PROSIMPLUS APPLICATION EXAMPLE

THREE STAGE LETDOWN

INTEREST OF THIS EXAMPLE
The objective of this example is to simulate a crude oil separation process. This separation process is based on the differences of pressure between the different 3-phase (liquid-liquid-vapor) and 2-phase (liquid-vapor) flashes used. This example makes use of petroleum cuts properties generation which are considered as pseudo-components as well as a specific thermodynamic model for water-hydrocarbon systems. This process includes several recycles and provides a simple example of use of the specification module to set a parameter of an output stream (here the pressure) by adjusting the operating pressure of a letdown stage.

ACCESS	☑ Free-Internet	☐ Restricted to clients	☐ Restricted	☐ Confidential

CORRESPONDING PROSIMPLUS FILE	*PSPS_EX_EN-Three-Stage-Letdown.pmp3*

.

Energy

Fives ProSim

Siège social : Immeuble Stratège A - 51 rue Ampère - 31670 Labège - FRANCE

Tél. : +33 (0)5 62 88 24 30

S.A.S. au capital de 147 800 € - 350 476 487 R.C.S. Toulouse - Siret 350 476 487 00037 - APE 5829C - N° TVA FR 10 350 476 487

www.fivesgroup.com / www.fives-prosim.com

TABLE OF CONTENTS

1. PROCESS MODELING

1.1. Process description

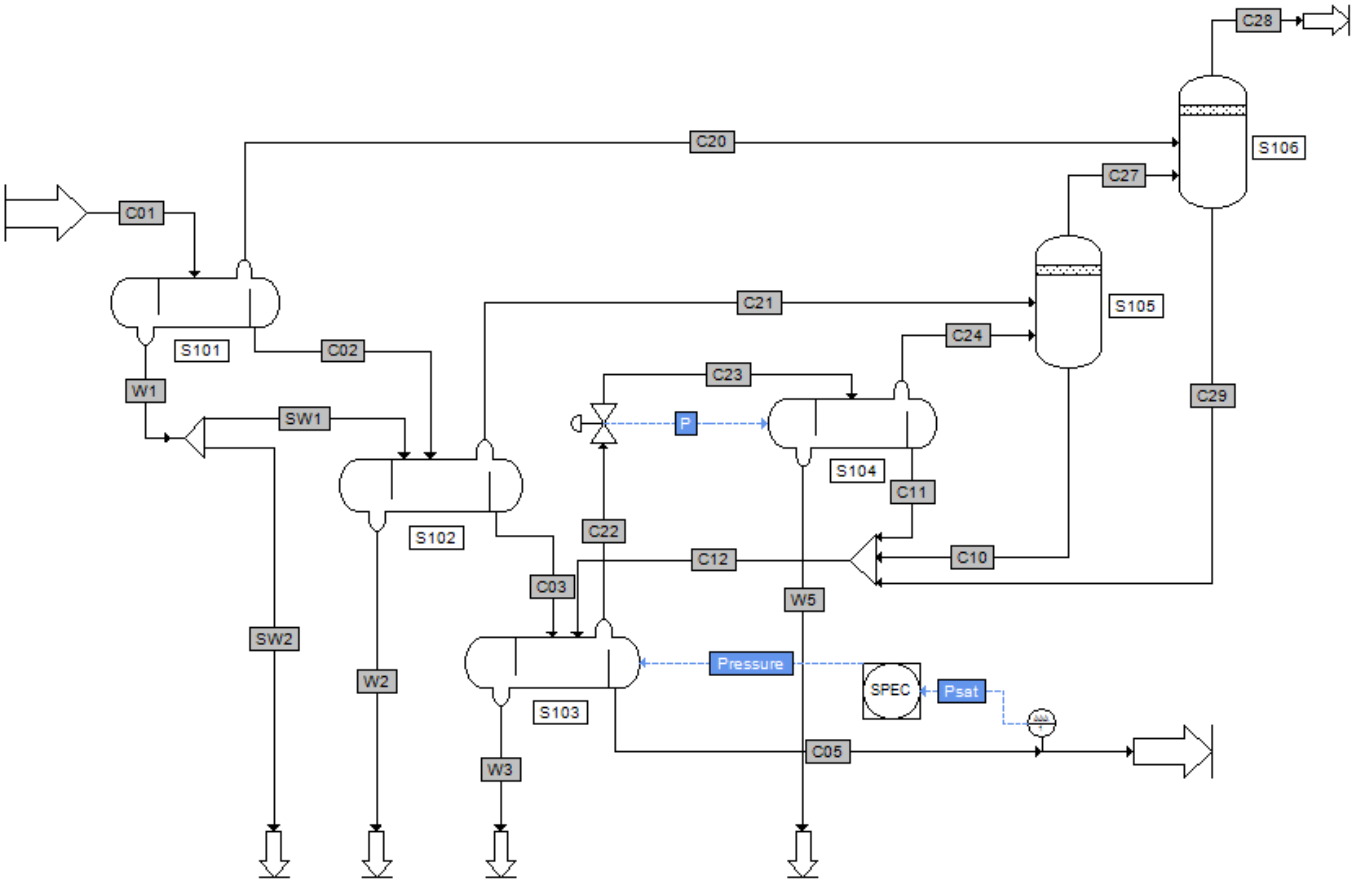
The crude oil is fed successively in three 3-phase flashes (S101, S102, S103). In each of them, the heaviest compound (water) is removed in the heavy stream (W1, W2, W3). The pressure decreases throughout the flashes. Light compounds such as methane are removed at the first flash level.

Vapors are recovered in two liquid-vapor flashes (S105 and S106). The heaviest compounds are sent in the last 3-phase flash, while the lightest get out of the unit (C28).

The bubble pressure of the oil outlet stream is specified and sets the pressure in the last 3-phase flash.

This example is taken from [1].

1.2. Process flowsheet



Three Stage Letdown process flowsheet

1.3. Specification

The pressure of the last letdown stage (S103) is adjusted in such a way that the bubble pressure of the product oil C05 is 14.7 psi at 100°F (true vapor pressure).

1.4. Components

Components taken into account in the simulation are of two kinds:

- A first set of components are taken from the ProSim standard database, provided with ProSim's software. These components are defined below:

  - ❖ Water
  - ❖ Carbon dioxide
  - ❖ Nitrogen
  - ❖ Methane
  - ❖ Ethane
  - ❖ Propane
  - ❖ Isobutane
  - ❖ n-Butane
  - ❖ IsopPentane
  - ❖ n-Pentane

- The second set of components are in fact petroleum cuts, i.e. mixtures of components. They are considered in the simulation as pseudo-components. For these components, the properties must be generated by using the pseudocompound generation service, from the knowledge of the following properties:

Name	MW (g/mol)	API Gravity	NBP (°F)
Cut 1	91	64	180
Cut 2	100	61	210
Cut 3	120	55	280
Cut 4	150	48	370
Cut 5	200	40	495
Cut 6	245	35	590
Cut 7	300	30	687
Cut 8	360	26	770
Cut 9	430	22	865
Cut 10	500	19	940

1.5. Thermodynamic model

Classical thermodynamic models such as equations of state with their mixing rules do not allow a satisfactory representation of the particular and complex behavior of phase equilibria in water-hydrocarbon mixtures (here, the term “hydrocarbon” should be taken in its most general meaning). For temperature and pressure conditions that are far from the critical point of the mixture and for water compositions less than 50 % (mole fraction), the following model gives satisfactory calculations of vapor-liquid, liquid-liquid and vapor-liquid-liquid equilibria of such systems, by taking especially into account the particular nature of water in these mixtures. This model consists in a specific calculation of the water equilibrium constant and in a standard calculation of the equilibrium constants for other components.

Thus, for a vapor-liquid-liquid equilibrium, assuming that a pure water phase exists, the water equilibrium constant between the vapor phase and the liquid phase rich in hydrocarbons is calculated using the following equation:

$$K_{water} = \frac{P^0_{water}}{x_{sol} P}$$

P^0_{water} Vapor pressure of water at the temperature of the system

P Total pressure of the system

x_{sol} Upper limit of the water solubility in hydrocarbons. This parameter depends on the temperature and the nature of the hydrocarbons.

In all cases, the composition of water in vapor phase is systematically considered as equal to the ratio between the vapor pressure of water and the total pressure of the system. Due to its structure, the specific nature of this calculation can be applied with any equation of state available in the library (SRK, PR, ANTOINE,…).

To use this option, component water must necessarily be taken from the standard database. Note that parameters (SOLA and SOLB below) involved in the calculation of solubility of water in hydrocarbons can be easily modified by the user. The expression and the default values of these constants are the following ones:

$$Ln x_{sol} = SOLA - \frac{SOLB}{T}$$, with T in Kelvin and x_{sol} in mol/mol

SOLA = 6.25043

SOLB = 4015.303

The default values of these constants are those obtained from the water solubility curve in kerosene from the API Data book (API Data Book fig 9A1-4, 1982). In the present case, the equation of state selected to represent phase equilibrium and enthalpy calculations is the cubic equation of state of Soave Redlich et Kwong (SRK) [2], without binary interaction parameters.

This model is selected by ticking the option "Water-hydrocarbons model" at the level of the thermodynamic model selection window. The default solubility parameters are used.

1.6. Operating conditions

✓ Process feed

Temperature (°F)	150
Pressure (psia)	1000

Compounds	Flowrate (lbmol/h)	Compounds	Flowrate (lbmol/h)
Water	3000.0	Cut 1	165.0
Carbon Dioxide	35.0	Cut 2	303.0
Nitrogen	30.0	Cut 3	560.0
Methane	890.0	Cut 4	930.0
Ethane	300.0	Cut 5	300.0
Propane	520.0	Cut 6	300.0
Iso-Butane	105.0	Cut 7	300.0
N-Butane	283.0	Cut 8	280.0
Iso-Pentane	100.0	Cut 9	260.0
N-Pentane	133.0	Cut 10	0.0

✓ Separator S101

Operating parameters	Value
Type of separator	3-phase Flash
Operating temperature	200 °F
Operating pressure	300 psi

✓ Separator S102

Operating parameters	Value
Type of separator	3-phase Flash
Operating mode	adiabatic
Operating pressure	100 psi

✓ Separator S103

Operating parameters	Value	Note
Type of separator	3-phase Flash	
Operating mode	adiabatic	
Operating pressure	37.25	Pressure will be adjusted to obtain a bubble pressure equal to 14.7 psi in the C05 stream

✓ Separator S104

Operating parameters	Value
Type of separator	3-phase Flash
Operating temperature (F)	120
Operating pressure (psi)	34.25

✓ Separator S105

Operating parameters	Value
Type of separator	Liquid-vapor separator
Operating temperature (F)	120
Operating pressure (psi)	97

✓ Separator S106

Operating parameters	Value
Type of separator	Liquid-vapor separator
Operating temperature (F)	120
Operating pressure (psi)	297

✓ Valve V101

Operating parameters	Value
Type of valve	Stream splitter
Split ratio for the SW1 ratio	0.4

- ✓ Valve V102

Operating parameters	*Value*
Type of valve	Expansion valve
Operating mode	adiabatic
Pressure drop (psi)	3

1.7. "Hints and Tips"

Pressure of flash S104 is in fact the exhaust pressure of valve V102. This pressure is transmitted to flash S104 by means of an *information steam*.

2. RESULTS

2.1. Comments on results

The calculation sequence (order of calculation of the unit operations) is automatically generated and there is no initialized stream.

Convergence is reached after 5 iterations.

The final pressure of the last flash drum S103 is 37.3 psi (pressure adjusted in such a way that the bubble pressure of C05 is 14.7 psia at 100°F).

2.2. Mass and energy balances

Streams		C01	C02	C03	C05	C06
From		Feed C1	S101	S102	S103	MS01
To		S101	S102	S103	MS01	Output 5
Partial flows		lb/h	lb/h	lb/h	lb/h	lb/h
WATER		54045.86	773.90	606.49	448.50	448.50
CARBON DIOXIDE		1540.34	711.61	246.43	52.19	52.19
NITROGEN		840.40	117.08	9.70	0.4175	0.4175
METHANE		14278.08	3638.45	604.40	52.79	52.79
ETHANE		9020.87	4718.38	1927.04	504.07	504.07
PROPANE		22930.16	16488.66	10409.07	5247.40	5247.40
ISOBUTANE		6102.95	5029.65	3855.41	2728.62	2728.62
n-BUTANE		16448.91	14085.81	11395.92	8912.26	8912.26
ISOPENTANE		7215.02	6620.17	5907.76	5518.82	5518.82
n-PENTANE		9595.98	8925.63	8117.76	7831.45	7831.45
CUT1b		15014.99	14665.53	14249.13	14675.04	14675.04
CUT2b		30299.98	29840.11	29303.85	30055.00	30055.00
CUT3b		67199.95	66852.55	66472.18	67163.21	67163.21
CUT4b		139499.89	139344.11	139190.55	139497.56	139497.56
CUT5b		59999.95	59993.92	59988.96	59999.95	59999.95
CUT6b		73499.94	73498.97	73498.30	73499.94	73499.94
CUT7b		89999.93	89999.80	89999.72	89999.93	89999.93
CUT8b		100799.92	100799.90	100799.89	100799.92	100799.92
CUT9b		111799.91	111799.91	111799.91	111799.91	111799.91
CUT10b		0	0	0	0	0
Total flow	lb/h	830133.04	747904.14	728382.46	718786.98	718786.98
Physical state		Liquid	Liquid	Liquid	Liquid	Liquid
Temperature	°F	150.0	200.0	192.7	179.1	179.1
Pressure	psi	1000.0	300.0	100.0	37.3	37.3
Enthalpic flow	Btu/h	-131568579.5	-59439166.9	-61069736.3	-65281206.1	-65281206.1
Vapor molar fraction		0.00	0.00	0.00	0.00	0.00

Streams		C10	C11	C12	C20	C21
From		S105	S104	M101	S101	S102
To		M101	M101	S103	S106	S105
Partial flows		lb/h	lb/h	lb/h	lb/h	lb/h
WATER		1154.88	0.44	2032.97	781.46	1060.85
CARBON DIOXIDE		3.41	0.2534	33.73	828.73	465.18
NITROGEN		0.0657	0.0013	2.52	723.33	107.37
METHANE		5.17	0.1880	100.29	10639.63	3034.05
ETHANE		28.36	2.38	251.40	4302.49	2791.34
PROPANE		239.45	29.60	1506.84	6441.50	6079.59
ISOBUTANE		116.08	17.07	614.03	1073.30	1174.24
n-BUTANE		378.41	59.67	1859.71	2363.10	2689.89
ISOPENTANE		226.18	40.76	932.65	594.85	712.42
n-PENTANE		319.77	60.45	1242.13	670.35	807.86
CUT1b		450.46	128.91	1210.78	349.45	416.41
CUT2b		707.23	257.20	1729.47	459.86	536.26
CUT3b		529.12	390.60	1330.18	347.40	380.37
CUT4b		166.44	215.47	539.63	155.78	153.56
CUT5b		4.9758	6.4173	17.4248	6.0313	4.9609
CUT6b		0.6760	0.7680	2.4129	0.9690	0.6758
CUT7b		0.0743	0.0725	0.2767	0.1299	0.0743
CUT8b		0.0101	0.0086	0.0404	0.0217	0.0101
CUT9b		0.0007	4.974E-04	3.152E-03	1.949E-03	7.060E-04
CUT10b		0	0	0	0	0
Total flow	lb/h	4330.77	1210.26	13406.49	29738.40	20415.12
Physical state		Liquid	Liquid	Liq./Vap.	Vapor	Vapor
Temperature	°F	120.0	120.0	72.2	200.0	192.7
Pressure	psi	97.0	34.3	34.3	300.0	100.0
Enthalpic flow	Btu/h	-1596804.7	-166375.0	-3575185.6	1409934.3	956063.6
Vapor molar fraction		0.00	0.00	0.20	1.00	1.00

Streams		C22	C23	C24	C27	C28
From		S103	V102	S104	S105	S106
To		V102	S104	S105	S106	Output 1
Partial flows		lb/h	lb/h	lb/h	lb/h	lb/h
WATER		1871.05	1871.05	384.31	290.28	194.09
CARBON DIOXIDE		227.97	227.97	227.72	689.48	1488.15
NITROGEN		11.80	11.80	11.80	119.11	839.99
METHANE		651.90	651.90	651.71	3680.59	14225.29
ETHANE		1674.37	1674.37	1671.99	4434.98	8516.80
PROPANE		6668.51	6668.51	6638.91	12479.06	17682.76
ISOBUTANE		1740.82	1740.82	1723.75	2781.91	3374.34
n-BUTANE		4343.37	4343.37	4283.70	6595.18	7536.64
ISOPENTANE		1321.59	1321.59	1280.83	1767.06	1696.20
n-PENTANE		1528.44	1528.44	1467.98	1956.07	1764.53
CUT1b		784.86	784.86	655.95	621.90	339.94
CUT2b		978.32	978.32	721.12	550.15	244.97
CUT3b		639.15	639.15	248.55	99.80	36.73
CUT4b		232.62	232.62 €	17.1525	4.2673	2.32
CUT5b		6.4378	6.4378	0.0205	0.0057	0.0052
CUT6b		0.7681	7.681E-01	1.708E-04	5.6013E-05	0.0001
CUT7b		0.0725	7.253E-02	9.471E-07	3.592E-07	0.0000
CUT8b		0.0086	8.562E-03	1.084E-08	4.290E-09	0.0000
CUT9b		4.974E-04	0.000497384	0	0	0.0000
CUT10b		0	0	0	0	0
Total flow	lb/h	22682.05	22682.05	19985.50	36069.84	57942.76
Physical state		Vapor	Vapor	Vapor	Vapor	Vapor
Temperature	°F	179.1	178.6	120.0	120.0	120.0
Pressure	psi	37.3	34.3	34.3	97.0	297.0
Enthalpic flow	Btu/h	939683.9	939683.9	306762.4	442784.7	239630.4
Vapor molar fraction		1.00	1.00	1.00	1.00	1.00

Streams		C29	SW1	SW2	W1	W2
From		S106	V101	V101	S101	S102
To		M101	S102	Output 2	V101	Output 3
Partial flows		lb/h	lb/h	lb/h	lb/h	lb/h
WATER		877.65	20996.20	31494.30	52490.50	20102.76
CARBON DIOXIDE		30.07	0	0	0	0
NITROGEN		2.45	0	0	0	0
METHANE		94.93	0	0	0	0
ETHANE		220.67	0	0	0	0
PROPANE		1237.79	0	0	0	0
ISOBUTANE		480.87	0	0	0	0
n-BUTANE		1421.64	0	0	0	0
ISOPENTANE		665.71	0	0	0	0
n-PENTANE		861.90	0	0	0	0
CUT1b		631.41	0	0	0	0
CUT2b		765.04	0	0	0	0
CUT3b		410.46	0	0	0	0
CUT4b		157.73	0	0	0	0
CUT5b		6.03	0	0	0	0
CUT6b		0.97	0	0	0	0
CUT7b		0.1299	0	0	0	0
CUT8b		0.0217	0	0	0	0
CUT9b		0.0019	0	0	0	0
CUT10b		0	0	0	0	0
Total flow	lb/h	7865.48	20996.20	31494.30	52490.50	20102.76
Physical state		Liquid	Liquid	Liquid	Liquid	Liquid
Temperature	°F	120.0	200.0	200.0	200.0	192.7
Pressure	psi	297.0	300.0	300.0	300.0	100.0
Enthalpic flow	Btu/h	-1812008.0	-19454393.9	-29181590.9	-48635984.8	-18779933.6
Vapor molar fraction		0.00	0.00	0.00	0.00	0.00

Streams		W3	W5
From		S103	S104
To		Output 6	Output 4
Partial flows		lb/h	lb/h
WATER		319.91	1486.29
CARBON DIOXIDE		0	0
NITROGEN		0	0
METHANE		0	0
ETHANE		0	0
PROPANE		0	0
ISOBUTANE		0	0
n-BUTANE		0	0
ISOPENTANE		0	0
n-PENTANE		0	0
CUT1b		0	0
CUT2b		0	0
CUT3b		0	0
CUT4b		0	0
CUT5b		0	0
CUT6b		0	0
CUT7b		0	0
CUT8b		0	0
CUT9b		0	0
CUT10b		0	0
Total flow	lb/h	319.91	1486.29
Physical state		Liquid	Liquid
Temperature	°F	179.1	120.0
Pressure	psi	37.3	34.3
Enthalpic flow	Btu/h	-303399.7	-1496896.9
Vapor molar fraction		0.00	0.00

3. REFERENCES

[1] Application Briefs
Process Simulation Program
Simulation Sciences Inc.
Revision 1, Jan 1983

[2] Soave G.
"Equilibrium constants from a modified Redlich-Kwong equation of state"
C.E.S., 27, 6,1197-1203 (1972)