From		Crude Feed	ST1	ST2	ST3	ST4
To		Flash	Column	Side Stripper 1	Side Stripper 2	Side Stripper 3
Total flow	lbmol/h	5306.5	270.3	31.0	30.0	30.5
Mole fractions						
WATER		0	1	1	1	1
NBP-286(K)		0.07262	0	0	0	0
NBP-305(K)		0.04447	0	0	0	0
NBP-316(K)		0.02341	0	0	0	0
NBP-328(K)		0.02360	0	0	0	0
NBP-339(K)		0.02328	0	0	0	0
NBP-350(K)		0.01796	0	0	0	0
NBP-361(K)		0.01977	0	0	0	0
NBP-372(K)		0.02518	0	0	0	0
NBP-383(K)		0.02519	0	0	0	0
NBP-395(K)		0.03198	0	0	0	0
NBP-405(K)		0.03823	0	0	0	0
NBP-416(K)		0.03460	0	0	0	0
NBP-427(K)		0.02629	0	0	0	0
NBP-438(K)		0.03465	0	0	0	0
NBP-450(K)		0.01641	0	0	0	0
NBP-461(K)		0.01538	0	0	0	0
NBP-472(K)		0.01356	0	0	0	0
NBP-483(K)		0.01024	0	0	0	0
NBP-494(K)		0.01093	0	0	0	0
NBP-506(K)		0.01354	0	0	0	0
NBP-517(K)		0.01825	0	0	0	0
NBP-528(K)		0.02016	0	0	0	0
NBP-539(K)		0.01641	0	0	0	0
NBP-550(K)		0.02296	0	0	0	0
NBP-561(K)		0.02279	0	0	0	0
NBP-572(K)		0.02187	0	0	0	0
NBP-583(K)		0.02019	0	0	0	0
NBP-602(K)		0.03245	0	0	0	0
NBP-631(K)		0.04841	0	0	0	0
NBP-658(K)		0.07300	0	0	0	0
NBP-685(K)		0.03980	0	0	0	0
NBP-713(K)		0.02569	0	0	0	0
NBP-741(K)		0.02184	0	0	0	0
NBP-769(K)		0.01910	0	0	0	0
NBP-797(K)		0.01708	0	0	0	0
NBP-825(K)		0.01560	0	0	0	0
NBP-853(K)		0.01443	0	0	0	0
NBP-880(K)		0.01266	0	0	0	0
NBP-907(K)		0.00743	0	0	0	0
NBP-935(K)		0.00479	0	0	0	0
NBP-963(K)		0.00382	0	0	0	0
Physical state		Liq./Vap.	Vapor	Vapor	Vapor	Vapor
Temperature	°F	617.00	792.0	792.0	792.0	792.0
Pressure	psi	25.00	77.3	77.3	77.3	77.3
Molar weight	g/mol	209.79	18.0	18.0	18.0	18.0

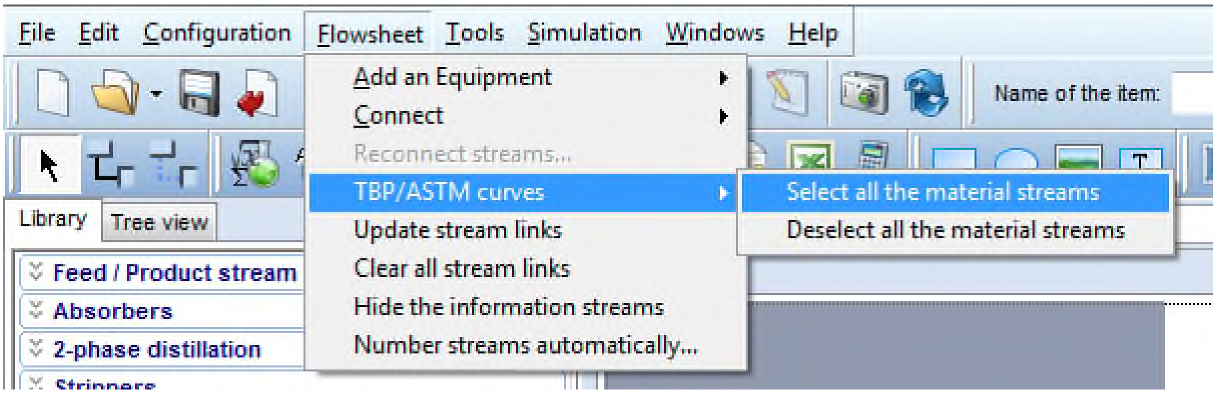
Outlet streams:

Streams		BT	HDIE	KERO	LDIE	NAPH
From		Column	Side Stripper 1	Side Stripper 3	Side Stripper 2	Column
To		Topped Crude	Heavy Diesel	Kerosene	Light Diesel	Naphtha
Total flow	lbmol/h	1852.9	347.9	145.8	390.1	2931.6
Mole fractions						
WATER		0.00796	0.00701	0.00817	0.00646	0.11629
NBP-286(K)		0.00008	0.00008	0.00007	0.00014	0.13137
NBP-305(K)		0.00008	0.00009	0.00009	0.00016	0.08041
NBP-316(K)		0.00005	0.00007	0.00007	0.00012	0.04230
NBP-328(K)		0.00007	0.00009	0.00012	0.00018	0.04263
NBP-339(K)		0.00010	0.00013	0.00018	0.00025	0.04202
NBP-350(K)		0.00010	0.00014	0.00022	0.00028	0.03238
NBP-361(K)		0.00015	0.00022	0.00038	0.00045	0.03558
NBP-372(K)		0.00026	0.00039	0.00076	0.00082	0.04522
NBP-383(K)		0.00036	0.00056	0.00121	0.00118	0.04507
NBP-395(K)		0.00065	0.00104	0.00246	0.00218	0.05695
NBP-405(K)		0.00106	0.00177	0.00459	0.00370	0.06759
NBP-416(K)		0.00132	0.00228	0.00647	0.00473	0.06057
NBP-427(K)		0.00135	0.00241	0.00761	0.00497	0.04540
NBP-438(K)		0.00236	0.00431	0.01549	0.00886	0.05876
NBP-450(K)		0.00150	0.00279	0.01232	0.00577	0.02705
NBP-461(K)		0.00185	0.00347	0.02085	0.00733	0.02425
NBP-472(K)		0.00212	0.00401	0.03691	0.00884	0.01972
NBP-483(K)		0.00208	0.00396	0.06136	0.00983	0.01239
NBP-494(K)		0.00285	0.00558	0.12947	0.01821	0.00846
NBP-506(K)		0.00449	0.00943	0.21427	0.04389	0.00405
NBP-517(K)		0.00754	0.01796	0.23812	0.09775	0.00129
NBP-528(K)		0.01028	0.02875	0.14948	0.14219	0.00022
NBP-539(K)		0.01033	0.03358	0.05188	0.12467	0.00002
NBP-550(K)		0.01758	0.06413	0.02636	0.16179	0.00000
NBP-561(K)		0.02106	0.08256	0.00825	0.13328	0.00000
NBP-572(K)		0.02414	0.09606	0.00223	0.09637	0.00000
NBP-583(K)		0.02622	0.09952	0.00052	0.06111	0.00000
NBP-602(K)		0.05388	0.16212	0.00006	0.04089	0E+00
NBP-631(K)		0.10407	0.17184	0.00000	0.01089	0E+00
NBP-658(K)		0.18096	0.14682	0.00000	0.00256	0
NBP-685(K)		0.10721	0.03585	0E+00	0.00016	0
NBP-713(K)		0.07210	0.00784	0	0.00001	0
NBP-741(K)		0.06216	0.00202	0	0.00000	0
NBP-769(K)		0.05460	0.00053	0	4E-08	0
NBP-797(K)		0.04889	0.00017	0	6E-09	0
NBP-825(K)		0.04467	0.00010	0	4E-09	0
NBP-853(K)		0.04130	0.00013	0	3E-08	0
NBP-880(K)		0.03621	0.00018	0	0.00000	0
NBP-907(K)		0.02128	0.00001	0	2E-09	0
NBP-935(K)		0.01373	1E-07	0	0	0
NBP-963(K)		0.01095	9E-10	0	0	0
Physical state		Liquid	Liquid	Liquid	Liquid	Vapor
Temperature	°F	611.5	552.4	415.6	487.7	319.5
Pressure	psi	33.0	32.5	30.2	31.6	28.7
Molar weight	g/mol	365.6	221.3	168.5	188.0	91.2

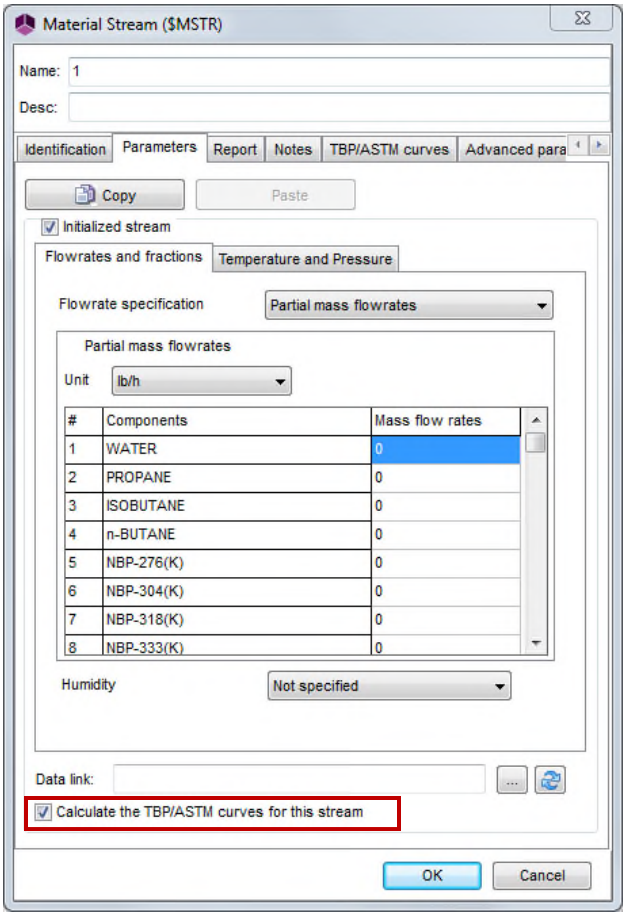
2.2. Process Performances

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:

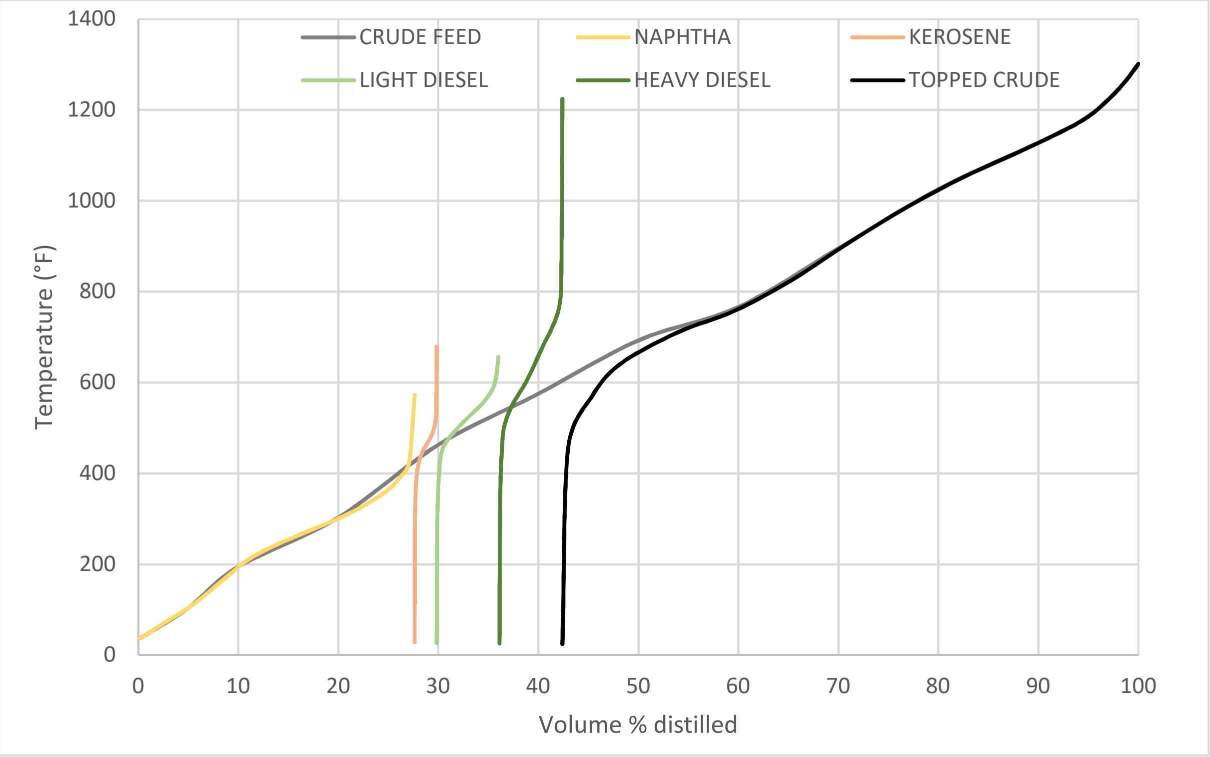


- Tick the “Calculate the TBP/ASTM curves for this stream” box in the configuration window of the material stream which TBP/ASTM curves have to be plotted during the next simulation as illustrated below:



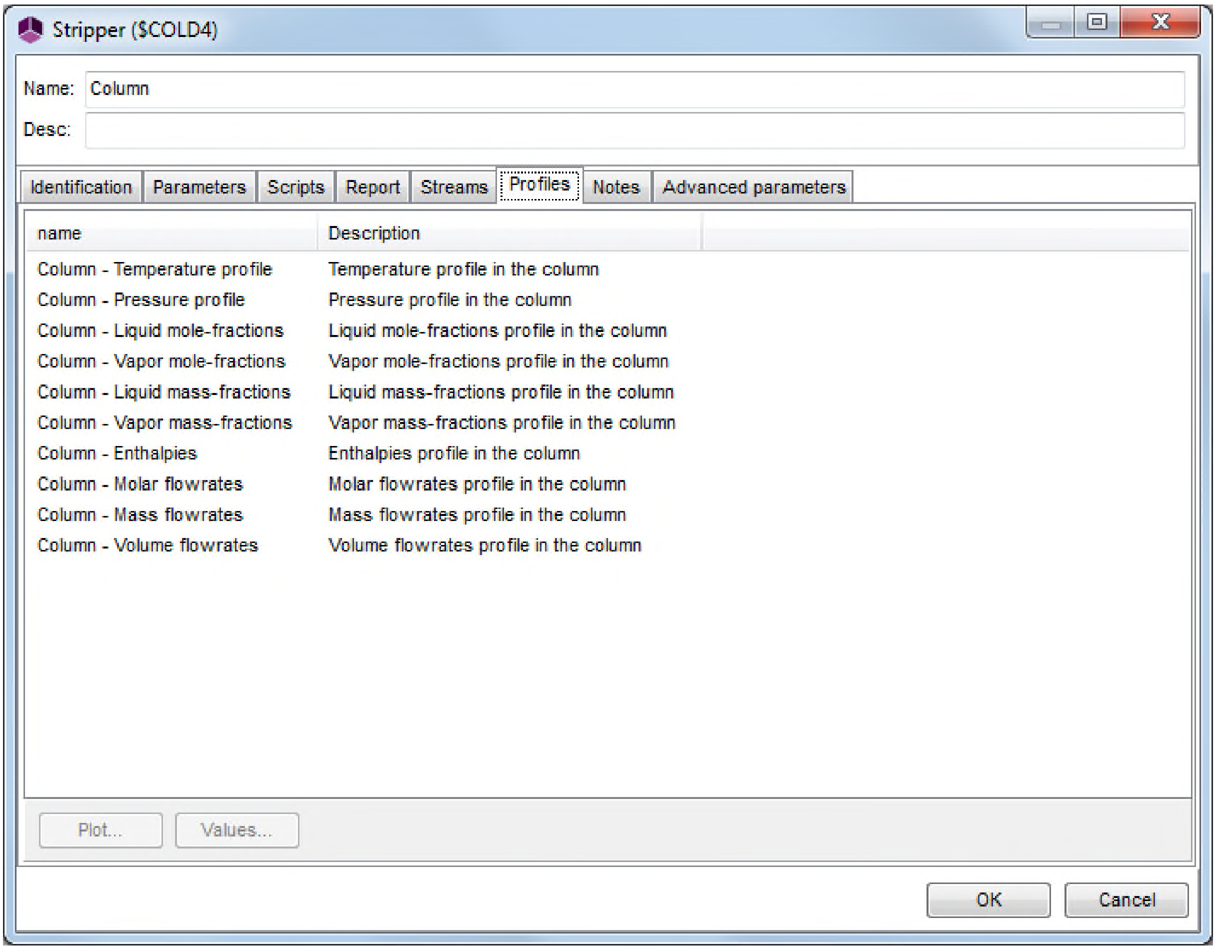
To reach this option the "Initialized stream" box has to be ticked and then unticked once the "Calculate the TBP/ASTM curves for this stream" box has been ticked.

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

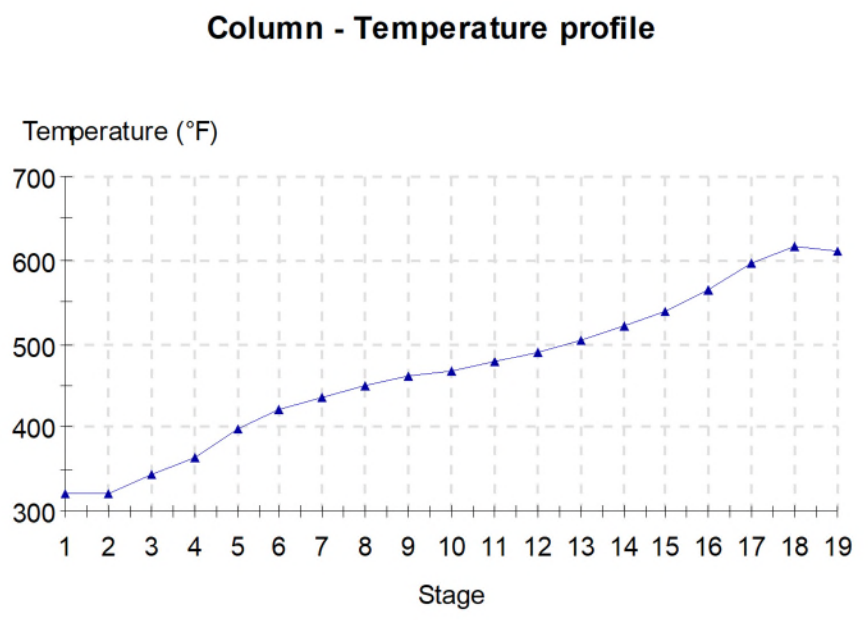


2.3. Column profiles

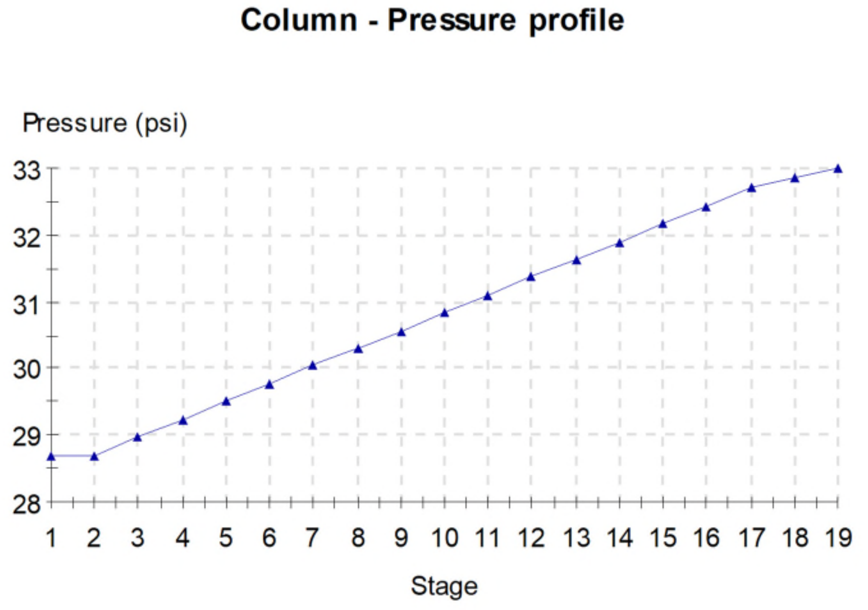
Profiles can be accessed after the simulation in each column configuration window, in the "Profiles" tab. Double clicking on the profile will generate the corresponding graph. It is important to note that, in ProSimPlus, the first stage corresponds to the top stage and the last stage to the bottom stage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



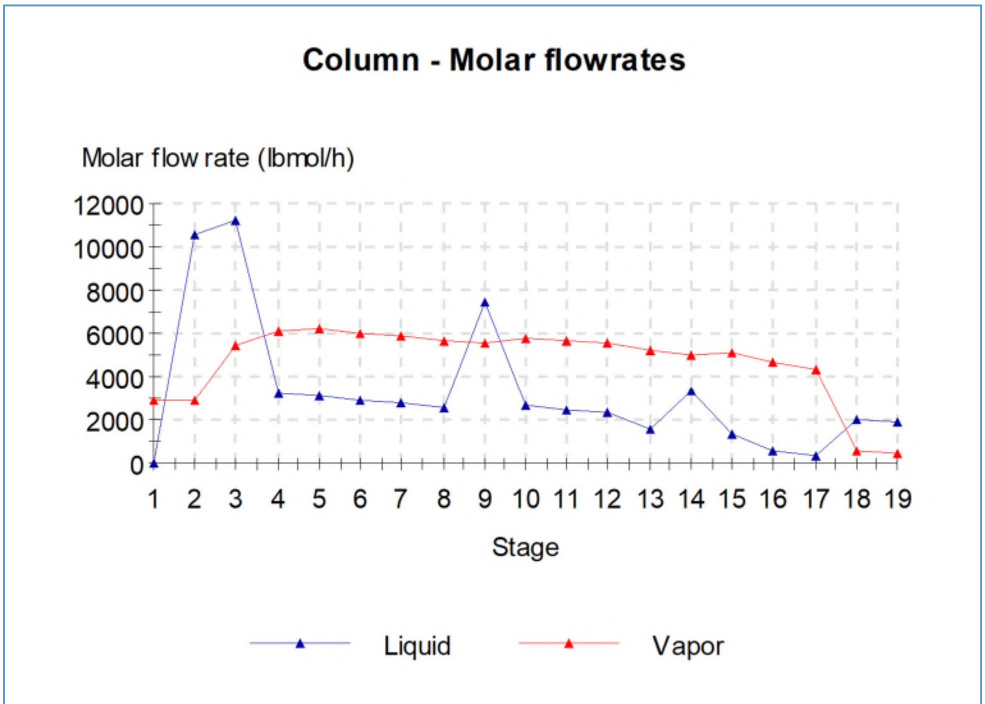
Column:



Temperature profile in the column

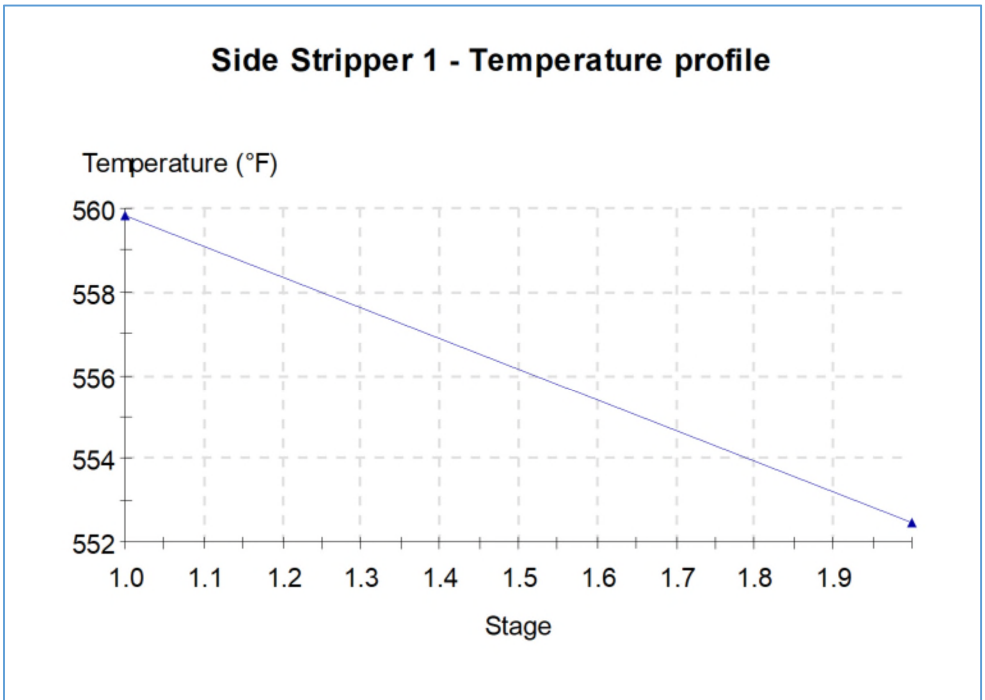


Pressure profile in the column

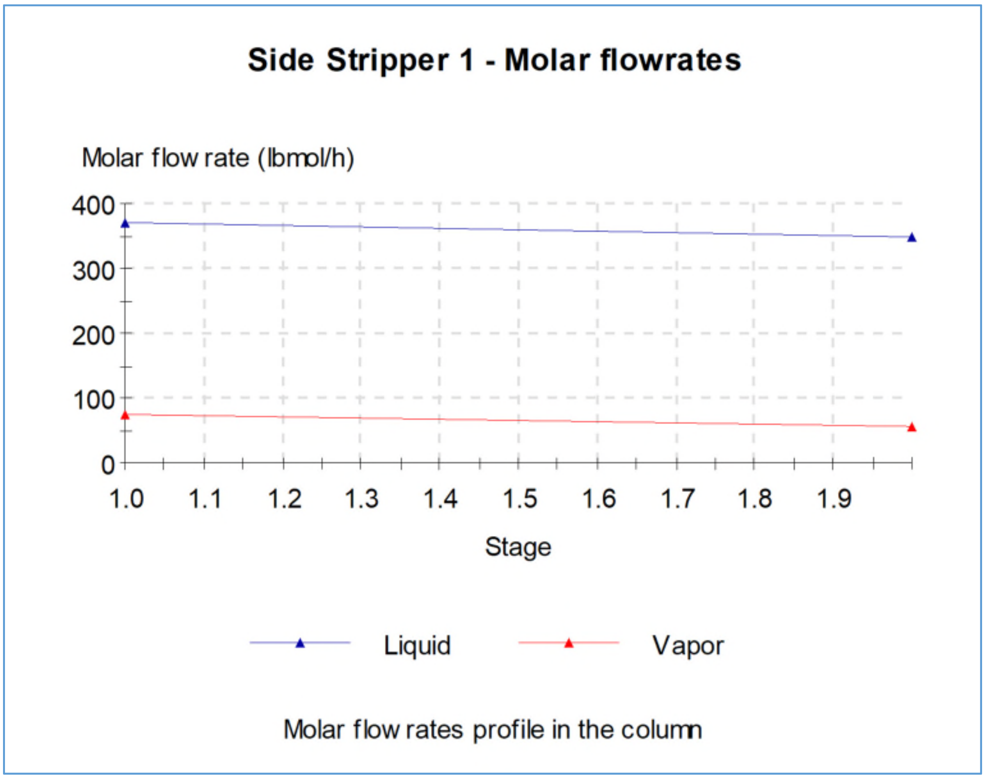


Molar flow rates profile in the column

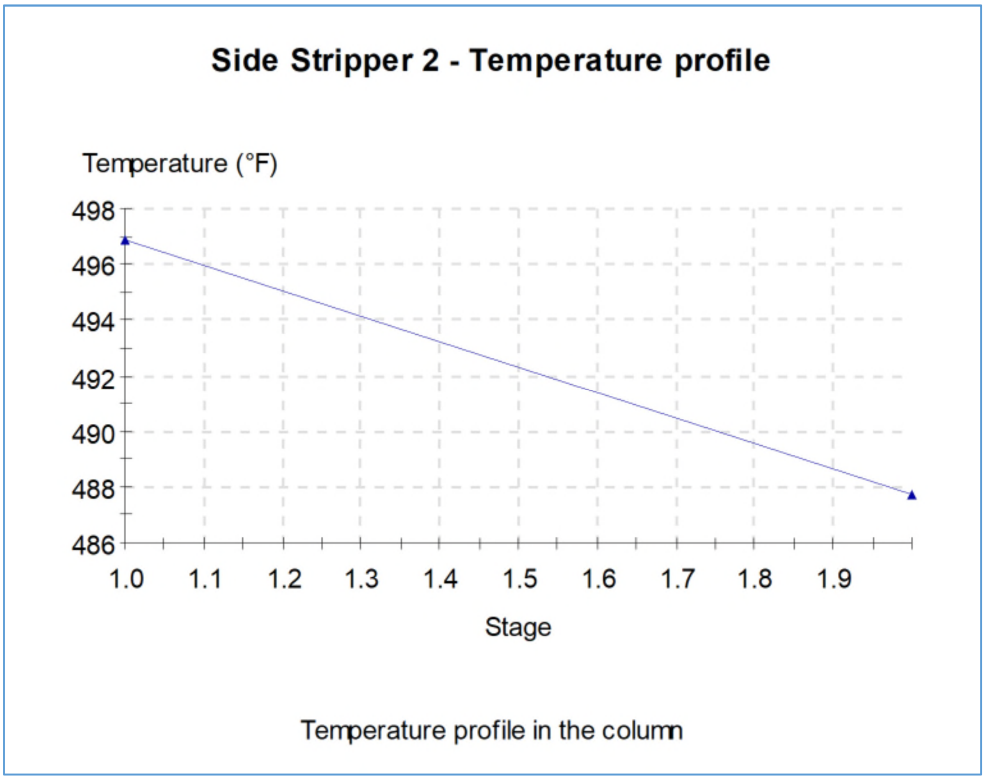
Side stripper 1:

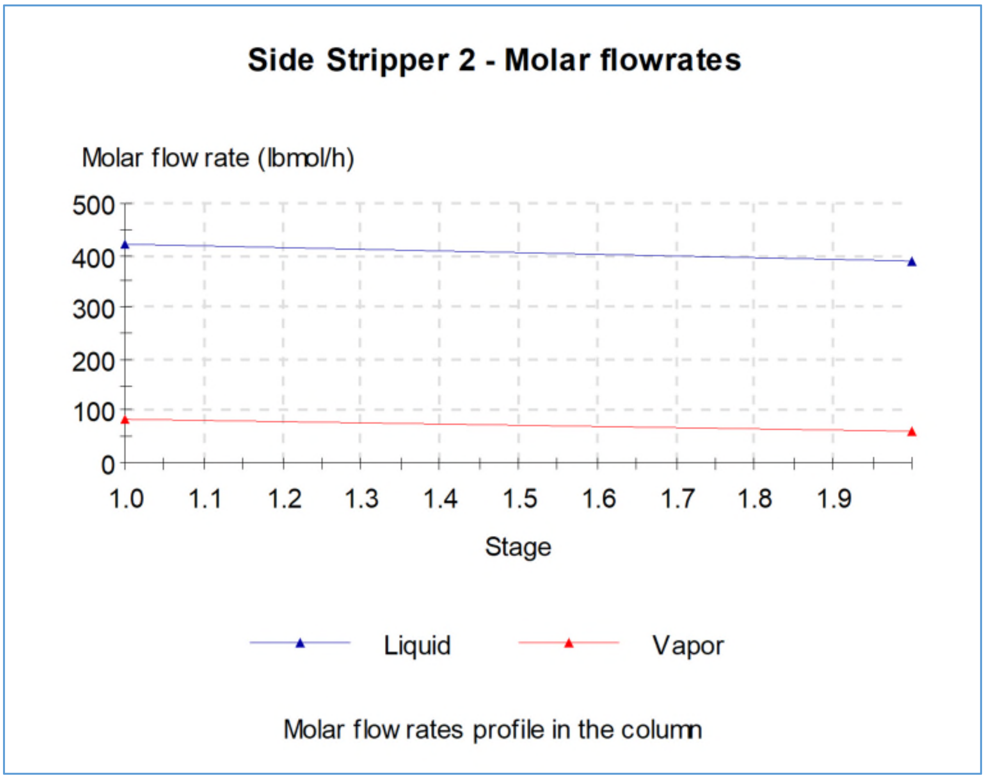


Temperature profile in the column

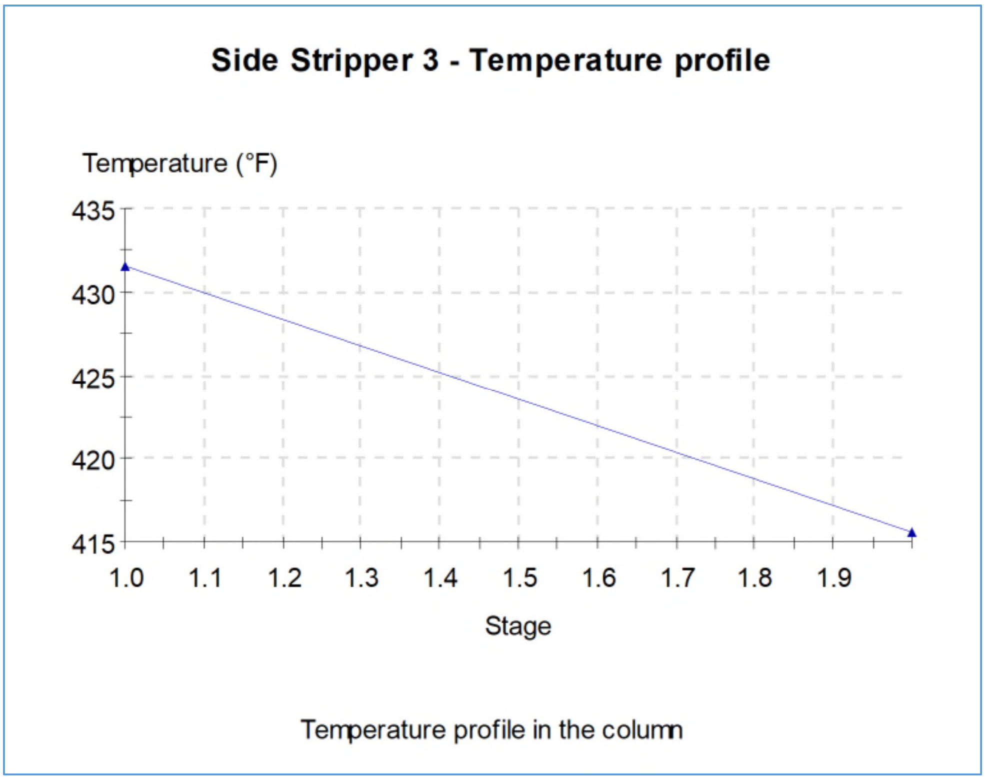


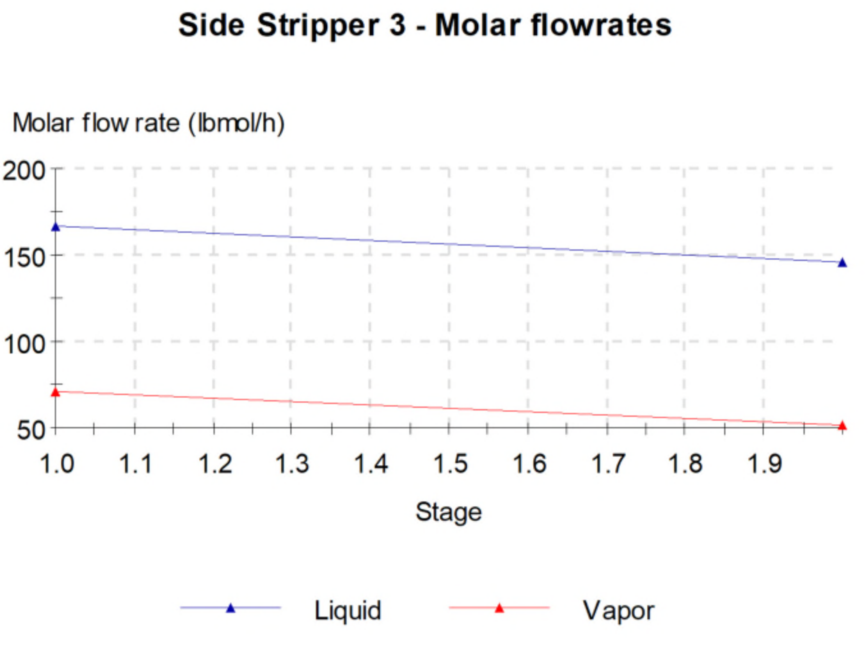
Side stripper 2:





Side stripper 3:





Molar flow rates profile in the column

REFERENCES

[SIM84] Simulation Sciences Inc., Cooling Distribution on Heavy Ends Cuts, SimSci Process – Technical Bulletin #34 (1984).

