5. RECOMBINATION OF RESERVOIR FLUIDS.

In the laboratory the arriving fluid samples need to be analyzed to determine the reservoir fluid composition, before further fluid behavior properties are determined.

Reservoir fluids are shipped to the laboratory for analyses as bottom hole samples or wellhead samples representing the reservoir fluid. Alternatively, the reservoir fluid arriving from the well to the platform is separated into a "separator liquid" and a "separator gas" at platform separator temperature T_{sep} and pressure P_{sep}. The principle of a two-stage flash separation is seen in Fig.5.1:

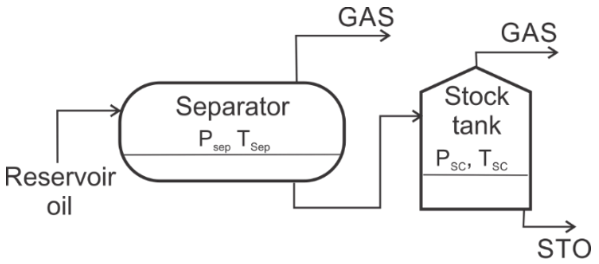

Fig. 5.1. Two stage flash of well stream (Reservoir Fluid)

All liquid samples containing dissolved gas (Reservoir fluid and Separator Liquid) need to be stabilized to prior to composition/chemical analyses.

5.1 Flash of fluids with dissolved gas

Reservoir fluid samples and separator liquid samples containing dissolved gas have to be flashed to Standard Conditions (SC) to separate the gas and liquid phase prior to chemical analyses. The principle of a plash test is described in Fig. 5.2.

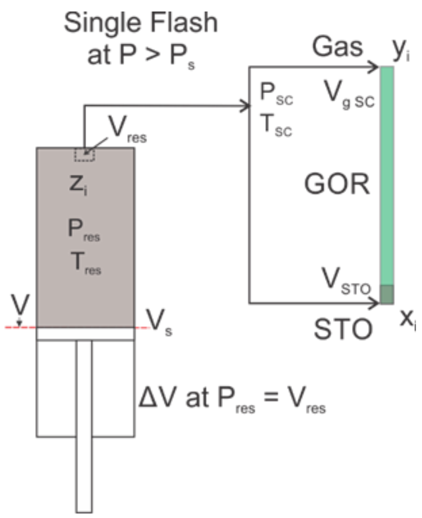

Fig. 5.2 Principle of single Flash experiment in laboratory

The fluid sample is the PVT cell is heated to test temperature T (T_{res} or T_{sep}) and the one phase fluid is equilibrated before pressure is reduced to test pressure P which could be reservoir pressure (P_{res}), saturation pressure (P_s), or separator pressure (P_{sep}).

- The cell volume $(V)_{P,T}$ is measured.
- Pressure is increased above P to secure that the only one phase fluid is removed from the cell during the flash.
- A small volume $(V_F)_{P,T}$ of the one phase fluid are flashed to $(P, T)_{SC}$

- Cell pressure is reduced again to P, and $(V_F)_{P,T}$ measured as reduced cell volume
- liberated gas volume $(V_g)_{SC}$ in the Flash apparatus is measured at SC
- mass of stabilized oil (m_{STO}) in the Flash apparatus are measured.
- ρ_{STO} measured at SC
- Representative samples of liberated gas ($(V_g)_{SC}$) and Stabilized oil (STO) from the flash experiment are collected for composition analyses (GC analyses).

Based on the flash results, V_{STO} could be calculated:

$$V_{STO} = \frac{m_{STO}}{\rho_{STO}} \tag{5.1}$$

GOR for the flashed fluid is;

$$(GOR)_{P,T} = \frac{V_{g\,SC}}{V_{STO}} \tag{5.2}$$

and the volume factor, $(B_o)_P$, for the fluid:

$$(B_o)_P = \frac{(V_F)_{P,T}}{V_{STO}} \tag{5.3}$$

5.2 Recombination calculations from Flash experiment

Flash performed on an oil sample with dissolved gas gives all data needed for a mathematical recombination of the composition (z_i) of the Flashed sample. GC analyses of the evolved Gas phase (y_i) and STO (x_i), combined with measured GOR from the flash and the amount of STO (m_{STO}) are used in the calculations. Moles Gas produced (n_g) relative to moles STO produced (n_{STO}) can easily be calculated if calculations are based on 1 m^3 STO.

Moles of Gas, n_g (V_{STO} =1m^3)

$$n_g = \frac{(V_g)_{SC}}{V_m} = \frac{GOR}{V_m}, \quad where\ GOR = \frac{(V_g)_{SC}}{V_{STO}} \tag{5.4}$$

Moles of STO, n_{STO} (V_{STO} =1m^3)

$$n_{STO} = \frac{m_{STO}}{M_{STO}} = \frac{\frac{\rho_{STO}}{V_{STO}}}{M_{STO}} = \frac{\rho_{STO}}{M_{STO}} \tag{5.5}$$

From GC analyses, the mass of the individual STO components is calculated :

$$m_i = R_s \cdot A_i, where\ R_s = \frac{m_s}{A_s}\ (s = internal\ standard) \tag{5.6}$$

For an analysis up to C10+, the mass of STO is expressed as:

$$m_{STO} = \sum_{C1}^{C9} m_i + m_{C10+} \tag{5.7}$$

and where the m_{C10+}:

$$m_{C10+} = m_{STO} - \sum_{C1}^{C9} m_i \tag{5.8}$$

We could then complete the $(m\%)_i$:

$$(m\%)_i = \frac{m_i \cdot 100}{m_{STO}} \tag{5.9}$$

The mole fraction of the individual components (x_i) by calculating

$$x_i' = \frac{(m\%)_i}{M_i} \tag{5.10}$$

and ny normalizing:

$$x_i = \frac{x_i'}{\sum x_i'} \tag{5.11}$$

as seen in Tbl. 5.1:

Tbl. 5.1 Composition analyses of STO

Comp	m_i	$(m\%)_i$	M_i	$x_i' = \frac{(m\%)_i}{M_i}$	Normalized $x_i = \frac{x_i'}{\sum x_i'}$	ρ_i
C1 C2 ⋮ i-C5 n-C5 C6 ⋮ C9 C10+			M_{C10+}			ρ_{C10+}
				$.\sum x_i'$	$.\sum = 1$	

x_i could be expressed in:

$g\ mole = \frac{m\ [g]}{M}$

$kg\ mole = \frac{m\ [kg]}{M}$, or

$lb\ mole = \frac{m\ [lb]}{M}$

To complete all the calculations of STO composition, also M_{C10+} and ρ_{C10+} is needed.

Molecule weight of the STO (M_{STO}) is measured in the laboratory by freezing point depression. In 100g STO, the calculated molecule weight of the C10+ fraction, M_{C10+}:

$$n_i = \frac{m_i}{M_i}, \qquad \frac{100}{M_{STO}} = \sum_{C1}^{C9} \frac{(m\%)_i}{M_i} + \frac{(m\%)_{C10+}}{M_{C10+}} \tag{5.12}$$

Density of STO, ρ_{STO}, is measured after the flash with an Anton-Parr densitometer. Based on 1 mole STO ($m_{STO} = M_{STO}$), then $x_i M_i = m_i$, and density of plus fraction, ρ_{C10+} could be calculated:

$$\rho_{STO} = \frac{m_{STO}}{V_{STO}} = \frac{M_{STO}}{\sum_{C1}^{C9} \frac{x_i \cdot M_i}{\rho_i} + \frac{x_{C10+} \cdot M_{C10+}}{\rho_{C10+}}} \tag{5.13}$$

Finally, the recombination calculations could be performed for the Flashed Oil when molar composition of the liberated Gas (y_i) and STO (x_i) are known:

$$z_i' = \frac{GOR}{V_m} y_i + \frac{\rho_{STO}}{M_{STO}} x_i \tag{5.14}$$

Tbl. 5.2 Recombination of Flashed Oil

Comp	(Gas)sc y_i	STO x_i	$z_i' = \frac{GOR}{V_m} y_i + \frac{\rho_{STO}}{M_{STO}} x_i$	$z_i = \frac{z_i'}{\sum z_i'}$
C1				
C2				
⋮				
⋮				
i-C5				
n-C5				
C6				
⋮				
⋮				
C9				
C10+				
			$\cdot\sum z_i'$	$\cdot\sum z_i = 1$

Normalized z_i' gives the Flashed Oil composition:

$$z_i = \frac{z_i'}{\sum z_i'} \tag{5.15}$$

5.3 Principle of Recombination of Reservoir fluid from separator test.

Reservoir fluid sampling from test separator, results in Separator gas and Separator liquid samples with a GOR_{rig}.

The GOR_{rig} is corrected to laboratory conditions, $GOR_{corr} = GOR_1$, where the recombination take place.

The separator gas is analyzed (GC) for composition, $(y_i)_1$.

The separator Liquid goes through a Flash to SC with a Gas oil ratio of GOR_2. GC analyses giving the composition of Gas $(y_i)_2$ and STO $(x_i)_2$. Fig. 5.3 describes the process:

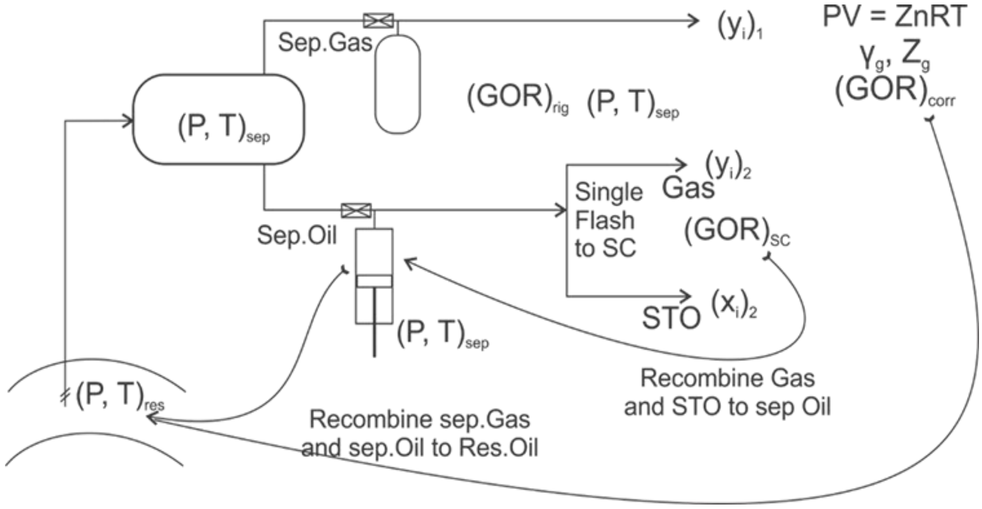

Fig. 5.3 Separator test and recombination to reservoir fluid.

The un-normalized separator oil composition z_i' are calculated based on one volume unit (1 m^3 STO)

$$z_i' = \frac{GOR_2}{V_m}(y_i)_2 + \frac{\rho_{STO}}{M_{STO}}(x_i)_2 \tag{5.16}$$

Un-normalized Reservoir Fluid z_i'' :

$$z_i'' = \frac{GOR_1}{V_m}(y_i)_1 + z_i' \tag{5.17}$$

Normalizing z_i'', gives reservoir fluid composition z_i :

$$z_i = \frac{z_i''}{\sum z_i''} \tag{5.17}$$

Tbl. 5.3 Recombination of Flashed Oil

Comp	(Gas)Sep $(y_i)_1$	STO $(x_i)_2$	(Gas)Flash $(y_i)_2$	$z_i' = \frac{GOR_2}{V_m}(y_i)_2 + \frac{\rho_{STO}}{M_{STO}}(x_i)_2$	$z_i'' = \frac{GOR_1}{V_m}(y_i)_1 + z_i'$	$z_i = \frac{z_i''}{\sum z_i''}$
C1 C2 ⋮ i-C5 n-C5 C6 ⋮ C9 C10+						
				$.\sum z_i'$		$.\sum z_i = 1$

5.4 Determination of Reservoir Fluid composition

The reservoir fluid arriving from the well to the platform is separated into a "separator liquid" and a "separator gas" at platform separator temperature T_{sep} and pressure P_{sep}. The separator liquid is in turn flashed at ambient conditions (T_{SC} and P_{SC}) in the laboratory. The principle of the two stage flash separation is shown in Fig. 5.1.

The reservoir fluid composition is obtained by combining the analyses of the laboratory gas and the stock tank oil, from which the composition of the separator liquid is determined as described in Fig.5.2.

The analysis of the separator liquid is in turn combined with the analysis of the separator gas to yield the composition of the reservoir fluid (or well stream), Fig. 5.3.

To recombine the previously mentioned analyses correctly, it is necessary to know the gas-to-liquid ratio, the so-called gas/oil ratio (GOR), both at platform and at ambient conditions.

An example of such data is given in Tbl. 5.4.

Basis for the recombination can be, e.g., 1 Sm^3 of stock tank oil (STO). The total number of moles of each component (or fraction or residue) in this Sm^3 of STO is calculated.

The molar volume, V_m, of an ideal gas at atmospheric pressure and 0°C equals 22.4 m^3. The total individual number of moles of gas sample corresponding to 1 Sm^3 of liquid sample may be obtained from:

$$Moles\ gas, n = \frac{GOR}{V_m \cdot \frac{T_{SC}}{273.15}} = \frac{GOR}{22.4 \cdot \frac{T_{SC}}{273.15}} \tag{5.18}$$

where:

GOR is either GOR_{sep} or GOR_{SC} [platform (field), or ambient conditions, respectively].

Tbl. 5.4. Composition Analyses, Gas/Oil Ratios, and Formation Volume Factors of separator Fluids for a volatile oil.

Component	Stock Tank Oil Mole%	Stock Tank Gas Mole%	Separator Gas Mole%
Nitrogen	0.00	0.20	0.66
Carbon dioxide	0.00	3.96	5.65
Methane	0.00	24.86	68.80
Ethane	0.20	20.40	12.86
Propane	2.14	28.42	7.94
i-Butane	1.10	4.78	0.94
n-Butane	4.25	10.97	1.96
i-Pentane	2.68	2.21	0.34
n-Pentane	4.32	2.53	0.42
Hexanes	6.66	1.05	0.22
Heptanes	11.90	0.54	0.15
Octanes	13.14	0.10	0.05
Nonanes	7.73	0.00	0.00
Decanes plus	45.89	0.00	0.00
∑	100.00	100.00	100.00

Gas/oil ratio at separator, GOR_{sep} = 442 Sm^3/m^3 separator oil
Gas/oil ratio at ambient flash, GOR_{SC} = 36.9 Sm^3/m^3 STO
Flash formation volume factor of separator liquid $(B_o)_{sep}$ = 1.165 m^3/m^3 STO
Average molecular weight (M) of the Stock Tank Oil M_{STO} = 160.4 kg/mole
Density of StockTankOil ρ_{STO} = 860 kg/m^3

From the moles of gas plus the composition of the gas samples (y_i), the amounts of individual gas-phase components in both gas streams can be determined.

Finally, the total number of moles of each component from the test separator phases could then be added (Fig. 5.3) and normalized to yield the composition of the recombined fluid, i.e., the reservoir fluid.

Example 5.1 Recombination of Stock Tank Oil, Stock Tank Gas, and Separator Gas.

A reservoir fluid is flashed at the field separator, and the separator liquid is flashed to ambient conditions in the laboratory, yielding a stock tank liquid and an evolved gas. The composition analysis and other experimental information are given in Tbl. 5.4.

Solution

From the available data, first compute the number of moles (n) in each of the streams.
As a basis for the calculations, we choose 1 m^3 of stock tank oil (STO).

Moles STO, n_{STO}:

$$n_{STO} = \frac{\rho_{STO}}{M_{STO}} = \frac{860\ kg}{160.4\ kg/mole} = 5.36\ moles$$

Moles of evolved gas at Stock Tank;

$$n_{gas,STO} = \frac{GOR}{22.4\ {}^{moles}/_{m^3} \cdot \frac{T_{SC}}{273.15}} = \frac{36.9\ Sm^3}{22.4 \cdot \frac{288}{273}} = 1.56\ moles$$

The volume of gas (Sm^3) per 1 m^3 STO ($V_{gas,SC}$):

$$V_{gas,SC} = GOR_{sep} \cdot B_{o,sep} = 442\ m^3 \cdot 1.165\ {}^{Sm^3}/_{m^3} = 515\ Sm^3$$

The number of moles of separator gas is thus:

$$n_{gas,sep} = \frac{GOR_{sep}}{22.4\,{}^{moles}/_{m^3} \cdot \frac{T_{SC}}{273.15}} = \frac{515\ Sm^3}{22.4 \cdot \frac{288}{273}} = 21.79\ moles$$

The total number of moles of the reservoir fluid per m³ stock tank oil is thus:

$$n_{res.fluid} = n_{STO} + n_{gas,STO} + n_{gas,sep} = 5.36 + 1.56 + 21.79 = 28.71 moles$$

The number of moles of each component in each stream may now be computed by multiplying the mole% given in the compositional analysis by the total number of moles in each stream and dividing by 100. The results are given in Tbl. 5.5.

Finally, the number of moles of each component in the reservoir fluid is obtained by adding the number of moles in each stream:

Moles of n-pentane in the reservoir fluid:

$$n_{n-C5,res.fluid} = 0.2316\ +\ 0.0395\ +\ 0.0915\ =\ 0.3626\ moles$$

The mole % of n-pentane in the reservoir fluid:

$$mole\%_{\ (n-C5,res.fluid)} = \frac{0.3626\ moles_{n-C5} \cdot 100}{28.71\ moles_{res.fluid}} = 1.26\ mole\%$$

Tbl. 5.5. Number of Moles of Each Component in Each Separator Stream

Component	Stock Tank Oil moles	Stock Tank Gas moles	Separator Gas moles
Nitrogen	-	0.0031	0.1438
Carbon dioxide	-	0.0618	1.2311
Methane	-	0.3878	14.9915
Ethane	0.0107	0.3182	2.8022
Propane	0.1147	0.4434	1.7301
i-Butane	0.0590	0.074k6	0.2048
n-Butane	0.2278	0.1711	0.4271
i-Pentane	0.1436	0.0345	0.0741
n-Pentane	0.2316	0.0395	0.0915
Hexanes	0.3570	0.0164	0.0479
Heptanes	0.6378	0.0084	0.0327
Octanes	0.7043	0.0016	0.0109
Nonanes	0.4143	-	-
Decanes plus	2.4597	-	-
∑	5.36	1.56	21.79

The final molar composition of the reservoir fluid is shown in Tbl. 5.6.

The recombination computations are normally performed for compositions to C10+. However, for equation of state calculations computations to C20+ are preferred. The C10 to C20+ compositions are normally obtained by extending the recombination result using the distillation data. Using these data, the recombined C10+-fraction is divided into its appropriate ratios up to C20+.

The result at this stage is a well checked, consistent composition analysis of the reservoir fluid.

Tbl. 5.6. Reservoir Fluid Composition

Component	Reservoir Fluid moles	Reservoir Fluid Mole%
Nitrogen	0.1469	0.51
Carbon dioxide	1.2920	4.50
Methane	15.3793	53.57
Ethane	3.1311	10.91
Propane	2.2882	7.97
i-Butane	0.3384	1.18
n-Butane	0.8260	2.88
i-Pentane	0.2522	0.88
n-Pentane	0.3626	1.26
Hexanes	0.4213	1.47
Heptanes	0.6789	2.36
Octanes	0.7168	2.50
Nonanes	0.4143	1.44
Decanes plus	2.4597	8.57
$\sum$	28.71	100.00

The recombination computations are normally performed for compositions to (C7+ or) C10+. However, for equation of state calculations computations to C20+ are preferred. The C10 to C20+ compositions are normally obtained by extending the recombination result using the distillation data. Using these data, the recombined C10+-fraction is divided into its appropriate ratios up to C20+.

The result at this stage is a well checked, consistent composition analysis of the reservoir fluid.