# Optimization of Separator Train in Oil Industry

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**Abstract -** The fluid that comes out a typical well is actually a combination of crude oil and natural gas often mixed with water, non-hydrocarbon gases and other impurities. That is the reason why the volume of crude oil and natural gas is so different from the reservoir and surface conditions. In general, the volume of oil remaining at the lowest pressure will be smaller for flash process and in surface separators, there is flash expansion of oil i.e. gas stays in equilibrium with oil. However, If multi-stage separation, then gas is physically removed from the first stage separator, before the oil enters the second stage separator at different P and T conditions thus making it a non-isothermal differential liberation. Hence, engineers should consider that differential liberation could take place in separator as the differential liberation test is considered to better describe the separation process taking place in the reservoir and is also considered to simulate the flowing behavior of hydrocarbon systems at conditions above the critical gas saturation. As the saturation of the liberated gas reaches the critical gas saturation, the liberated gas begins to flow, leaving behind the oil that originally contained it. This is attributed to the fact that gases have, in general, higher mobility than oils. Consequently, this behavior follows the differential liberation sequence. The test is carried out on reservoir oil samples and involves charging a visual PVT cell with a liquid sample at the bubble-point pressure and at reservoir temperature. The volume of oil remaining is also measured at each pressure level. The remaining oil is subjected to continual compositional changes as it becomes progressively richer in the heavier components. This paper describes the optimization performed in crude oil facility to enhance the oil recovery.

*Key Words*:  **(Bubble point pressure, oil formation value factor, oil-gas ratio, constant composition expansion.)**

## 1.  INTRODUCTION

In recent times of Separation of crude oil as it reaches the surface from the reservoir it must be processed so that it can be sent either to storage or to a refinery for further processing. In fact, the main purpose of the surface facilities is to separate the produced multiphase stream into its vapor and liquid fractions. On production platforms, a multiphase separator is usually the first equipment through which the well fluid flows, followed by other equipment such as heaters, exchangers, and distillation column as shown in Figure 1.
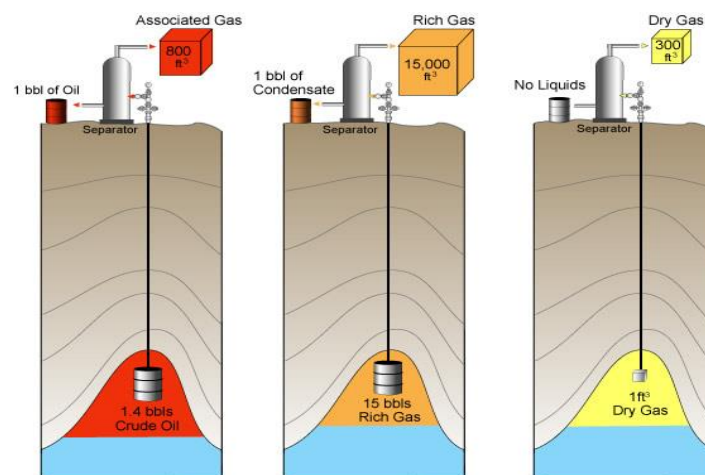


**Fig:-1:** Separation of reservoir fluid.

## 2.  SEPARATION

Separator tests are conducted to determine the changes in the volumetric behavior of the reservoir fluid as the fluid passes through the separator (or separators) and then into the stock. The resulting volumetric behavior is influenced to a large extent by the operating conditions, i.e., pressures and temperatures, of the surface separation facilities. The primary objective of conducting separator tests, therefore, is to provide the essential laboratory information necessary for determining the optimum surface separation conditions, which in turn will maximize the stock-tank oil production. In addition, the results of the test, when appropriately combined with the differential liberation test data, provide a means of obtaining the PVT parameters (Bo, Rs, and Bg) required for petroleum engineering calculations. These separator tests are performed only on the original oil at the bubble point.The test involves placing a hydrocarbon sample at its saturation pressure and reservoir temperature in a PVT cell. The volume of the sample is measured as Vsat. The hydrocarbon sample is then displaced and flashed through a laboratory multistage separator system—commonly one to three stages. The pressure and temperature of these stages are set to represent the desired or actual surface separation facilities. The gas liberated from each stage is removed and its specific gravity and volume at standard conditions are measured. The volume of the remaining oil in the last stage (representing the stock-tank condition) is measured and recorded as (Vo)st. These experimental, measured data can then be used to determine the oil formation volume factor and gas solubility at the bubble-point pressure as follows:

$$B_{ofb} = \frac{V_{sat}}{\left(V_o\right)_{st}}$$

$$R_{sfb} = \frac{\left(V_g\right)_{sc}}{\left(V_o\right)_{st}}$$

The above laboratory procedure is repeated at a series of different separator pressures and at a fixed temperature. It is usually recommended that four of these tests be used to determine the optimum separator pressure, which is usually considered the separator pressure that results in minimum oil formation volume factor. At the same pressure, the stock tank oil gravity will be maximum and the total evolved gas, i.e., the separator gas and the stock-tank gas will be at a minimum.

### 2.1 One separator test:

The goal of the one-separator test is to find the separation pressure and temperature such that the solution gas oil ratio at the bubble point is a minimum, the API gravity of the oil at stock tank conditions is a maximum, and the formation volume factor at the bubble point (BoSb ) is a minimum.

### 2.2 Two or more separator test: The objective here is the same as with one separator (obtain a maximum API gravity oil), but  here you need to optimize the pressure and temperature of two separators.  We use the output  from one of these tests to illustrate the calculation procedure.

### 2.3 Flash and Differential liberation test: In order to measure GOR lab measurements of crude oil the two basic laboratory experiments are:

1.  Flash liberation:

In flash liberation,  crude oil is flashed in separator, therefore less Rs & Bo from the solution— hence, gas remains in equilibrium with oil and Overall hydrocarbon   composition remains same (components are re-distributed between the gas and liquid phase).

2. Differential liberation:

At each stage of depletion gas physically removes from contact with oil and there is continual change of fluid composition on the other hand Remaining hydrocarbons in progressively become heavier (mol. wt. continually increases).

## 3. METHODOLOGY & CALCULATIONS

**Constant compositional expansion and Differential liberation test:**

The following compositional information as shown in table 1 computed by PETE 310 for Reservoir fluids will help us in interpreting our results.

The reservoir temperature is T= 220 F and the initial reservoir pressure is 2200 psia

**Constant Composition Expansion (CCE) Results.**

Table 2 shows the CCE data with pressure steps of 200 psia, here the experiment ends at 200 psia The table displays the liquid and vapor fraction, the compressibility factor, and the volumes of oil and gas at each pressure stage. From this table we can find the bubble point pressure graphically.

**Table 1**— Compositional data of crude oil sample.

| Component | Mol. Wt. | Pc (psia) | Tc ($^\delta$F) | Accentric factor | Moles | Zi |
|---|---|---|---|---|---|---|
| Methane | 16 | 667.4 | -116.9 | 0.008 | 48.5 | 0.36283384 |
| Ethane | 30 | 708.5 | 89.7 | 0.098 | 9.67 | 0.07234234 |
| n-pentane | 72.2 | 489.5 | 385.3 | 0.251 | 10 | 0.0748111 |
| n-hexane | 86 | 477.2 | 453.5 | 0.275 | 65.5 | 0.49001272 |

**Table 2 –**Constant composition expansion results.

| Pressure (PSI) | Fw | Fo | Fg | Zw | Zo | Zg | vw(cc) | vo (cc) | vg (cc) |
|---|---|---|---|---|---|---|---|---|---|
| 2200 | 0.0000 | 1.0000 | 0.0000 | 0.0000 | 0.5240 | 0.0000 | 0.0000 | 14.5072 | 0.0000 |
| 2000 | 0.0000 | 1.0000 | 0.0000 | 0.0000 | 0.4833 | 0.0000 | 0.0000 | 14.7182 | 0.0000 |
| 1800 | 0.0000 | 1.0000 | 0.0000 | 0.0000 | 0.4420 | 0.0000 | 0.0000 | 14.9569 | 0.0000 |
| 1600 | 0.0000 | 1.0000 | 0.0000 | 0.0000 | 0.4001 | 0.0000 | 0.0000 | 15.2307 | 0.0000 |
| 1400 | 0.0000 | 0.9972 | 0.0028 | 0.0000 | 0.3884 | 0.8042 | 0.0000 | 15.2694 | 0.0886 |
| 1200 | 0.0000 | 0.8366 | 0.1634 | 0.0000 | 0.3114 | 0.8352 | 0.0000 | 13.2223 | 6.9278 |
| 1000 | 0.0000 | 0.7622 | 0.2378 | 0.0000 | 0.2650 | 0.8532 | 0.0000 | 12.3008 | 12.3578 |
| 800 | 0.0000 | 0.6947 | 0.3053 | 0.0000 | 0.2168 | 0.8713 | 0.0000 | 11.4667 | 20.2564 |
| 600 | 0.0000 | 0.6286 | 0.3714 | 0.0000 | 0.1666 | 0.8897 | 0.0000 | 10.6317 | 33.5403 |
| 400 | 0.0000 | 0.5535 | 0.4465 | 0.0000 | 0.1140 | 0.9078 | 0.0000 | 9.6088 | 61.7229 |
| 200 | 0.0000 | 0.4134 | 0.5866 | 0.0000 | 0.0587 | 0.9229 | 0.0000 | 7.3857 | 164.8516 |

From P-V graph by the intersection of two lines we can see that the bubble point pressure for this mixture is between 1600 & 1400 psia. Refining the search provides Pb = 1545 psi, note that at this pressure the volume of gas obtained is very small.

**Differential liberation**

Table 3 displays the differential liberation results for our example mixture. This output includes the fraction of liquid and vapour, the compressibility factor, and the volume of oil and gas at the specified pressure and temperature. This volume of gas is removed from the cell before the next expansion. Using data from this table we can compute $R_{sd}$, $B_{od}$, and $B_g$ as indicated below in calculations.
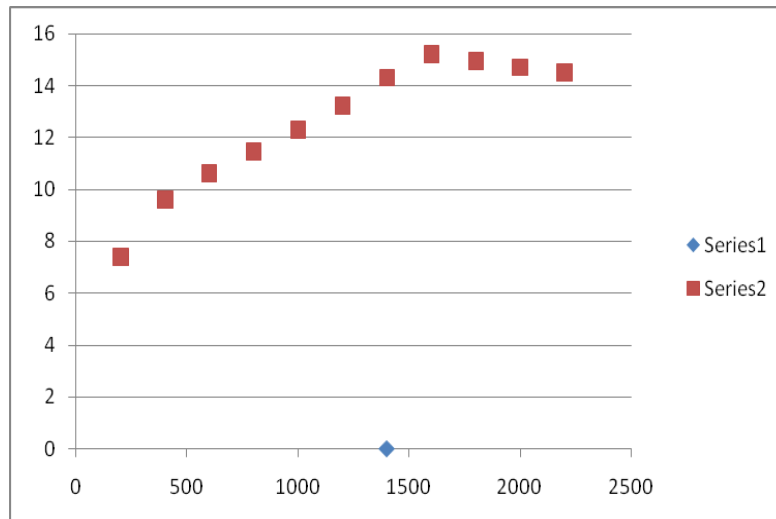


**Table 3 –** Differential liberation results at T =220$^\delta$F

| Pressure (Psi) | Fo | Fg | Zo | Zg | Vo , cm*3 | Vg, cm*3 |
|---|---|---|---|---|---|---|
| 1545 | 1.0000 | 0.0000 | 0.3966 | 0.0000 | 11.9553 | 0.0000 |
| 1000 | 0.9429 | 0.0571 | 0.2653 | 0.8154 | 11.6517 | 2.1677 |
| 500 | 0.7892 | 0.2108 | 0.1469 | 0.8974 | 10.1858 | 16.6163 |
| 100 | 0.8114 | 0.1886 | 0.0325 | 0.9711 | 9.1343 | 63.4813 |
| 14.7 | 0.9234 | 0.0766 | 0.0049 | 0.9886 | 8.7055 | 144.8846 |
| 14.7 psi, 60F | 1.0000 | 0.0000 | 0.0049 | 0.0000 | 8.7055 | 0.0000 |

**Separator Tests**

The objectives of the separator tests are to optimize the amount of oil produced at the surface. You will conduct tests with one and two separators; your goal is to find the best pressure and temperature combinations (for one or multiple separators) that maximize liquid production. The stock tank, which acts as another separator at standard temperature and pressure, is included automatically in your computation. The goal of the one-separator test is to find the separation pressure and temperature such that the solution gas oil ratio at the bubble point is a minimum, the API gravity of the oil at stock tank conditions is a maximum, and the formation volume factor at the bubble point (Bosb) is a minimum.

**Table 4 –** Single separator test results

| Pressure (psia) | T (°F) | Fo | Fg | Z0 | Zg | Vo in cm³ | Vg( cm³ ) | ρo ,( lb /ft³) | ρg, (lb /ft³) |
|---|---|---|---|---|---|---|---|---|---|
| 1545 | 220 | 0.9972 | 0.0028 | 0.3884 | 0.8042 | 15.2694 | 0.0886 | 30.3073 | 6.6528 |
| 150 | 100 | 0.5871 | 0.4129 | 0.0466 | 0.9640 | 9.1312 | 132.7221 | 42.5594 | 0.5587 |
| 14.7 | 60 | 0.9208 | 0.0792 | 0.0049 | 0.9898 | 8.4342 | 145.4989 | 44.5354 | 0.0893 |

**One Separator Test Results**

Table 4 shows the PVT properties from the example mixture at its bubble point (computed earlier) and at a separator pressure and temperature of 150 psia and 100 °F. The corresponding PVT properties from the separator test are computed as follows:

1. **Bosb** = volume of oil at bubblepoint pressure/volume of oil at standard conditions ( in bbl/sto).

= 15.2694/8.4342

= 1.81 bbl/sto

2. The volume of gas released from the separator at standard conditions :

$$\mathbf{Vsc1} = (Ps.Vs/Zs.Ts) \times (Tsc.Psc)$$

$$= \frac{150 \times 132.77 \times (60+460)}{.9640 \times (100+460) \times 14.7}$$

$$= 1257.88 \text{ cm3.}$$

3. The solution-gas -oil -ratio of the separator is then :

**RsSb** = Vsc+Volume of gas at standard conditions / Volume of oil at standard conditions (in scf/sto)

$$= \frac{1257.88 + 145.4989}{8.4342} \times 5.614 \text{ scf/sto}$$

=934.121 scf/sto

4. Density of oil at standard conditions :

**ρo** (Tsc, psc) = 44.5354 lbm/ft3

or in **API** = 141.5/(44.5354/62.4)-131.5 = 66.77

**Two Separators**

The objective here is the same as with one separator (obtain a maximum API gravity oil), but here we need to optimize the pressure and temperature of two separators. We use the output from one of these tests to illustrate the calculation procedure.

In this example we chose Separator 1 at 500 psia and 100 °F and Separator 2 at 100 psia and 80 °F.

The corresponding PVT properties from this separator     test are computed as follows:

1. **Bosb** =volume of oil at bubble point pressure/volume of oil at standard conditions (in bbl/sto)

       = 15.2694/8.6498

        = 1.76 bbl/sto.

2. The volume of gas released from the separator at standard conditions:

(a.)**Vsc1** = (Ps.Vs.Tsc /Zs.Ts.Psc)……………… (At 500 psia and 100 $^\delta$f).

**Table 5 –** Two separator test results

$$= \frac{500 \times 26.3569 \times (60+460)}{.9098 \times (100+460) \times 14.7}$$

   = 914.99 cm3

(b.)**Vsc2** = (Ps.Vs.Tsc /Zs.Ts.Psc)……………… (at 100 psia and 80 $^\delta$f)

$$= \frac{100 \times 49.7227 \times (60+460)}{.9715 \times (80+460) \times 14.7}$$

= 335.27 cm3

3. The total solution-gas –oil-ratio is the sum of all volumes of gas released in each stage divided the oil volume at standard conditions :

 **RsSb =** Vsc1 + Vsc2 + volume of gas at standard conditions/volume of oil  at standard conditions .

$$= \frac{914.99+335.27+139.9513}{8.6498} \times 5.614 \text{ scf/sto.}$$

   = 902.29 scf/sto.

4. Density of oil at standard conditions:

**ρo** (Tsc, psc) = 44.4944 in lbm/ft$^3$

or in **API** = 141.5/(44.4944/62.4)-131.5 = 66.94

**Table 5 –** Two separator test results

| P,psia | T *f | Fo | Fg | Zo | Zg | Vo , cm³ | Vg , cm³ | ρo, lb/ft³ | ρg, lb/ft³ |
|--------|------|--------|--------|--------|--------|----------|----------|-----------|-----------|
| 1545 | 220 | 0.9972 | 0.0028 | 0.3884 | 0.8042 | 15.2694 | 0.0886 | 30.3073 | 6.6528 |
| 500 | 100 | 0.7104 | 0.2896 | 0.1440 | 0.9098 | 10.2350 | 26.3569 | 40.7404 | 1.7375 |
| 100 | 80 | 0.8449 | 0.1551 | 0.0325 | 0.9715 | 9.0628 | 49.7227 | 43.9127 | 0.3822 |
| 14.7 | 60 | 0.9254 | 0.0746 | 0.0049 | 0.9887 | 8.6498 | 139.9513 | 44.4944 | 0.0936 |

In the above case, we have lower Bosb, and higher API gravity than in the previous n case. Clearly, by adding a separation stage we will have a better oil quality and less gas production

## 4. CONCLUSION AND SCOPE

In general the volume of oil remaining at the lowest pressure will be smaller for flash expansion & in separator there is flash expansion of oil. However if multi-stag separation is done then gas is physically removed from the first stage separator, before the oil enters the second stage separator at different P & T conditions thus making it is as non-isothermal differential liberation .Hence engineers should consider that multi-stage separation could take place in separators as the differential liberation test is

considered to better describe the separation process taking place in reservoir and is also considered to simulate the flowing behavior of hydrocarbon systems at conditions above the critical gas saturation, as the saturation of gas reaches critical gas saturation, the liberated gas begins to flow leaving behind the oil original contained in it .This is attributed from the fact that gas have higher mobility than oils.

## 5. REFERENCES

1. H.Y. Al-yousef (king fahd university of petroleum and minerals) | M.A. Al-marhoun (king fahd university of petroleum and minerals) published by journal of Canadian petroleum technology, march 1995.

2. Ali Pourahmadi Laleh and William Y. Svrcek, University of Calgary, "Computational Fluid Dynamics-Based Study of an Oilfield Separator"

3. McCain, W.D. Jr. : " Analysis of Black oil PVT reports Revisited," paper SPE 77386 presented at the SPE Annual Conference and Exhibition, San Antonio ,Texas ,29 sept – 2 oct.

4. Moses, P.L.: "Engineering Applications of Phase Behavior of Crude Oil and Condensate Systems," JPT (July 1986) 715.

5. Al-Marhoun, M.A.: "Adjustment of Differential Liberation Data to Separator Conditions," paper SPE 68234 presented at the 2001 SPE Middle East Oil Show, Bahrain, 17–20 March.

6. Instructional materials for reservoir fluids class from Prof. Maria A Barrufet, Texas A&M University.