ProSim

PROSIMPLUS APPLICATION EXAMPLE

LPG RECOVERY UNIT

USING PROPANE REFRIGERATION

SIMULATION OF BPFHE WITH PROSEC CAPE-OPEN UNIT OPERATION

INTEREST OF THIS EXAMPLE
This example shows a process of LPG recovery in a natural gas with a propane refrigeration loop. This process is particularly inter-connected and includes several recycling loops. Additionally, beside the implementation of the absorber module and of the refrigeration loop, this process uses a brazed plate-fin heat exchanger. This heat exchanger is modeled using ProSec, ProSim's CAPE-OPEN compliant unit operation dedicated to the simulation of brazed plate-fin heat exchangers. ProSec allows taking into account the effect of the stacking and of the pressure drop on the enthalpy curves.

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CORRESPONDING PROSIMPLUS FILE	*PSPS_E17_EN - LPG Recovery with BPFHE.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.

TABLE OF CONTENTS

1. PROCESS MODELING

1.1. Process description

The objective of this process is to recover LPG (Liquefied Petroleum Gases) with a fixed mass fraction of methane, from a natural gas mixture. The main LPG components are hydrocarbons (mainly in the C3-C4 range), propane and butane.

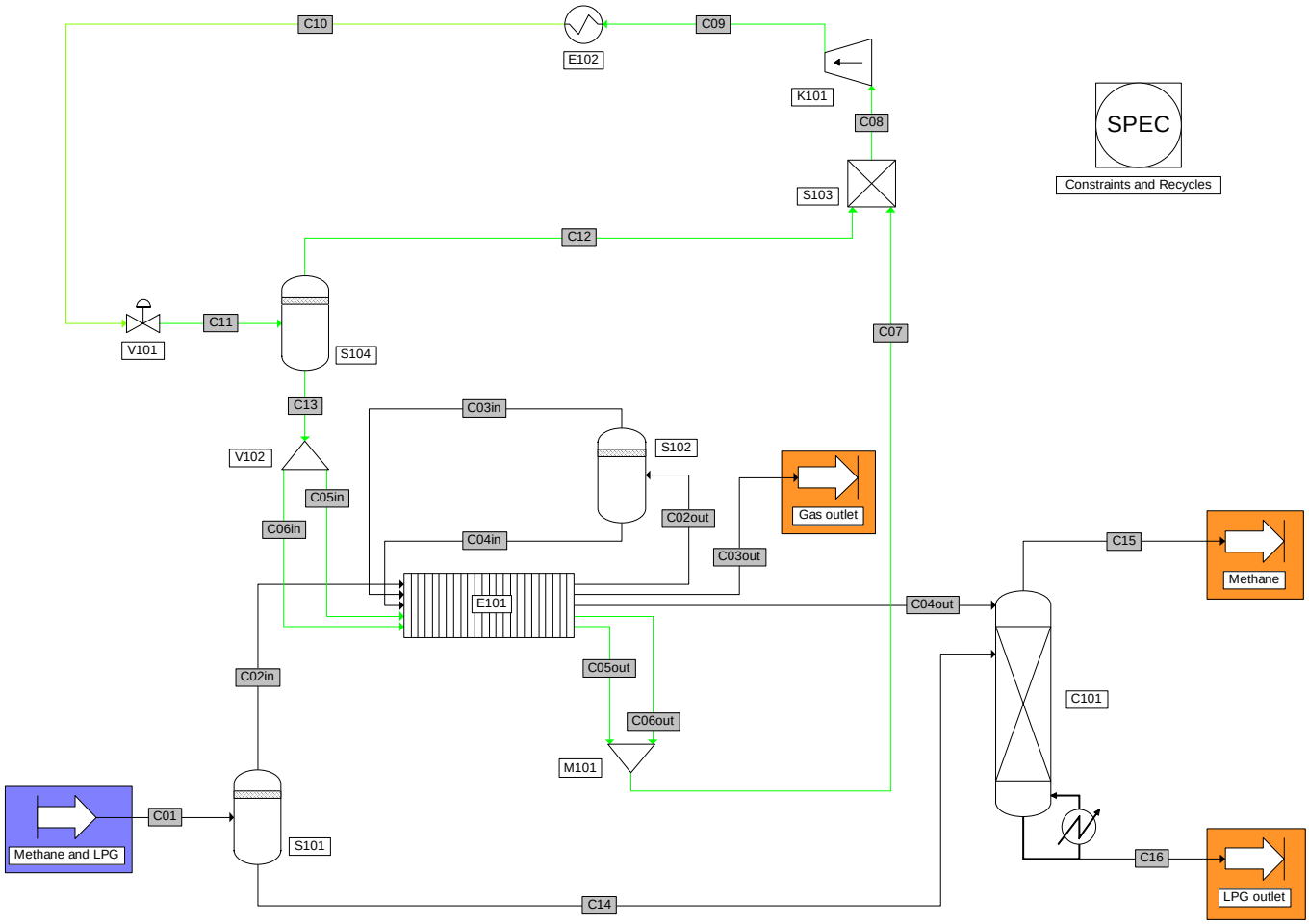
The initial gas mixture is sent in a two-phase separator (S101) in order to eliminate the heaviest compounds which are sent to the distillation column (C101). The others leave at the top of the vessel and are cooled in the brazed plate-fin heat exchanger (E101). They are then forwarded in another two-phase separator (S102) to separate heavies and lights. The two output streams (heavies and light) are sent back in the plate-fin heat exchanger as cold streams. Once treated, the gas is mainly composed of methane and ethane and flows out of the exchanger (stream C03out). The gas, not entirely liquefied, is sent in a deethanizer column (C101), like the bottom stream of the first two-phase separator. This column is set to recover at the bottom a liquid having the specified mass fraction of methane.

The main cold streams of the plate-fin heat exchanger are the two propane streams (C05out and C06out). On the outlet side of the brazed plate-fin heat exchanger, they are mixed and sent in a compressor (K101) which increases their pressure and their temperature. The heat generated is recovered in a heat exchanger (E102). Propane then flows in an expansion valve (V101) in order to decrease its pressure. A liquid-gas mixture is formed and sent in a separator (S104). Liquid propane is returned in the brazed plate-fin heat exchanger (streams C05in and C06in). The gas propane (stream C12) is mixed with hot streams of propane leaving the brazed plate-fin heat exchanger (E101). Propane circulates in closed loop in the system where it acts as a refrigerant.

This process uses a brazed plate-fin heat exchanger (E101). Only one of these exchangers can contain more than ten different streams. Thanks to its low cost of production and its high performances (they are generally made of aluminum) it is widely used in cryogenic processes. The model implemented in ProSec CAPE-OPEN unit operation is a detailed model which takes into account all the complexity of the geometry of this type of type of exchangers. The staking is taken into account. The assumption of common wall temperature is used only in the initialization step.

The example is extracted from [POL89].

1.2. Process flowsheet



1.3. Compounds

The compounds taken into account in the simulation, their chemical formula and CAS numbers are shown in the following table. Their pure component properties are extracted from the standard data base provided with ProSimPlus [ROW11].

Compound	Chemical formula	CAS number
Nitrogen	N_2	7727-37-9
Methane	CH_4	74-82-8
Ethane	C_2H_6	74-84-0
Propane	C_3H_8	74-98-6
Isobutane	C_4H_{10}	75-28-5
n-butane	C_4H_{10}	106-97-8
Isopentane	C_5H_{12}	78-78-4
n-pentane	C_5H_{12}	109-66-0
n-hexane	C_6H_{14}	110-54-3
n-heptane	C_7H_{16}	142-82-5

1.4. Thermodynamic model

The thermodynamic model is based on an equation of state approach. The chosen equation of state is the Peng Robinson (PR) [PEN76] model with binary interaction parameters extracted from the ProSimPlus database.

1.5. Operating parameters

1.5.1. Process feed

	Methane and LPG
Temperature (°F)	115
Pressure (psi)	833
Total flow rate (lb/h)	26297.8
Mass fractions	
Nitrogen	0.000228
Methane	0.591275
Ethane	0.098868
Propane	0.141162
Isobutane	0.040548
n-butane	0.044816
Isopentane	0.020351
n-pentane	0.014024
n-hexane	0.016791
n-heptane	0.031937

1.5.2. Brazed plate-fin heat exchanger E101

✓ General parameters

Parameters	Value
Type of exchanger	ProSec
Number of body	1
Orientation	Horizontal
Fin data base	2011 -> 2015
Material	Aluminium TRANE
Used width (in)	18
Thickness of the side bars (in)	1
Thickness of the end bars (in)	0.25
Thickness of the separation plates (in)	0.1

✓ Streams parameters

	Stream				
Parameter	**C02**	**C03**	**C04**	**C05**	**C06**
Flow direction	From top to bottom	From bottom to top			
Heat exchange correlation	HTFS85				
Pressure drop	Taken into account				
Maximum pressure drop (psi)	5	21	5	1	1

✓ Fins characteristics

Name	Fin #1	Fin #2	Fin #3
Origin	User		
Calculation mode	From geometry		
Reference	2848	2859	2923
Type	Serrated		Perforated
Height (in)	0.25		0.25
Thickness (in)	0.016		0.010
Fins number per meter	669	748	551
Porosity (%)	-		5
Serration length (in)	0.125		-

- ✓ Reference passages

The fins used for each stream are shown in the table below:

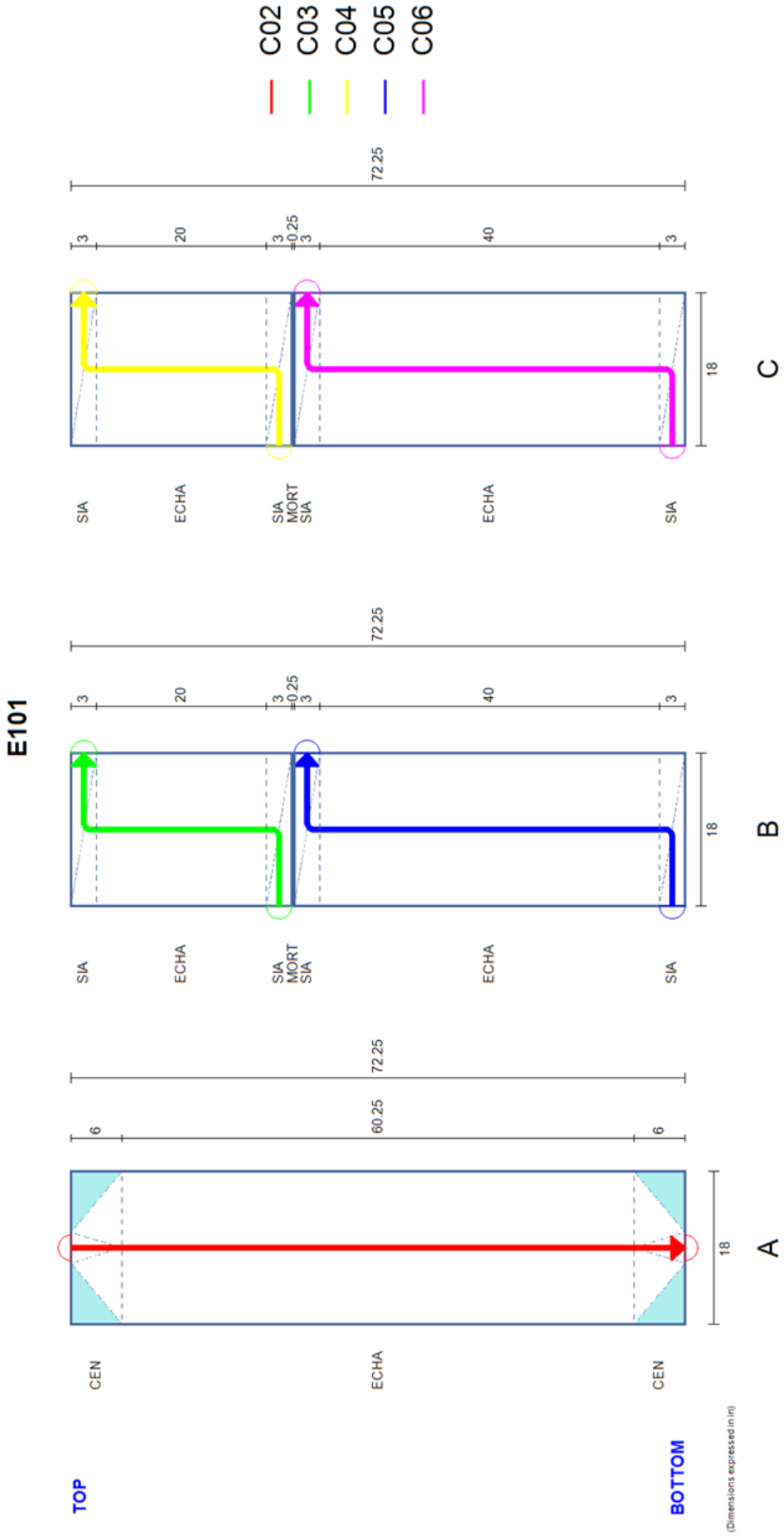
Stream	Fin
C02	Fin #1
C03	Fin #1
C04	Fin #2
C05	Fin #3
C06	Fin #3
“MORT” elementary zone	Fin #3

The figure of the next page shows the three reference passages of the heat exchanger.

The characteristcis of the distributors are displayed in the following table:

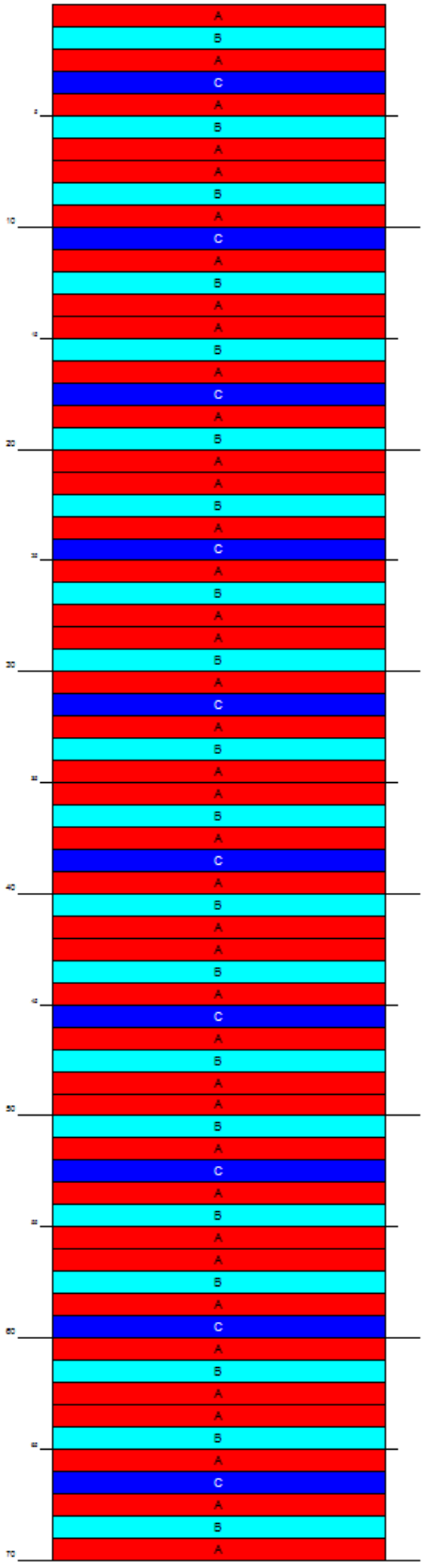
	Distributor type	
Parameter	**CEN**	**SIA**
Opening (in)	3	3
Height (in)	6	3
Head height (in)	1.5	1.5

Dimensions are expressed in inch.

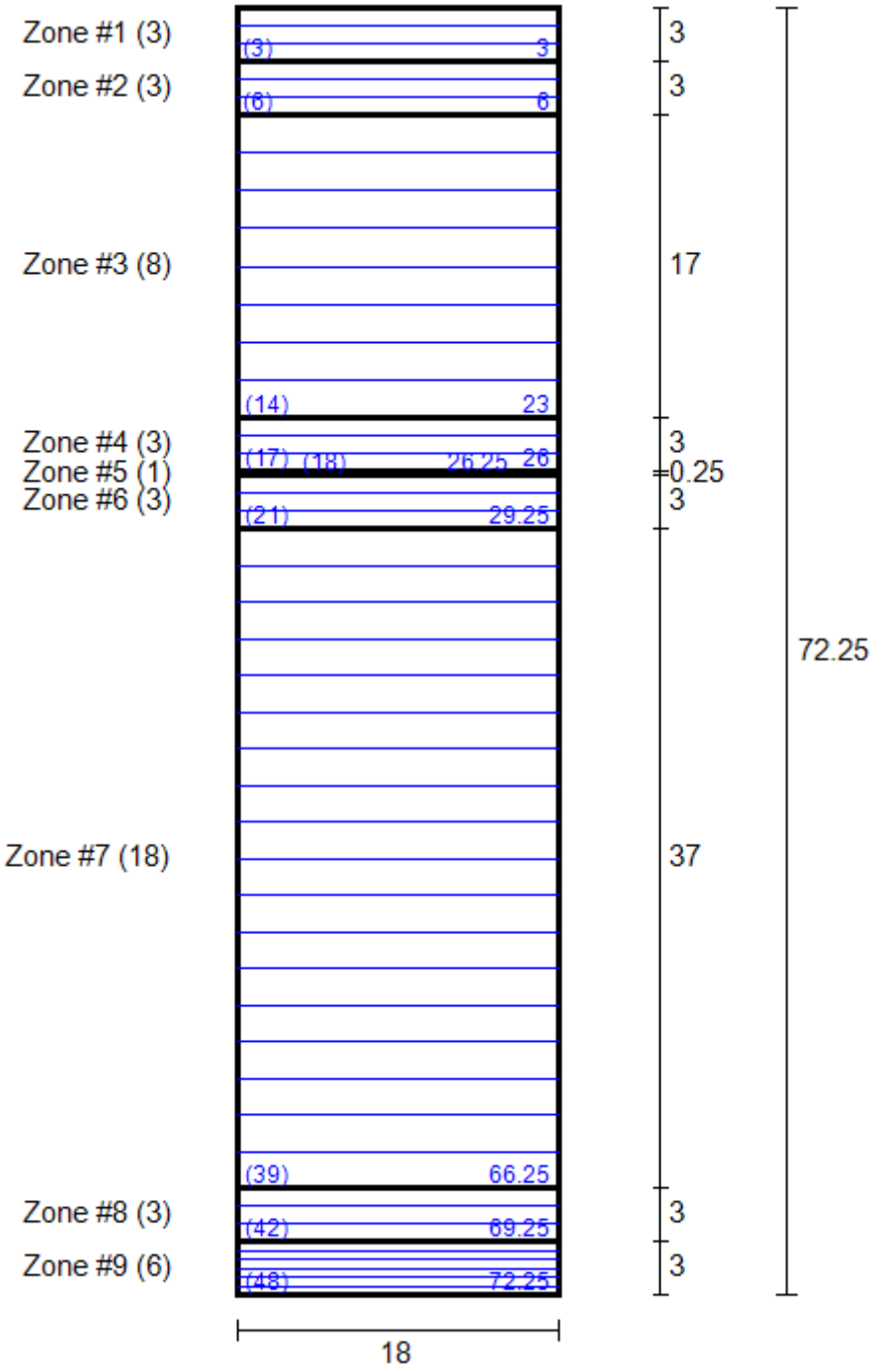


✓ Stacking

Parameters	Value
Number of repetitions of the sequence	10
Sequence	A B A C A B A



✓ Number of meshs for each elementary zone (dimensions are expressed in inch)



1.5.1. Heat exchanger E102

Operating parameters	Value
Type of exchanger	Cooler/Heater
Outlet temperature (°F)	-7

1.5.2. Seraparators

✓ Separator S101

Operating parameters	Value
Type of separator	Liquid-vapor separator
Flash type	Constant temperature and pressure
Temperature (°F)	113
Pressure	The lowest of the feed streams

✓ Separator S102

Operating parameters	Value
Type of separator	Liquid-vapor separator
Flash type	Constant temperature and pressure
Temperature (°F)	-5
Pressure	The lowest of the feed streams

✓ Separator S103

Operating parameters	Value
Type of separator	2-phase separator with one outlet stream
Flash type	Constant temperature and pressure
Temperature	Feeds adiabatic mixing temperature
Pressure	The lowest of the feed streams
Pressure drop (psi)	9

✓ Separator S104

Operating parameters	Value
Type of separator	Liquid-vapor separator
Flash type	Constant temperature and enthalpy
Pressure	The lowest of the feed streams
Heat duty	Adiabatic

1.5.3. Compressor K101

Operating parameters	Value
Exhaust pressure (psi)	258
Isentropic efficiency	0.72
Mechanical efficiency	1

1.5.4. Expansion valve V101

Operating parameters	Value
Pressure (psi)	31

1.5.5. Stream splitter V102

Operating parameters	Value
Type of splitter	Stream splitter
Splitting ratio of stream C06in	0.50
Outlet pressure	Equal to the feed pressure

1.5.6. Mixer M101

Operating parameters	Value
Type of mixer	Other mixer
Outlet pressure	Equal to the lowest of the feeds

1.5.7. Deethanizer C101

✓ Operating parameters

Operating parameters	Value
Type of column	Absorber with a reboiler
Number of theoretical stages	30
Feed stage	10
Overhead vapor flow rate (lbmol/h) (initialization)	70

✓ Objectives / Constraints

Specification	Value
Methane purity at the bottom liquid product (mass)	0.05
Adjusted variable	**Value**
Vapor distillate flow rate	

1.6. Initialization

The propane refrigeration loop can operate with any circulating propane flowrate, as it is a closed loop (the flow among C07 and the flow of C13 exit are equal). In order to set the flowrate of propane circulating in the loop it is necessary to initialize one of the streams of the loop, here the stream C10 was selected. In order to modify the refrigeration efficiency it will be necessary to modify this initialization of the flowrate of C10.

As the stream C02out is recycled at the inlet of the brazed plate-fin heat exchanger by the streams C03in and C04in, the stream C02out has been initialized to avoid convergence difficulties.

	C10	**C02out Initialization**
Temperature (°F)	-7	-5
Pressure (psi)	258	833
Total flow rate (lb/h)	6253.52	25450
	Mole fractions	**Mass fractions**
Nitrogen	0	0.000246
Methane	0	0.608940
Ethane	0.0104	0.101000
Propane	0.9694	0.142070
Isobutane	0.0168	0.039875
n-butane	0.0034	0.043558
Isopentane	0	0.018874
n-pentane	0	0.012827
n-hexane	0	0.012995
n-heptane	0	0.019615

1.1. “Hints & Tips”

As a recycle is present in this process (stream C02out), the accuracy of the enthalpy balance can be improved by selecting the enthalpies as tear streams iterative variables instead of the temperatures (default option). It requires to add a “Constraints and Recycles” module is added to the simulation. This module allows to access to the parameters of the solver and to modify these parameters.

2. RESULTS

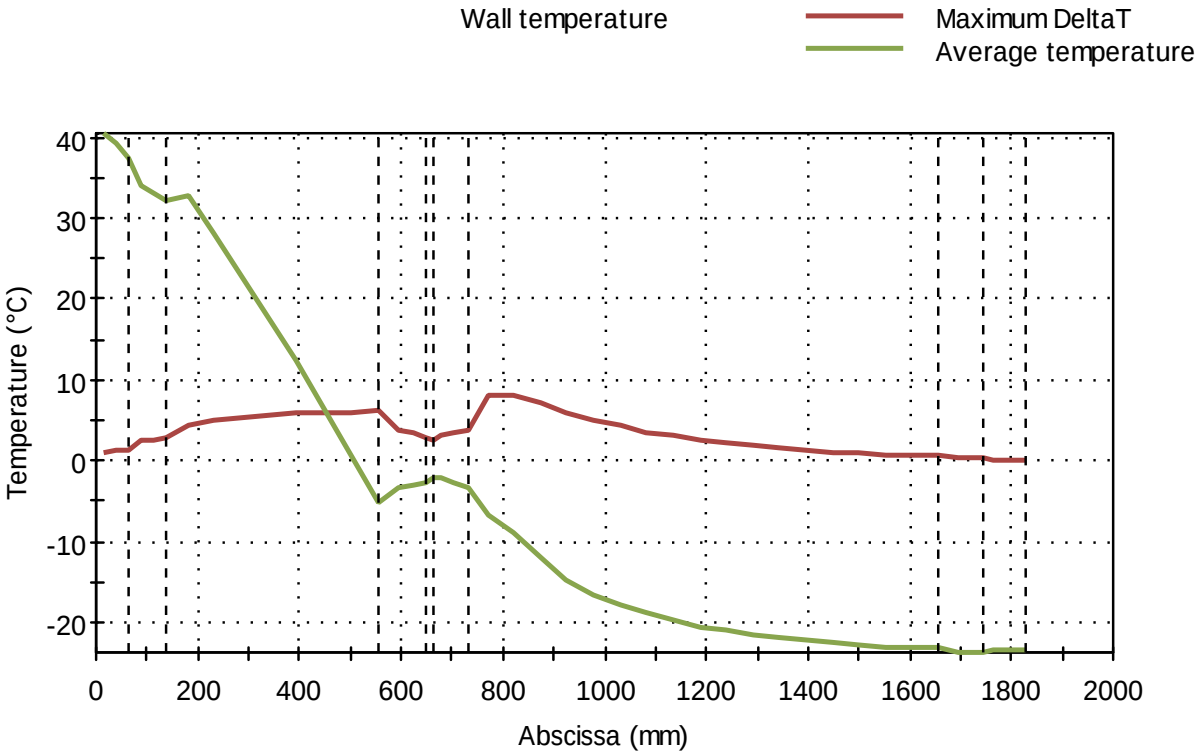
2.1. Mass and energy balances

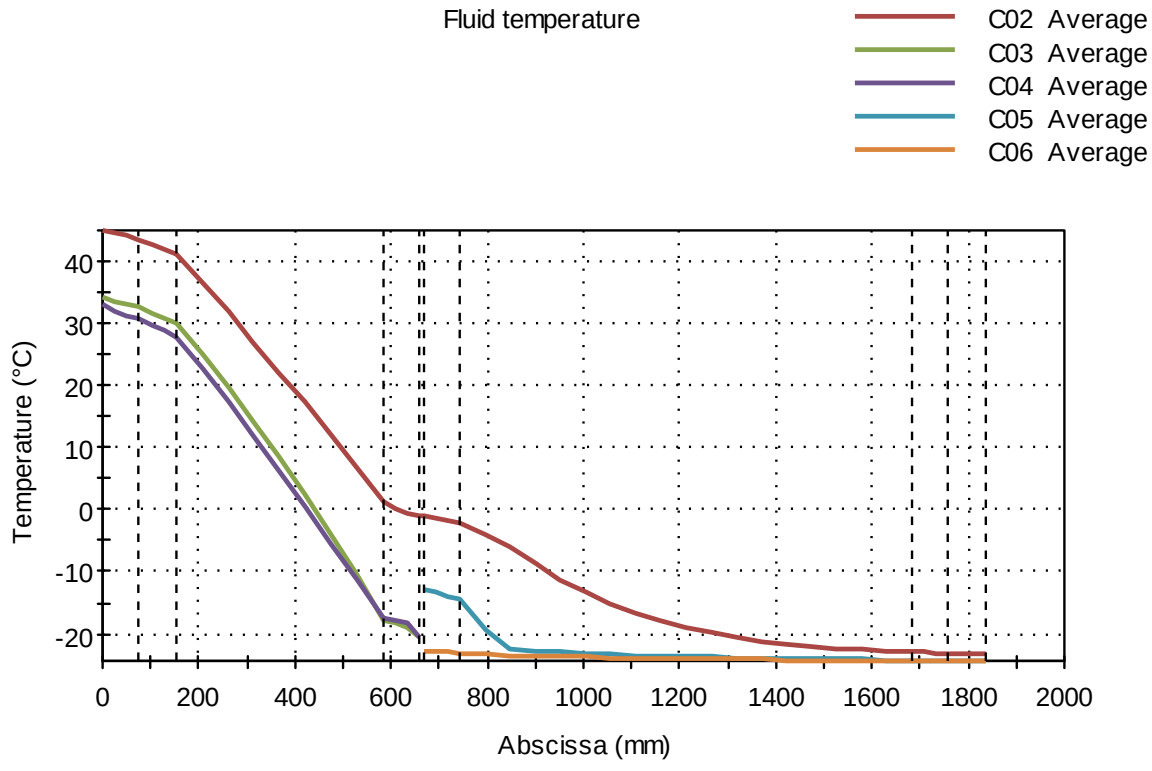
This document presents only the most relevant stream results. In ProSimPlus, mass and energy balances are provided for every stream.

Streams		C01	C02in	C03out	C04out	C07	C15	C16
From		Methane an...	S101	E101	E101	M101	C101	C101
To		S101	E101	Gas outlet	C101	S103	Methane	LPG outlet
Partial flows		lb/h	lb/h	lb/h	lb/h	lb/h	lb/h	lb/h
NITROGEN		5.9959	5.9874	5.7996	0.1878	0	0.19367	0.0026633
METHANE		15549	15498	14224	1273.7	0	1026.9	298.45
ETHANE		2600	2570.6	1799.4	771.15	40.365	335.53	465.05
PROPANE		3712.3	3615.9	1588.9	2027	5934.5	479.77	1643.6
ISOBUTANE		1066.3	1014.9	261.94	752.94	137.33	104.98	699.4
n-BUTANE		1178.6	1108.6	232.53	876.04	27.833	102.91	843.12
ISOPENTANE		535.19	480.34	53.238	427.1	0	29.887	452.06
n-PENTANE		368.8	326.46	32.36	294.1	0	18.85	317.59
n-HEXANE		441.57	330.77	10.243	320.53	0	8.4327	422.89
n-HEPTANE		839.87	499.29	6.2982	492.99	0	6.6554	826.92
Total flow	lb/h	26298	25450	18215	7235.7	6140	2114.1	5969.1
Mass fractions								
NITROGEN		0.000228	0.00023526	0.0003184	2.5955E-005	0	9.1608E-005	4.4618E-007
METHANE		0.59127	0.60894	0.78091	0.17603	0	0.48573	0.05
ETHANE		0.098868	0.101	0.09879	0.10657	0.0065742	0.15871	0.077909
PROPANE		0.14116	0.14207	0.087232	0.28013	0.96653	0.22694	0.27535
ISOBUTANE		0.040548	0.039877	0.014381	0.10406	0.022367	0.049659	0.11717
n-BUTANE		0.044816	0.043558	0.012766	0.12107	0.0045331	0.048678	0.14125
ISOPENTANE		0.020351	0.018874	0.0029228	0.059027	0	0.014137	0.075734
n-PENTANE		0.014024	0.012827	0.0017766	0.040646	0	0.0089166	0.053206
n-HEXANE		0.016791	0.012997	0.00056233	0.044298	0	0.0039888	0.070847
n-HEPTANE		0.031937	0.019618	0.00034577	0.068133	0	0.0031481	0.13853
Physical state		Liq./Vap.	Vapor	Vapor	Liq./Vap.	Liq./Vap.	Vapor	Liquid
Temperature	°F	115	113	92.509	89.85	-9.813	89.82	182.69
Pressure	psi	833	833	808.39	824.53	30.321	824.53	824.53
Enthalpic flow	Btu/h	-4.5011E005	-3.8094E005	-3.9423E005	-8.3906E005	-3.2303E005	-71781	-4.6905E005
Vapor molar fraction		0.98927	1	1	0.34038	0.90485	1	0

2.2. Brazed plate-fin heat exchanger E101 profiles

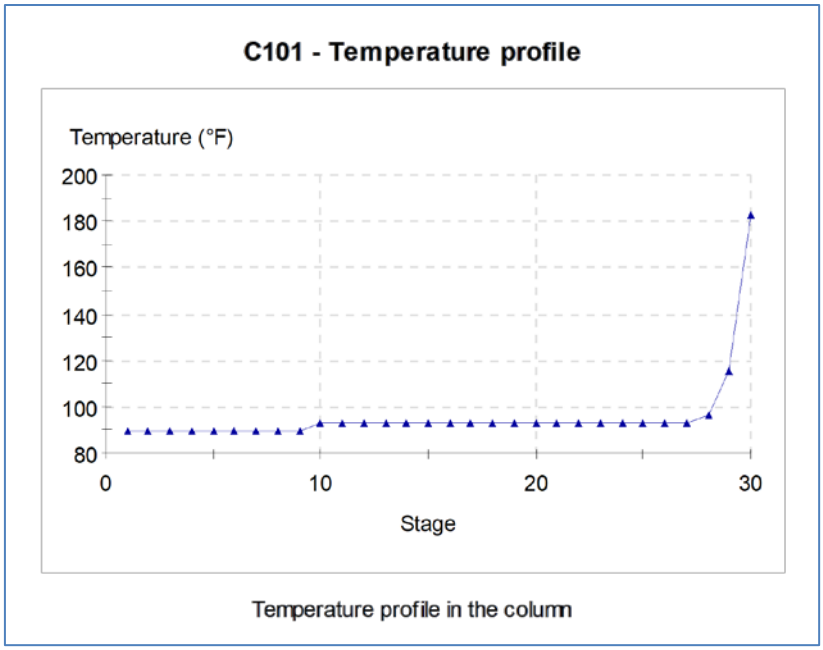
Several profiles (wall temperature, fluid temperature, pressure, heat transfer coefficient, vaporization ratio…) in the heat exchanger are available after the simulation from ProSec edition window (“Results” tab). The following figures show the wall temperature profiles (average and maximal deviation) and the fluid mean temperature profiles along the length of the heat exchanger.



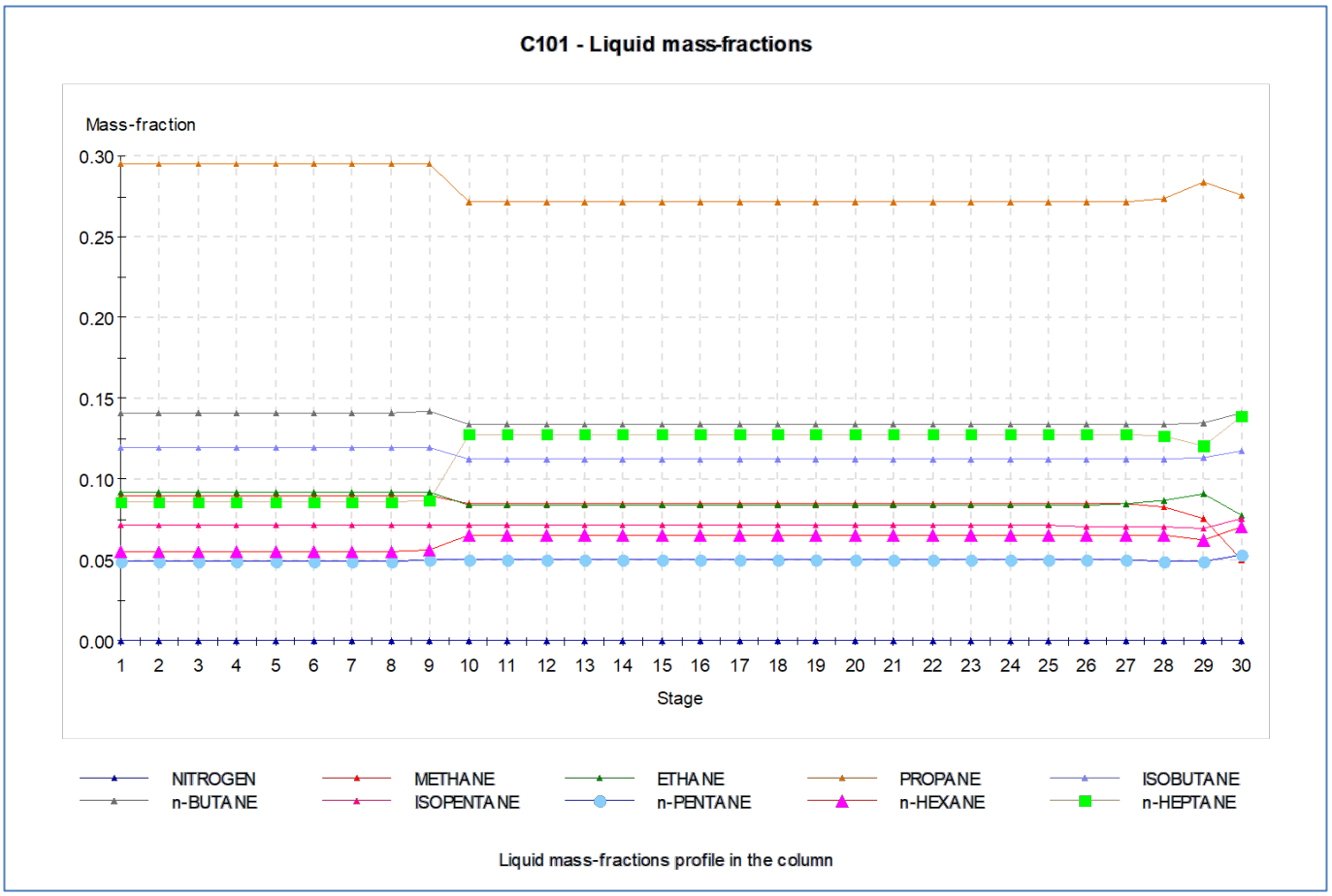


2.3. Deethanizer C101 profiles

Several profiles (temperature, pressure, compositions and flow rates) in the column are available after the simulation from column configuration window (“Profiles” tab). It is important to note that, in ProSimPlus, first stage correspond to condenser, if present, and last stage to reboiler, if present (numbering from top to bottom).



Temperature profile in the column



Liquid mass-fractions profile in the column

3. REFERENCES

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[ROW11] ROWLEY R.L., WILDING W.V., OSCARSON J.L., GILES N.F., "DIPPR® Data Compilation of Pure Chemical Properties", Design Institute for Physical Properties, AIChE, New York, NY (2011)

