# 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.<br><br>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.<br><br>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 ProSim clients | ☐ Restricted | ☐ Confidential |
|---|---|---|---|---|

| CORRESPONDING PROSIMPLUS FILE | *PSPS_E03_EN – Three Stage Letdown.pmp3* |
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# 1. PROCESS MODELING

## 1.1. Process description

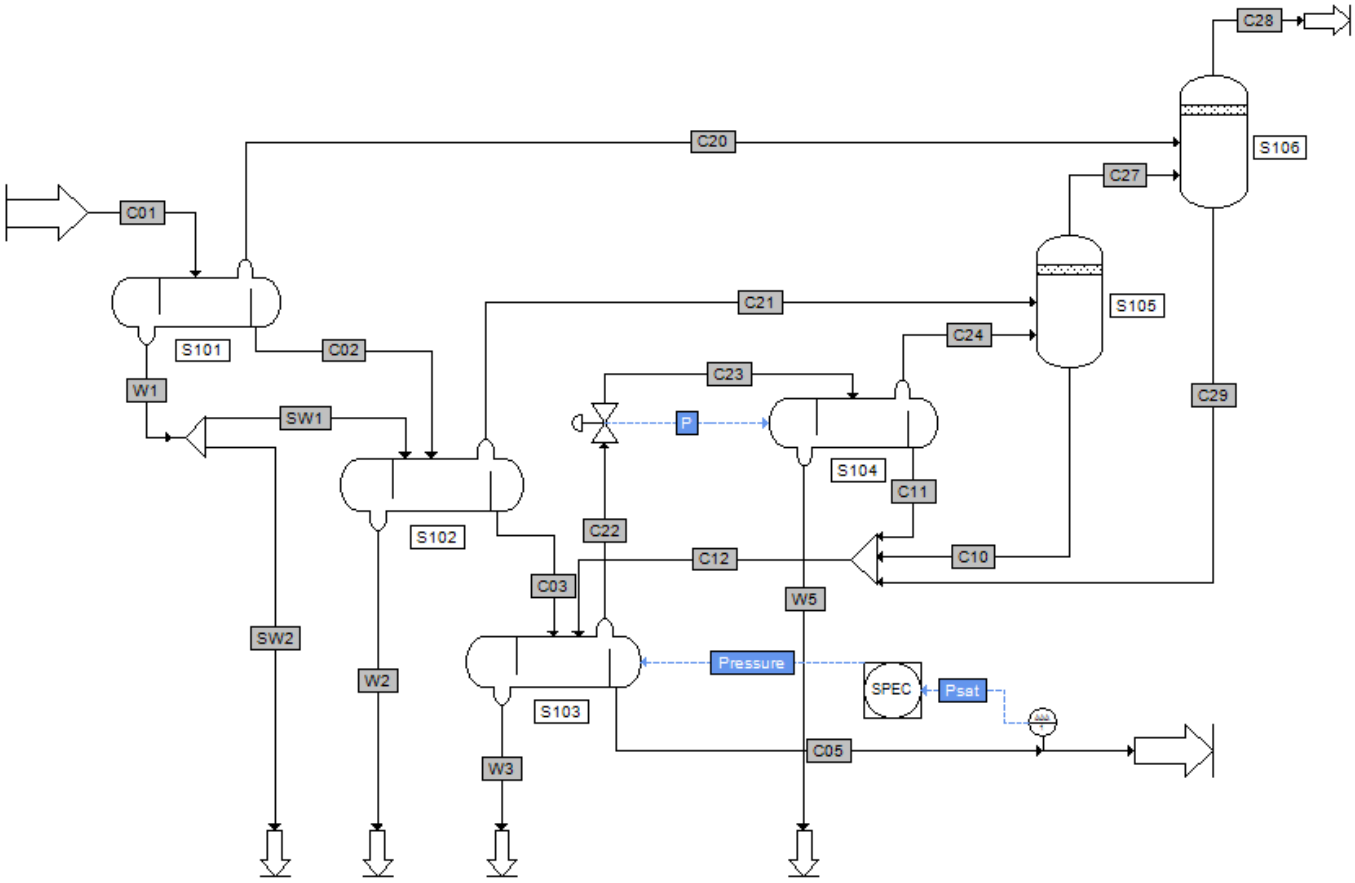
The crude oil is fed successively in three 3-phase flashes (S101, S102, S103). In each of them, the heaviest compound (water) is removed in the heavy stream (W1, W2, W3). The pressure decreases throughout the flashes. Light compounds such as methane are removed at the first flash level.

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:

$$Lnx_{sol} = SOLA - \frac{SOLB}{T}$$, 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)