Chapter

Gases Reservoirs Fluid Phase Behavior

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Abstract

This chapter discusses the fundamentals of the phase behavior of hydrocarbon fluids. Real reservoir fluids contain many more than two, three, or four components; therefore, phase-composition data can no longer be represented with two, three or four coordinates. Instead, phase diagrams that give more limited information are used. The behavior of reservoir of a reservoir fluid during producing is determined by the shape of its phase diagram and the position of its critical point. Many of producing characteristic of each type of fluid will be discussed. Ensuing chapters will address the physical properties of these three natural gas reservoir fluids, with emphasis on retrograde gas condensate gas, dry gas, and wet gas.

Keywords: phase behavior, reservoirs fluid, physical properties

1. Introduction

Petroleum reservoirs are mixtures of hydrocarbon organic compounds that may be in the liquid state or in a gaseous state or in combinations of gas and liquid as will describe in this chapter [1]. The most important part in petroleum engineering for production and reservoir engineers is studying hydrocarbon phase behavior of reservoirs and characteristics of it early in the life of reservoir to suggest maximize development in the future [2]. Petroleum reservoirs can be classified into gas reservoirs, oil reservoirs, and this classification according to phase behavior diagram. This category of natural gas reservoirs is a unique type of hydrocarbon system because it has special thermodynamic behavior of the gas reservoir fluid that controlling in development [3]. To predict the original of natural gas in place, we use many equations as material balance equations [4]. This chapter describes the gas reservoirs principle only and we will continue description oil reservoirs in another chapter.

2. Classification of gas reservoirs fluids

In general, reservoirs temperature is more than the hydrocarbon fluid critical temperature, the reservoirs are considered as a natural gas reservoir [5]. There are three types of gas petroleum reservoirs subdivided into retrograde gas, wet gas, and dry gas [3]. All this gas reservoir fluid type can be determined by experimentally working and by the stock-tank liquid gravity (API), the color of liquid, heptane plus and producing a gas-oil ratio. These differences in phase behavior lead to different physical properties for each reservoir. This classification according to initial formation temperature and pressure, production surface temperature and pressure and composition of the reservoir fluid. In addition, the classification of hydrocarbon fluids can be by the composition analysis of the fluid mixture, where it is one of strongest effect on the fluid characteristics as shown in the ternary diagram (**Figure 1**) [6].

The diagram conditions under which these phases expressed is a pressure-temperature diagram or phase diagrams, where these diagrams are a different multicomponent system with a different phase diagram [7, 8]. The gases phase's diagrams are used to define the phase behavior and natural of these three types of hydrocarbon systems. To understand any gases phase's diagrams, it is necessary to define these key points on these diagrams [9]:

- **Hydrocarbon phase envelope:** it is region enclosed by the dew-point curve, where gas and liquid coexist in equilibrium phase. In addition, it can be called by two-phase region.
- **Dew-point pressure:** it is pressure at which separating the vapor-one phase region from the two-phase region.
- **Critical point:** it is pressure P_c and temperature T_c of the mixture hydrocarbon at which liquid and gas phase's properties are equal.
- **Cricondenbar (Pcb):** it is a maximum pressure above which no gas can be formed regardless of temperature.
- **Cricondentherm (Act):** it is a maximum temperature above which no liquid can be formed regardless of pressure.
- **Quality lines:** it is dashed lines inside the phase diagram that define the temperature and pressure for equal volumes of liquids [10].

Depending on reservoir conditions, natural gases reservoirs fluids can be classified into:

- Retrograde gas-condensate
- Wet gas
- Dry gas

2.1 Retrograde gas-condensate reservoirs

The retrograde gas-condensate reservoir is also called retrograde condensate gases, condensate, retrograde gas and gas condensates. In this type of natural gas, reservoir prefer called gas-condensate and not condensate only because this reservoir exhibits retrograde behavior [11]. In case of the reservoir temperature more than a critical temperature and less than a critical temperature, the reservoir is classified as a retrograde gas-condensate reservoir as shown in **Figure 1**. As a result of the critical point of the retrograde gas phase is further down the left side of the envelope as shown in **Figure 2**, heavy hydrocarbons will be fewer as compared with oils [12].

In the bagging of the reservoir, the hydrocarbon system will be totally one phase gas (i.e., vapor phase) because the reservoir pressure is above the dew-point pressure. As the reservoir pressure decrease from the initial formation pressure through the production until dew-point pressure, where the liquid starts to condense from the gas

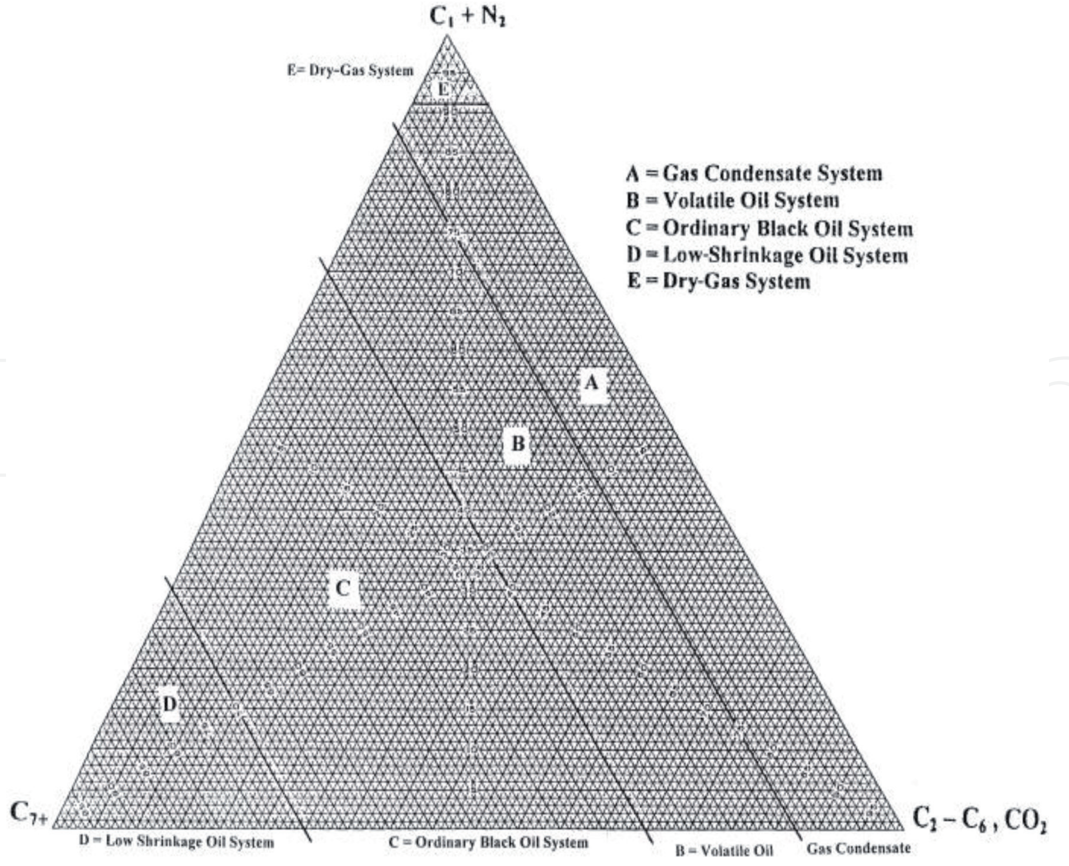

Figure 1.
Compositions of various reservoir fluid types.

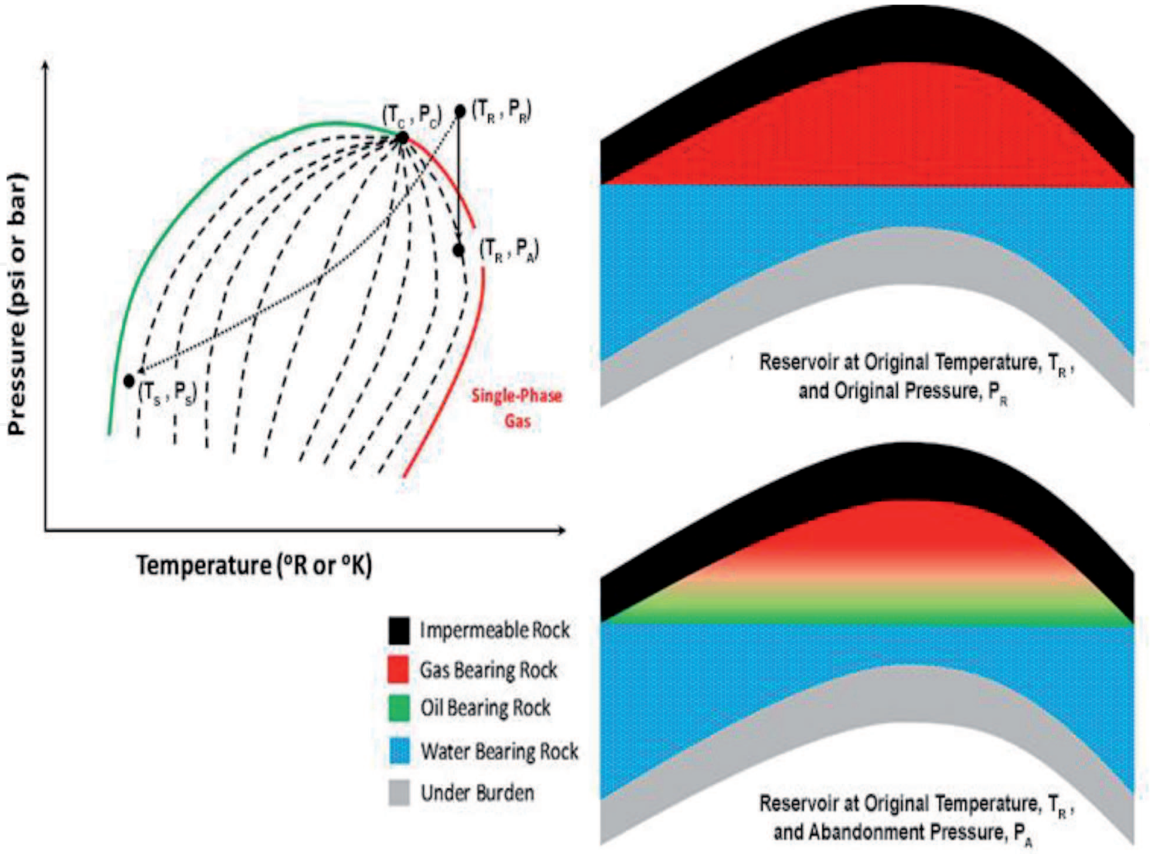

Figure 2.
Retrograde gas-condensate reservoir phase diagram.

Reservoir information	Sample 1	Sample 2	Sample 3
Reservoir pressure, psi	6740	6243	5876
Reservoir temperature, °F	321	304	220
C_7^+, Mole %	6.3511	0.4408	1.4177
Average mole weight	30.38	23.78	22.11
Dew point pressure, psi	4433	5030	4854
GOR, STB/SCF	9088.49	26766.81	36155.894
API	49.30	51.55	60.64
Compositional analysis of reservoir fluid to C36+			
Component	**Mole %**	**Mole %**	**Mole %**
Hydrogen	0.0000	0.0000	0.0000
Hydrogen sulfide	0.0000	0.0000	0.0000
Carbon dioxide	7.5475	5.4118	0.4068
Nitrogen	0.9154	0.1125	0.0262
Methane	73.5809	76.2140	83.2475
Ethane	5.4077	9.3173	6.9531
Propane	2.5521	3.9001	4.0096
i-Butane	1.0076	0.7866	1.1481
n-Butane	1.0066	0.8496	0.9764
Neo-Pentane	0.0000	0.0000	0.0000
i-Pentane	0.7871	0.4966	0.5337
n-Pentane	0.1538	0.2918	0.5244
Hexanes	0.5606	0.5099	0.4908
M-C-Pentane	0.0397	0.0237	0.0846
Benzene	0.0372	0.0234	0.0438
Cyclohexane	0.0528	0.2295	0.1374
Heptanes	0.4160	0.4434	0.2230
M-C-Hexane	0.0226	0.0391	0.0773
Toluene	0.0381	0.1241	0.0682
Octanes	0.3214	0.1875	0.1866
E-Benzene	0.3010	0.1540	0.0071
M/P-Xylene	0.0273	0.0087	0.0600
O-Xylene	0.1804	0.0219	0.0229
Nonanes	0.8192	0.2011	0.1285
1,2,4-TMB	0.0486	0.0097	0.0120
Decanes	1.0640	0.2024	0.1075
Undecanes	0.9636	0.1369	0.0992
Dodecanes	0.5167	0.0580	0.0791
Tridecanes	0.3672	0.0440	0.0655
Tetradecanes	0.2981	0.0438	0.0518

Component	Mole %	Mole %	Mole %
Pentadecanes	0.2494	0.0303	0.0466
Hexadecanes	0.2013	0.0267	0.0402
Heptadecanes	0.1556	0.0166	0.0351
Octadecanes	0.0973	0.0116	0.0217
Nonadecanes	0.0704	0.0185	0.0175
Eicosanes	0.0632	0.0072	0.0172
Heneicosanes	0.0387	0.0078	0.0098
Docosanes	0.0264	0.0063	0.0096
Tricosanes	0.0176	0.0097	0.0088
Tetracosanes	0.0126	0.0097	0.0073
Pentacosanes	0.0087	0.0033	0.0045
Hexacosanes	0.0073	0.0029	0.0034
Heptacosanes	0.0050	0.0020	0.0023
Octacosanes	0.0040	0.0016	0.0018
Nonacosanes	0.0025	0.0010	0.0013
Triacontanes	0.0036	0.0017	0.0008
Hentriacontanes	0.0019	0.0007	0.0006
Dotriacontanes	0.0006	0.0003	0.0003
Tritriacontanes	0.0004	0.0002	0.0002
Tetratriacontanes	0.0001	0.0001	0.0002
Pentatriacontanes	0.0003	0.0001	0.0001
Hexatriacontanes plus	0.0001	0.0001	0.0001
Total	100.00	100.00	100.00

Table 1.
Examples of retrograde gas-condensate reservoirs.

phase to form a free liquid in the reservoir as a result of molecules attraction between light and heavy components move further apart [13]. The condensate liquid still is inside the reservoir and cannot be produced from it. The condensate liquid volume not more than 15–19% of the pore volume, so this liquid still be inside the reservoir and cannot be produced as it is not large volume enough to flow. All of this indicates by reservoir pressure path as shown in the retrograde gas-condensate figure [14].

Physical characteristics identification:

- **Gas-oil ratios (GOR):** common gas-oil ratios between 8000 and 70,000 SCF/STB. But the lower gas-oil ratio is approximately 3300 SCF/STB and the upper limit is over 150,000 SCF/STB. In case of low gas-oil ratio condense the liquid may be reached to 35% or more. With time, the gas-oil ratio of condensate reservoir increases due to heavy components loss.

- **Stock-tank gravity (API):** is usually above 40° API stock-tank and increase as formation pressure decrease below dew point pressure.

- **Heptane's plus fraction:** is less than 12.5-Mole% by laboratory analysis. But in case heptane plus fraction is less than one percent, the retrograde liquid volume is small so it is negligible.

- **Color:** may be slightly colored, orange, brown, greenish and water-white, so color is not depended on indicator if this reservoir gas condensate or oil.

Table 1 shows data of reservoir information and compositional analysis of reservoir fluid for three different examples of retrograde gas-condensate reservoirs.

2.2 Wet gas reservoirs

It is the second type of natural gas reservoir fluid. In this type, reservoir temperature exceeds hydrocarbon system cricondentherm, so the reservoir fluid always remains in the gas phase as the reservoir pressure decrease. No condensate liquid is formed in the formation as a result of the pressure path does not inside the phase envelope as shown in a wet gas phase diagram (**Figure 3**) [15]. Some of the liquid is formed at the surface due to separator conditions (separator pressure and temperature) still inside the phase envelope and is called condensate. The expression of "wet gas" does not mean that the gas is wet with water but means condensation that occurs at the surface [16].

Physical characteristics identification:

- **Gas-oil ratios (GOR):** is very high producing gas-oil ratios reached from 60,000 to 100,000 SCF/STB. During wet gas reservoir life, the gas-oil ratio does not change.

- **Stock-tank gravity (API):** as gravities of retrograde gas condensate reservoir and reach above 60° API. Also during wet gas reservoir life, stock-tank gravity of condensate liquid remains constant.

- **Color:** water-white.

Table 2 shows data for three different examples of wet gas reservoirs.

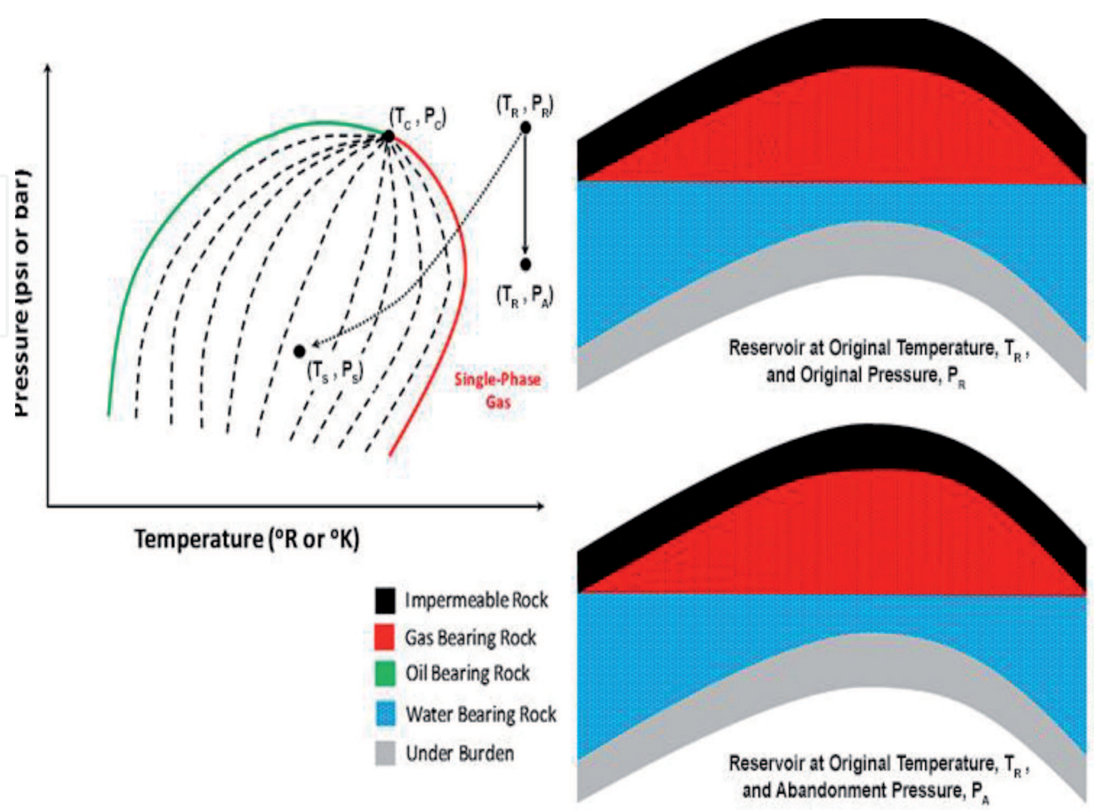

Figure 3.
Wet gas reservoir phase diagram.

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Reservoir information	**Sample 1**	**Sample 2**	**Sample 3**
Reservoir pressure, psi	1248.52	6040	9118.3
Reservoir temperature, °F	120	286	221
C_7^+, Mole %	0.3494	0.3806	0.8714
Average mole weight	20.4650	21.14	19.40
GOR, STB/SCF	238,346.92	360,000.00	67,142.857
API	54.800	58.55	47.88
Compositional analysis of reservoir fluid to C36+			
Component	**Mole %**	**Mole %**	**Mole %**
Hydrogen	0.0000	0.0000	0.0000
Hydrogen sulfide	0.0000	0.0000	0.0000
Carbon dioxide	0.1450	4.8233	0.3852
Nitrogen	0.0232	0.0639	0.0018
Methane	84.6734	78.7860	90.9414
Ethane	5.5664	10.6768	3.9810
Propane	5.8349	3.5138	2.0867
i-Butane	0.8776	0.3639	0.4953
n-Butane	1.5846	0.6540	0.5146
Neo-Pentane	0.0000	0.0000	0.0000
i-Pentane	0.5351	0.2036	0.2605
n-Pentane	0.0855	0.1961	0.0880
Hexanes	0.1991	0.1784	0.2267
M-C-Pentane	0.0446	0.0311	0.0390
Benzene	0.0199	0.0670	0.0369
Cyclohexane	0.0606	0.0609	0.0714
Heptanes	0.0801	0.0478	0.1015
M-C-Hexane	0.0501	0.0545	0.0434
Toluene	0.0384	0.1240	0.0425
Octanes	0.0479	0.0337	0.0993
E-Benzene	0.0100	0.0048	0.0040
M/P-Xylene	0.0248	0.0239	0.0281
O-Xylene	0.0145	0.0028	0.0107
Nonanes	0.0234	0.0160	0.0600
1,2,4-TMB	0.0040	0.0003	0.0056
Decanes	0.0185	0.0153	0.0662
Undecanes	0.0128	0.0121	0.0642
Dodecanes	0.0052	0.0096	0.0599
Tridecanes	0.0030	0.0069	0.0475
Tetradecanes	0.0026	0.0059	0.0452
Pentadecanes	0.0022	0.0048	0.0388
Hexadecanes	0.0016	0.0041	0.0348
Heptadecanes	0.0014	0.0035	0.0241
Octadecanes	0.0013	0.0026	0.0217
Nonadecanes	0.0014	0.0020	0.0169
Eicosanes	0.0012	0.0016	0.0137

Component	Mole %	Mole %	Mole %
Heneicosanes	0.0014	0.0011	0.0120
Docosanes	0.0013	0.0009	0.0088
Tricosanes	0.0008	0.0008	0.0042
Tetracosanes	0.0009	0.0006	0.0051
Pentacosanes	0.0004	0.0005	0.0026
Hexacosanes	0.0004	0.0004	0.0022
Heptacosanes	0.0002	0.0003	0.0016
Octacosanes	0.0001	0.0002	0.0014
Nonacosanes	0.0001	0.0001	0.0009
Triacontanes	0.0001	0.0001	0.0008
Hentriacontanes	0.0001	0.0001	0.0007
Dotriacontanes	0.0001	0.0001	0.0005
Tritriacontanes	0.0000	0.0000	0.0003
Tetratriacontanes	0.0001	0.0000	0.0002
Pentatriacontanes	0.0001	0.0000	0.0000
Hexatriacontanes plus	0.0000	0.0000	0.0020
Total	100.00	100.00	100.00

Table 2.
Examples of wet gas reservoirs.

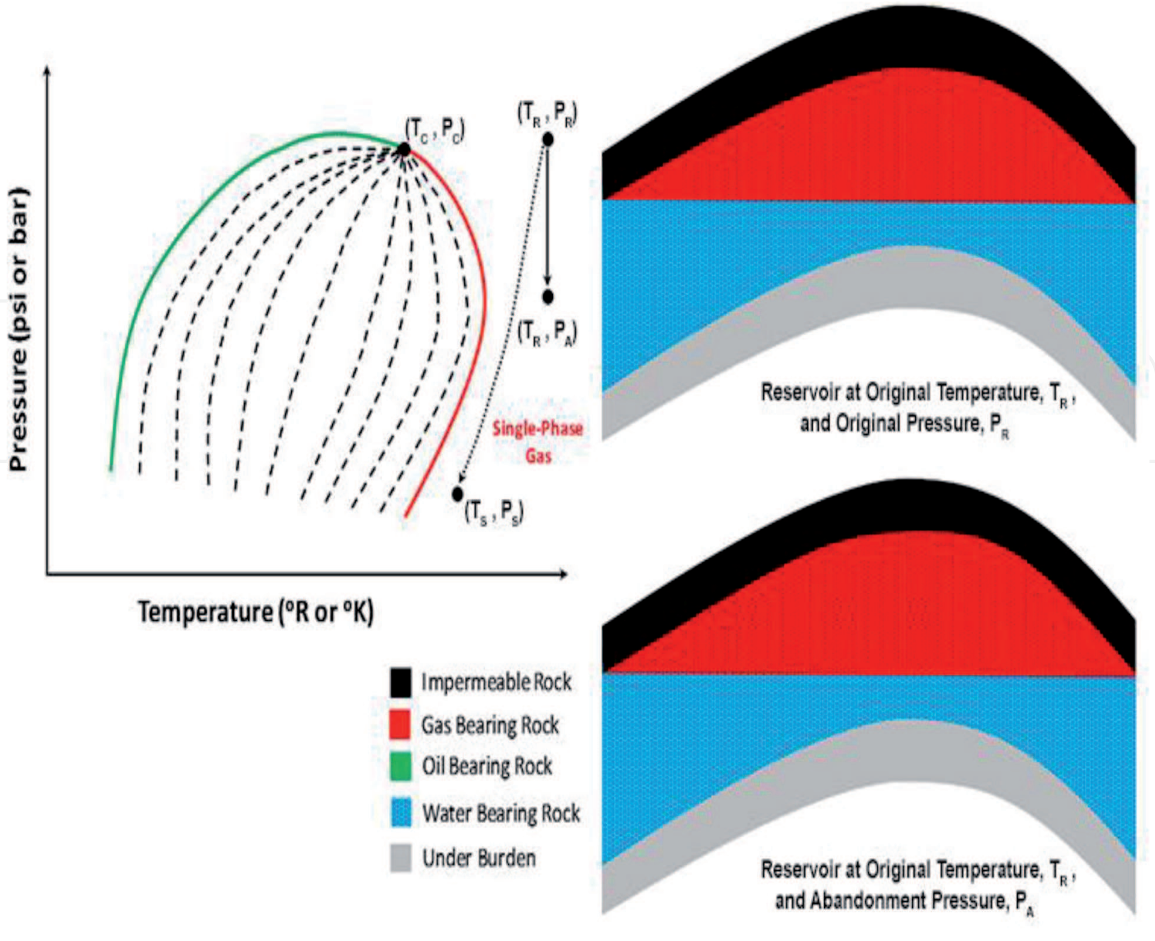

Figure 4.
Dry gas reservoir phase diagram.

Reservoir information	**Sample 1**	**Sample 2**	**Sample 3**
Reservoir pressure, psi	6754	7853	6545
Reservoir temperature, °F	234	330	301
C_7^+, Mole %	0.0370	0.0175	0.0101
Average mole weight	16.6817	16.455	16.57
GOR, STB/SCF	320,000.00	270,000.00	232,100.00
Compositional analysis of reservoir fluid to C36+			
Component	**Mole %**	**Mole %**	**Mole %**
Hydrogen	0.0000	0.0000	0.000
Hydrogen sulfide	0.0000	0.0000	0.000
Carbon dioxide	0.4370	0.4112	0.081
Nitrogen	0.1450	0.0054	0.012
Methane	97.5760	98.2135	97.812
Ethane	0.9540	0.9099	1.102
Propane	0.3520	0.2989	0.615
i-Butane	0.2190	0.0306	0.152
n-Butane	0.1540	0.0547	0.113
Neo-Pentane	0.0000	0.0000	0.000
i-Pentane	0.0560	0.0164	0.054
n-Pentane	0.0240	0.0158	0.015
Hexanes	0.0350	0.0134	0.022
M-C-Pentane	0.0060	0.0024	0.003
Benzene	0.0020	0.0055	0.003
Cyclohexane	0.0030	0.0046	0.004
Heptanes	0.0140	0.0025	0.003
M-C-Hexane	0.0070	0.0031	0.004
Toluene	0.0050	0.0094	0.002
Octanes	0.0030	0.0011	0.001
E-Benzene	0.0010	0.0003	0.000
M/P-Xylene	0.0010	0.0011	0.000
O-Xylene	0.0010	0.0000	0.000
Nonanes	0.0020	0.0000	0.000
1,2,4-TMB	0.0010	0.0000	0.000
Decanes	0.0020	0.0000	0.000
Undecanes	0.0000	0.0000	0.000
Dodecanes	0.0000	0.0000	0.000
Tridecanes	0.0000	0.0000	0.000
Tetradecanes	0.0000	0.0000	0.081
Pentadecanes	0.0000	0.0000	0.012
Hexadecanes	0.0000	0.0000	97.812
Heptadecanes	0.0000	0.0000	1.102
Component	**Mole %**	**Mole %**	**Mole %**

Component	Mole %	Mole %	Mole %
Nonadecanes	0.0000	0.0000	0.152
Eicosanes	0.0000	0.0000	0.113
Heneicosanes	0.0000	0.0000	0.000
Docosanes	0.0000	0.0000	0.054
Tricosanes	0.0000	0.0000	0.015
Tetracosanes	0.0000	0.0000	0.022
Pentacosanes	0.0000	0.0000	0.003
Hexacosanes	0.0000	0.0000	0.003
Heptacosanes	0.0000	0.0000	0.004
Octacosanes	0.0000	0.0000	0.003
Nonacosanes	0.0000	0.0000	0.004
Triacontanes	0.0000	0.0000	0.002
Hentriacontanes	0.0000	0.0000	0.001
Dotriacontanes	0.0000	0.0000	0.000
Tritriacontanes	0.0000	0.0000	0.000
Tetratriacontanes	0.0000	0.0000	0.000
Pentatriacontanes	0.0000	0.0000	0.000
Hexatriacontanes plus	0.0000	0.0000	0.000
Total	100.00	100.00	100.00

Table 3.
Examples of wet gas reservoirs.

2.3 Dry gases reservoirs

This type is a gas phase in the reservoir and in the surface condition, where surface separator conditions located outside the phase envelope as given in **Figure 4** [17]. This diagram also shows that no liquid is formed at stock-tank condition (temperature and pressure) as a result of no attraction between molecules. This type also simply called a gas reservoir. Dry gas is mainly methane component with some intermediates components. The expression of “dry gas” refers to does not have heavier molecules to form condensate liquid at the surface condition. In this case, gas-oil ratios are reached more than 100,000 SCF/STB [18]. **Table 3** shows data for three different examples of wet dry reservoirs.

3. Conclusion

This chapter converses the hydrocarbon fluids phase behavior. The physical properties of these three natural gas reservoir fluids, with emphasis on retrograde gas condensate gas, dry gas, and wet gas. The behavior of reservoir is determined by phase diagram shape and critical point position. All examples show the details of each fluid type by reservoir information and compositional analysis of reservoir fluid.

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