Fluid Modeling Group Canada Product

July 2018

PVT Test Simulation (FMGCloud_PVT)

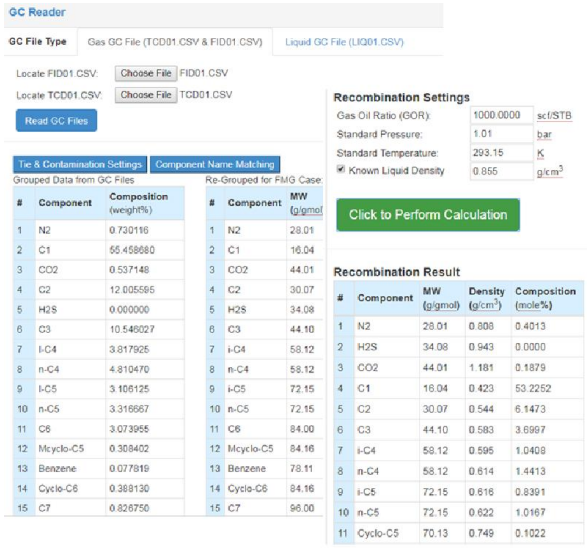
In order to optimize the exploration and production from the oil and gas fields, the reservoir fluids are sampled and sent to the laboratory for a series of tests to gain the knowledge of producing best quality products in a most economical way. These tests are usually carried out under the step-by-step changes of pressure and temperature. For example, it is essential to understand at what conditions the initial one-phase fluid splits into two phases, and the compositions and the properties of each phase, etc. Such tests are called PVT tests and the obtained PVT properties through the tests are usually expressed as functions of pressure and temperature.

These equations-of-state-based simulation modules are designed and developed for petroleum and petrochemical engineers as well as for laboratory technologists. This package interprets gas chromatograph (GC) files, determines sample compositions, analyzes and de-contaminates samples, performs reservoir fluid characterization, calculates multiple phase equilibria, and simulates a series of conventional PVT tests, etc. It provides an essential tool for the laboratory measurement planning, data processing and data QC.

1. GC Reader and Fluid Recombination

Gas chromatography (GC) is commonly used in the PVT laboratory to analyze compounds for gas and liquid samples.

This module of cloud computing reads the liquid and gas analysis CSV files from gas chromatography system and interprets them into liquid and gas compositions. For liquid analysis, an option is given whether or not an Internal Standard is added in analysis, and the module will then determine the liquid composition accordingly. For gas analysis, the module reads both FID and TCD files and combines them to generate gas composition through a tie component, such as, C1 or C2. An option is also given whether or not the air (through O2) is considered as a contaminant and hence the module will perform a correction on the gas composition.



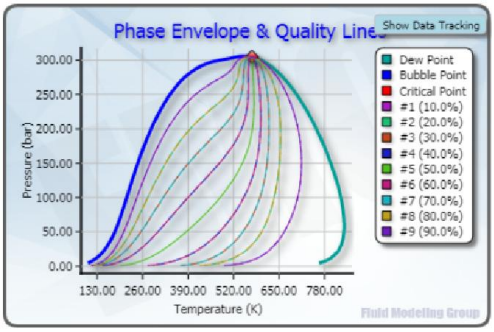
Once the liquid and gas compositions are determined, the module will perform liquid-gas recombination based on a given GOR to obtain a representative reservoir fluid sample.

2. Phase Envelope and Quality Lines

On a P-T diagram of a multicomponent mixture, it shows a temperature and pressure region usually encircled by a curve known as phase envelope. The closed area co-exists two phases. The phase envelope usually consists of a bubble point curve, a dew point curve and a critical point.

In the two-phase region on the P-T diagram, a curve graphing temperature against pressure on which the volume of the mixture remains constant is called isochore or isometric line. For reservoir engineers, the phase envelope and isochore provides essential information to further understand the reservoir fluid properties and make strategic plan on reservoir production.

Technically, the phase envelope may be obtained through a series of bubble point and dew point calculations. It is, however, time consuming and sometime causes a non-converging issue. In this module of the cloud computing, the mothed established by Michael L. Michelsen (1980) is adopted for the calculations of phase envelope and isometric lines.



3. VLE and Multi Phase Equilibria

The module performs Vapor-Liquid equilibria calculations including PT, PH, PS and PV flash and gives the fluid properties for both vapor and liquid streams.

The calculation of multiphase equilibrium is also called multiphase P-T flash calculation. The module performs the calculation of multiphase equilibria in the systems containing more than two phases: a gas phase, a liquid hydrocarbon phase, an aqueous phase and solid phase should the system exist multiple phases. At certain conditions, the system exists a CO_2-rich liquid phase.

Composition:

#	Component	MW (g/gmol)	Feed (mole%)	Vapor (mole%)	Liquid1 (mole%)	Liquid2 (mole%)	Liquid3 (mole%)
1	H2O	18.02	20.1447	0.3269	0.9327	99.5939	3.1237
2	N2	28.01	0.0802	0.2636	0.1278	5.3361e-6	0.0426
3	CO2	44.01	63.4166	90.9551	90.7234	0.4052	54.3150
4	H2S	34.08	0.0000	0.0000	0.0000	0.0000	0.0000
5	C1	16.04	2.7631	6.2663	3.8695	7.5512e-4	2.4972
6	C2	30.07	0.7751	0.9639	0.8977	6.8190e-5	1.0618
7	C3	44.10	0.5060	0.4023	0.5001	2.2766e-6	0.8563
8	i-C4	58.12	0.0642	0.0380	0.0579	5.6420e-9	0.1189
9	n-C4	58.12	0.5541	0.2743	0.4620	1.0305e-7	1.0993
10	i-C5	72.15	0.2653	0.0949	0.1985	1.1522e-9	0.5690
11	n-C5	72.15	0.3615	0.1134	0.2548	1.3527e-9	0.8049
12	C7-C10	112.83	4.3363	0.2691	1.4803	1.6606e-13	12.5976
13	C11-C14	168.83	2.6377	0.0298	0.3982	3.6350e-20	8.5979
14	C15-C19	230.54	1.8956	2.3172e-3	0.0875	5.2010e-24	6.5484
15	C20-C26	311.13	1.2785	6.2480e-5	9.6522e-3	1.1873e-25	4.5080
16	C27-C80	478.87	0.9208	5.9252e-8	1.5028e-4	1.2198e-23	3.2594

4. Characterization of Reservoir Fluids

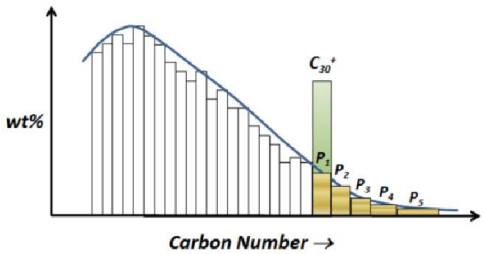
The characterization of the end fraction in reservoir fluids plays an important role in predicting the fluids properties and its phase behavior using equations of state. The reservoir fluid samples analyzed by the laboratory consist of an end fraction (Cn+) which is a mixture with unknown properties. The characterization on the end fraction is to use a group of pseudo-components to represent it by estimating the physical properties (critical temperature, Tc, critical pressure Pc and acentric factor, ω), so that the cubic equations of state may perform the calculations.

The certain rules have to be followed in the characterization of the end fraction in reservoir fluids including selection of a number of pseudo-components and appropriate correlations for the critical properties. There are three aspects in the fluid characterization:

1. To determine a distribution function for the reservoir fluid components
2. To define a number of pseudo-components and group lumping technic
3. To select the appropriate correlations for the critical properties of the pseudo-component

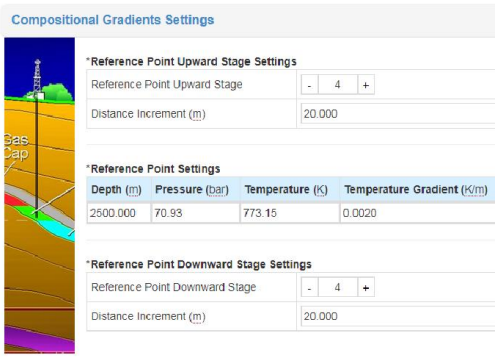
Please note the results of the characterization for the same fluid sample could be significantly altered by the choice of the distribution functions and the correlations of the critical properties.

In this module, the multiple distribution functions and a group of correlations for critical properties are provided for selection as well as a default setting.



5. Composition Gradient in Reservoir

The temperature and pressure as well as the compositions of the reservoir fluids vary with depth. While the deeper the depth, the higher the temperature and pressure, the compositions of the reservoir fluids are not necessarily changed monotonously. In general, the concentrations of the light components decrease with the depth while that of the heavy components increase. The changes of the compositions cause the changes of the fluid properties, such as, density and viscosity, etc. It is, therefore, very important to understand the composition gradient with the depth in reservoir in order to assess the reservoir and to make strategic plan in exploration and production.



There are many factors lead to the variation of the reservoir fluid compositions, for example, biodegradation, and mass transfer caused by the convection of the reservoir fluids. In this module of cloud computing, the equations of state are applied for the calculations of fluid compositions and properties changed with the depth in reservoir that are driven by fluid gravity, heat diffusivity and chemical potential.

The results of the calculations are displayed in terms of tables and 3-D phase diagram. The attached plot shows the phase behavior changed at the depth of 2,500 meter to 2,520 meter for a given reservoir fluids.。

Compositional GradientsCalculation Result:

Fluid Properties:

Property	2420(m)	2440(m)	2460(m)	2480(m)	2500(m)	2520(m)	2540(m)	2560(m)	2580(m)
Temperature (K)	772.99	773.03	773.07	773.11	773.15	773.19	773.23	773.27	773.31
Pressure (psia)	1017.08	1019.90	1022.77	1025.71	1028.72	1043.54	1058.60	1073.89	1089.39
Psat (psia)	0.00	0.00	783.04	941.35	1028.72	1013.71	999.84	986.40	974.72
Oil or Gas	Compositional Gradients Components: A+ A-								
GOR (vol/vol)									
Density (g/cm³)									
Viscosity (mPa.s)									
STO Density (g/cm³)									
C6+ MW (g/gmol)									
FVF									
Molar Volume (cm³/gmol)									
Tot. Solubility									

Composition (mole%)

#	Component	MW	2420(m)	2440(m)	2460(m)	2480(m)	2500(m)	2520(m)	2540(m)	2560(m)	2580(m)
1	N2	28.01	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	H2S	34.08	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	CO2	44.01	1.1147	1.1085	1.1019	1.0946	1.0000	0.4173	0.4102	0.4037	0.3977
4	C1	16.04	51.5235	51.1849	50.8314	50.4433	46.0000	18.8945	18.5508	18.2365	17.9463
5	C2	30.07	6.6118	6.5792	6.5450	6.5073	6.0000	2.8539	2.8079	2.7656	2.7265
6	C3	44.10	4.3474	4.3321	4.3159	4.2978	4.0000	2.1209	2.0897	2.0609	2.0342
7	i-C4	58.12	1.0740	1.0715	1.0688	1.0658	1.0000	0.5769	0.5689	0.5616	0.5548
8	n-C4	58.12	2.1423	2.1378	2.1329	2.1273	2.0000	1.1796	1.1639	1.1493	1.1358
9	i-C5	72.15	1.0579	1.0569	1.0558	1.0545	1.0000	0.6403	0.6324	0.6251	0.6183
10	n-C5	72.15	2.1121	2.1105	2.1086	2.1062	2.0000	1.2669	1.2511	1.2364	1.2227
11	C6	84.80	2.0820	2.0831	2.0839	2.0846	2.0000	1.4196	1.4037	1.3889	1.3751
12	C7-C13	131.56	14.1948	14.3024	14.4133	14.5343	14.9999	17.1323	17.0195	16.9116	16.8079
13	C14-C19	223.76	6.4303	6.5247	6.6230	6.7308	7.6351	12.8587	12.8594	12.8475	12.8304
14	C20-C27	319.19	4.3771	4.3898	4.4072	4.5744	5.8723	13.7976	13.8676	13.9292	13.9857
15	C28-C39	451.91	2.2916	2.3629	2.4384	2.5223	4.0558	13.8175	13.9977	14.1632	14.3184
16	C40-C80	702.08	0.7404	0.7758	0.8139	0.8568	2.4379	12.9840	13.3472	13.6965	14.0172

6. PVT Test Process Simulation

A series of conventional PVT tests includes Constant Composition Expansion/Constant Mass Expansion (CCE) Test, Differential Liberation (DL) Test, Constant Volume Depletion (CVD) Test, Separator Test and Swelling Test. The module can be used for measurement planning, test workflow and estimating the test results.

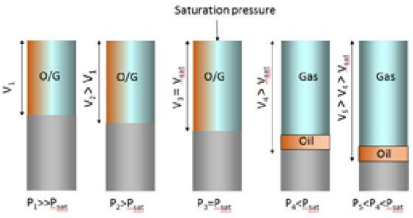
1) CCE Test

Once the compositions are determined at the laboratory, the CCE test is usually the first undergo test for either conventional oil or gas condensates. The test starts from the pressure higher than bubble point pressure at the reservoir temperature, and gradually decreases the pressure (hence the volume being expended at constant composition). The bubble point or dew point and the fluid properties changed with pressure and temperature are obtained from the test.

CCE Simulation Result:

(Temperature: 333.15 K, Sample State: Oil, Bubble Point Pressure: 217.86 bar)

	551.58 (bar)	395.99 (bar)	318.19 (bar)	240.39 (bar)	217.86 (bar)	162.59 (bar)	84.80 (bar)	7.00 (bar)	1.01 (bar)
Liq. Molar Vol. [cm³/gmol]	96.760	99.948	102.076	104.796	105.739	120.321	149.708	218.226	237.722
Liq. Density [g/cm³]	0.652	0.631	0.618	0.602	0.597	0.646	0.714	0.806	0.825
Liq. Viscosity [mPa.s]	0.2702	0.2436	0.2296	0.2149	0.2104	0.2779	0.4534	1.4924	2.2069
Vol/Vol(bt)	100.0000	100.0000	100.0000	100.0000	100.0000	71.6929	34.3540	1.9696	0.2515
Vol/Vol(sat)	91.5271	94.5231	96.5356	99.1082	100.0000	84.8426	70.0564	54.3385	50.4051
Vol(tot)/Vol(sat)	0.9153	0.9452	0.9654	0.9911	1.0000	1.1834	2.0393	27.5856	200.4046
Liq. MW [g/gmol]	63.10	63.10	63.10	63.10	63.10	77.69	105.90	175.79	196.15
Liq. Z Factor	1.9271	1.4268	1.1725	0.9095	0.8316	0.7063	0.4563	0.0651	0.0067
Liq. Compressibility [1/bar]	1.7574e-4	2.4489e-4	0.0003	3.8204e-4	4.1390e-4	-	-	-	-
Vap. Molar Vol. [cm³/gmol]	-	-	-	-	101				
Vap. Density [g/cm³]	-	-	-	-	0.1				
Vap. Viscosity [mPa.s]	-	-	-	-	2.4				
Vap. MW [g/gmol]	-	-	-	-	21.				
Vapor Z Factor	-	-	-	-	0.8				
Vapor Gravity	-	-	-	-	0.7				
Y Function	-	-	-	-	-				
Surface Tension [mN/m]	-	-	-	-	1.7				
Bulk Density [g/cm³]	0.652	0.631	0.618	0.602	0.5				



2) DL Test

The DL test starts from the bubble point pressure (for conventional oil) or dew point pressure (for gas condensate), and gradually decreases the pressure at a constant temperature. The volumes of the oil and the gas at each step are measured and the depleted gas is collected. Like CCE test, the purpose of the DL test is to understand the phase behavior and the PVT properties of the reservoir fluid at the reservoir conditions. It is also to obtain the information of the oil volume at the reservoir conditions as compared to that at the standard conditions, i.e., the oil formation volume factor, Bo and the gas formation volume factor, Bg.

3) CVD Test

The CVD test starts at the dew point pressure of the gas condensate, and measures the saturation volume at the dew point, Vsat. As the pressure decreases, the volume increases to form the gas-oil two phases. The gas is depleted from a valve at the top of the cylinder to keep the total volume of the two phases equal to the saturation volume at a constant pressure (see the schematic diagram). The percentage of the depleted gas as to the original gas is measured as well as the percentage of the liquid dropout of the liquid volume as to the saturation volume.

The PVT properties of the gas condensate or the volatile oil as they may change with each stage in the productions are obtained.

4) Separator Test

The objective of the separator test is to optimize the amount of oil produced at the surface. The test is carried out for either oil and gas condensate in single or multiple separators with the last stage at atmospheric pressure and temperature.

A sample of reservoir fluid is placed in the laboratory cell and brought to reservoir temperature and bubble point pressure. Then the oil is expelled from the cell to the next separator stage while the gas is let out and transferred to standard conditions. The process is repeated until stock tank conditions are reached. The solution GOR and the oil formation volume factor, Bo are measured in the test.

Separator Calculation Result:

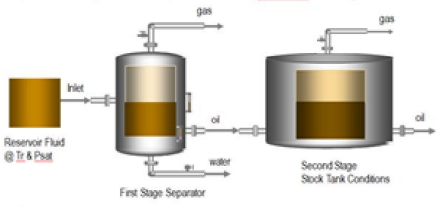
(Temperature: 350.00 K) Sample State: Oil, Bubble Point

- Liquid Molar Volume [cm³/gmol]
- Liquid Density [g/cm³]
- Liquid Viscosity [mPa.s]
- Liquid Heating Value [MJoule/m³]
- Liquid MW [g/gmol]
- Liquid Z Factor
- Liquid
- Vapor
- Vapor Molar Volume [cm³/gmol]
- Vapor Density [g/cm³]
- Vapor Viscosity [mPa.s]
- Vapor MW [g/gmol]
- Vapor Z Factor
- Vapor Gravity
- STO GOR [scf/STB]
- Separator GOR [scf/STB]
- Accumulated STO GOR [scf/STB]
- Bo
- Bg
- Heating Value [MJoule/m³]
- Surface Tension [mN/m]

VLE Equilibrium 1 (P=10.00 bar; T=323.15 K):

Fluid Properties:

Property	Feed	Vapor	Liquid	Unit/Description
Surface Tension	-	22.6400		mN/m
Z Factor	0.7178	0.9719	0.0773	PV/RT
Viscosity	0.0495	1.2914e-2	1.4653	mPa.s
Mole %	100.0000	71.5983	28.4017	mole%
Weight %	100.0000	25.0611	74.9389	wt%
Volume %	100.0000	96.9426	3.0574	vol%
MW	63.10	22.09	166.48	g/gmol
Specific Gravity	0.7133	0.4973	0.8346	
Molar Volume	1928.6837	2611.3958	207.6210	cm³/gmol
Density	0.033	8.457e-3	0.802	g/cm³
Heating Value	54.7800	45.8898	336.6643	MJoule/m³
Enthalpy (H)	5893.9054	11700.8488	-8744.9342	joule/mole
Entropy (S)	221.8690	210.4384	250.6845	joule/mole/K
Heat Capacity (Cp)	125.3184	45.6064	326.2658	joule/mole/K
Heat Capacity (Cv)	111.5557	36.1203	301.7224	joule/mole/K
dP/dT	0.0000	0.0326	4.7924	bar/K/mol
dP/dV				
dV/dT				
Light (mole%)				
Intermediate (mole%)				
Heavy (mole%)				
Gibbs Free Ene (G)				
Helmholtz (A)				



5) Swelling Test

The swelling test in a laboratory is a simulation process in which gas is injected into a reservoir containing usually under saturated oil. The injected gas or solvent dissolves causing the reservoir fluid to swell. In each stage of gas injection, the obtained fluid mixture is subjected to CCE test to determine the saturation pressure, relative volume, shrinkage factor and density and viscosity of single phase fluid.

The conventional swelling test is repeated until the saturation pressure of the mixed fluid reaches the experimental system pressure or the mixed fluid becomes gas condensates.

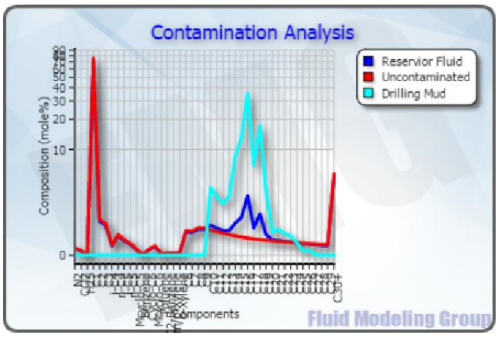
7. Contamination Analysis of Reservoir Fluids

The oil-based muds (OBM) are commonly used in the drilling process of crude oil due to its resistance to high temperature and corrosion, good lubrication and least to formation damage. However, the samples taken from the underground in an open hole well are often contaminated by the OBM which fail to represent the compositions and properties of the original reservoir fluids. It is, therefore, necessary to determine the contamination degree of the samples and to correct the PVT properties that are measured based on the contaminated samples, such as, saturation pressure, GOR, viscosity, density and formation volume factor, etc. In general, the compositions of the "clean samples" appear to follow a certain distribution pattern which can be used to determine the contamination of the fluid samples.

There are two methods to determine the contamination for a given sample: the Subtracting Method where the composition of the OBM is known; and the Skimming Method where the composition of the OBM is unknown.

Once the contamination is determined, i.e., the compositions of the "clean sample" are obtained, the correction of the PVT properties can be done following the procedures below:

- Performing the characterization using a couple of pseudo-components to represent the OBM (see Characterization of End Fraction in Reservoir Fluids);
- Creating a "new oil sample" to include the pseudo-components;
- Tuning the EOS model to match the measured the PVT properties based on the contaminated sample;
- Predicting the PVT properties of the "clean oil sample" (setting compositions of the pseudo-components to zero) and comparing them to that of the contaminated oil sample.



Other Functions:

1. Twelve popular Equations of State:
   1) Soave-Redlich-Kwong (SRK), 1972
   2) Peng-Robinson (PR), 1978
   3) Peng-Robinson (PR), 1976
   4) Peng-Robinson (Magoulas & Tassios revision), 1990
   5) Adachi-Lu-Sugie (ALS), 1983
   6) Patel-Teja, 1982
   7) Valderrama-Patel-Teja, 1990
   8) Schmidt-Wenzel, 1980
   9) Yu-Lu, 1987
   10) Modified Du-Guo, 1989
   11) Trebble-Bishnoi, 1987
   12) Salim Modified Trebble-Bishnoi, 1994

2. Popular viscosity modules
    - Lohrenz-Bray-Clark (LBC) Model
    - 2-Reference Corresponding States
    - 1-Reference Corresponding States
    - Peng-Robinson EOS Model
    - Friction Theory Model
3. Calculations of fluid PVT properties including Gas FVF, Oil FVF, GOR and Gas Recovery
4. Correlations of fluid properties including density, viscosity, compressibility, FVF, GOR, GWR and gas Z factor, etc. for gas, gas condensate, conventional oil, heavy oil and formation water
5. Quality check for DL, CVD and Separator Test data
6. Comprehensive model tuning against the measured data
7. Database of pure chemical compounds that is extendable as per user's request
8. Unit conversion and customization that accepts and adopts user defined units
9. Generation of the reports in pdf format as per user's specification