Tishk International University
Engineering Faculty
Petroleum and Mining Department

Petroleum Production Engineering II

Lecture 4: Separation System

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Introduction

Oil and gas produced from wells are normally complex mixtures of hundreds of different compounds. A typical well stream is a turbulent mixture of oil, gas, water, and sometimes solid particles. The well stream should be processed as soon as possible after bringing it to the surface.

Field separation processes fall into two categories:

1. Separation that separates oil, water, and gas;
2. Dehydration that removes condensable water vapor and other undesirable compounds, such as hydrogen sulfide or carbon dioxide.

Introduction

Various Names of Separator

separators are referred to as **scrubbers**, **knockouts,** and **free liquid knockouts**. All these vessels are used for the same purpose: to separate free liquids from the gas stream.

Principles of Separation

Separator works based on gravity segregation and/or centrifugal segregation. A separator is normally constructed in such a way that it has the following features:

1. It has a centrifugal inlet device where the primary separation of the liquid and gas is made.
2. It provides a large settling section of sufficient height or length to allow liquid droplets to settle out of the gas stream with adequate surge room for slugs of liquid.
3. It is equipped with a mist extractor or eliminator near the gas outlet to coalesce small particles of liquid that do not settle out by gravity.
4. It allows adequate controls consisting of level control, liquid dump valve, gas backpressure valve, safety relief valve, pressure gauge, gauge glass, instrument gas regulator, and piping.

Principles of Separation

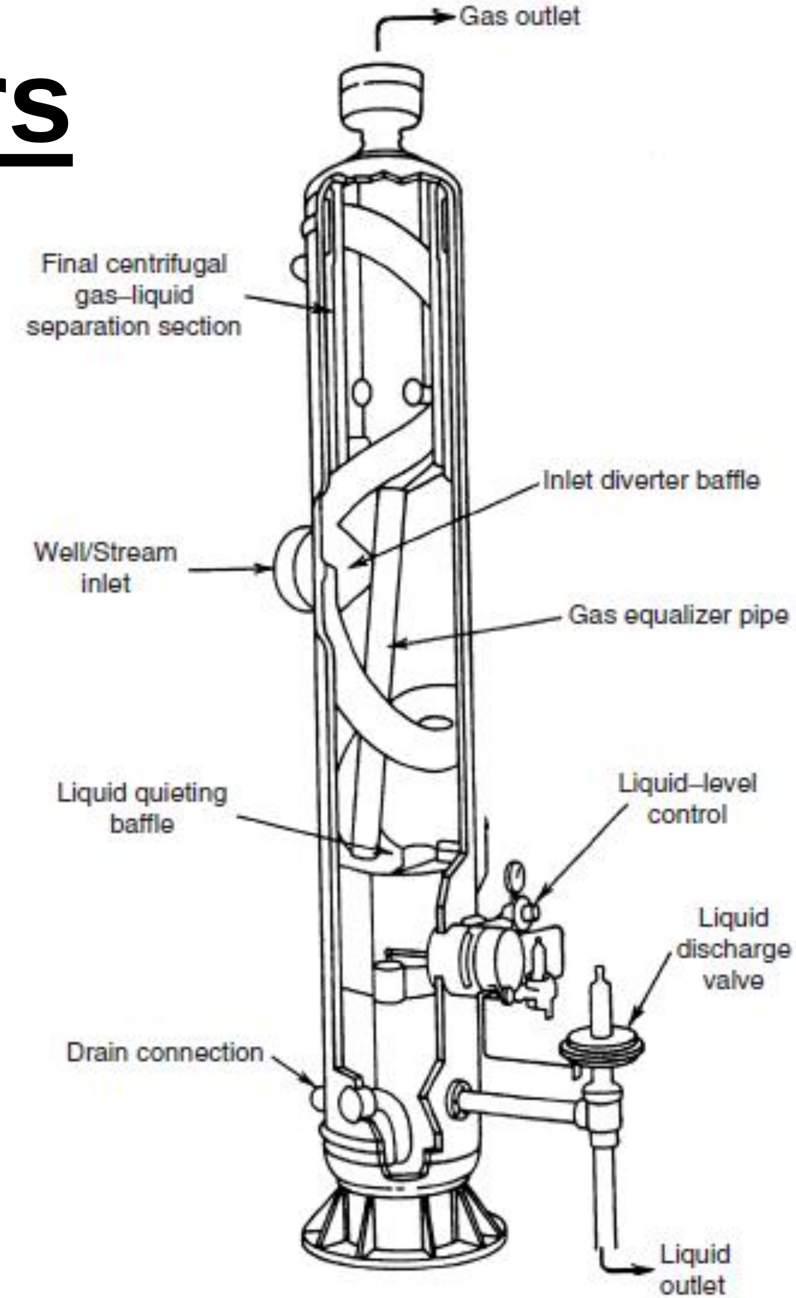
Types of Separators

Three types of separators are generally available from manufacturers:

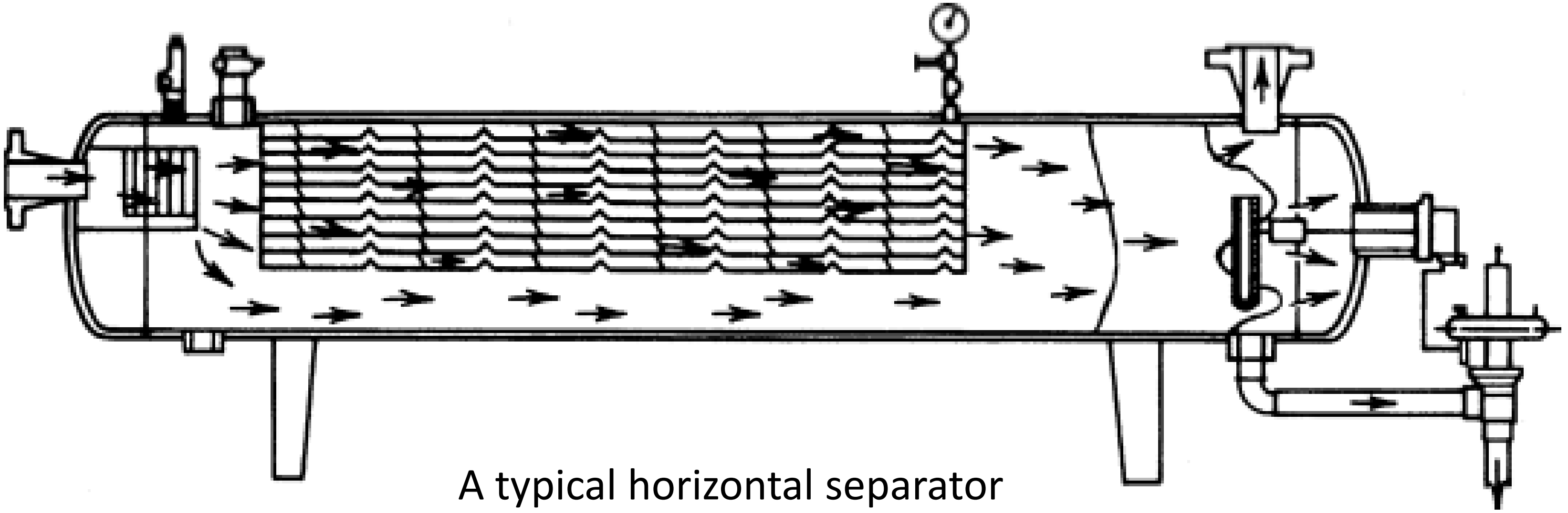
1. Vertical
2. Horizontal
3. Spherical separators

Vertical Separators

The figure shows a sketch of a vertical separator

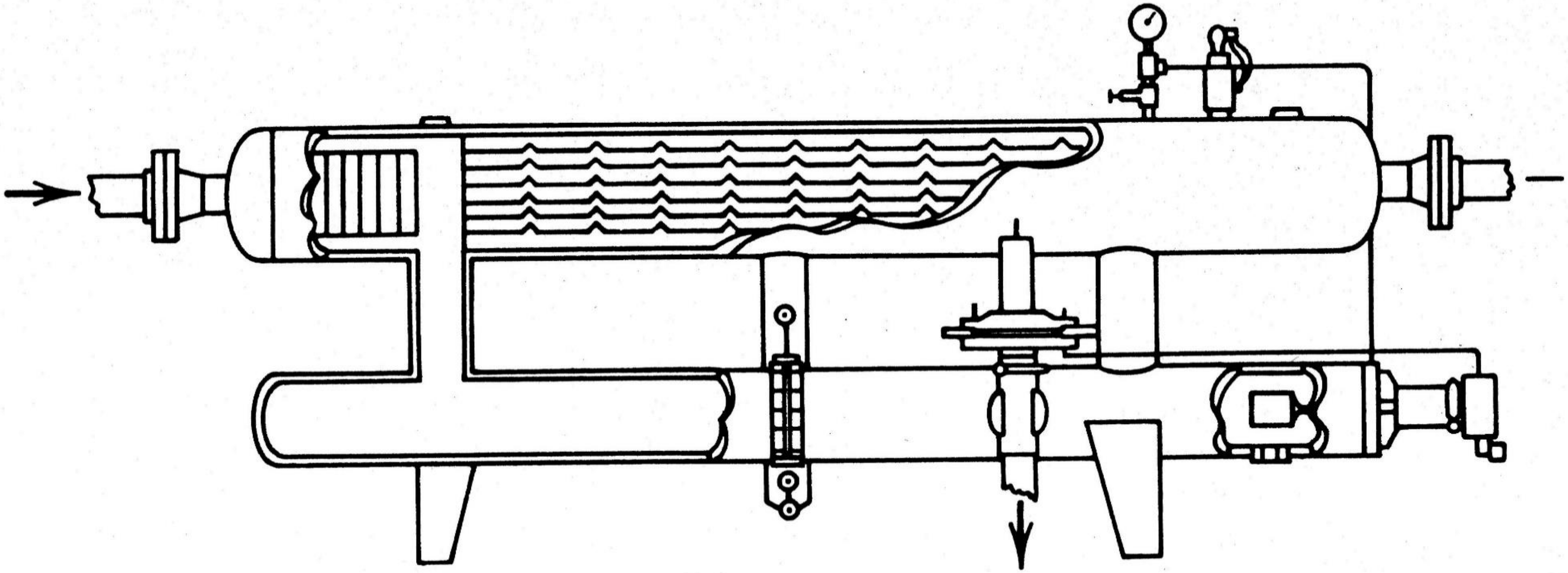


Horizontal Separators



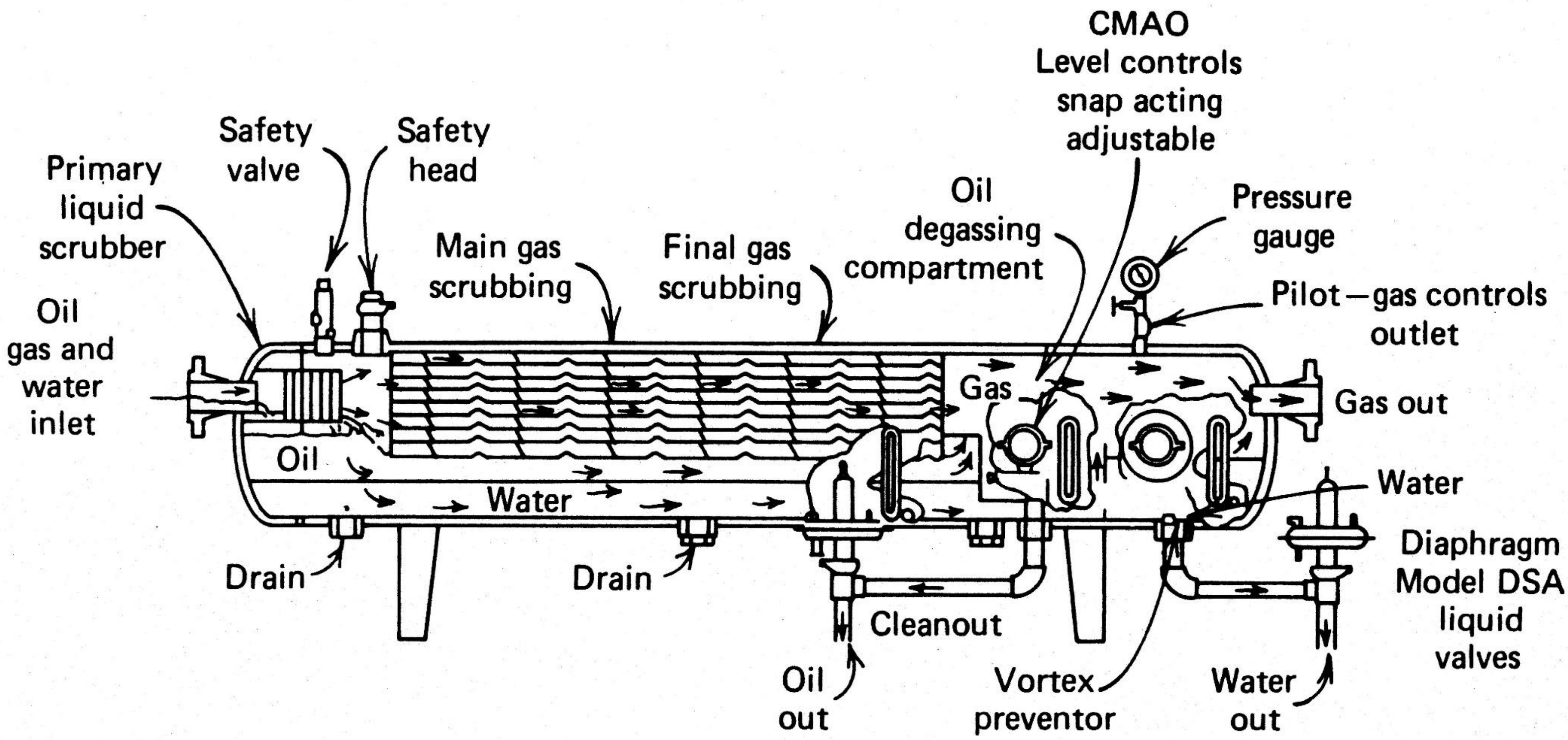
A typical horizontal separator

Horizontal Separators



A typical horizontal double-tube separator

Horizontal Separators

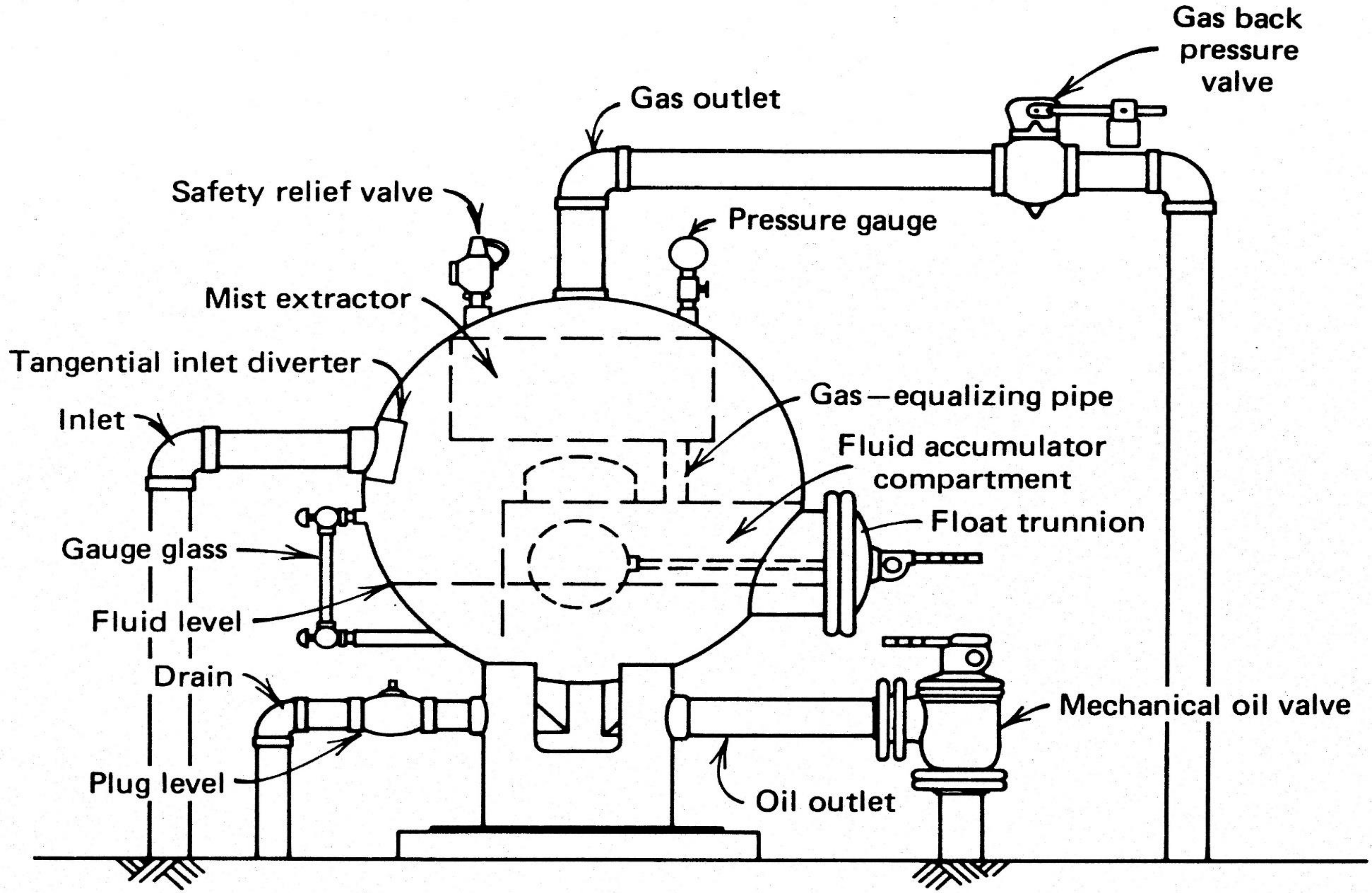


A typical horizontal three-phase separator

Spherical Separators

A typical spherical low-pressure separator

Spherical Separators



A typical spherical low-pressure separator

Factors Affecting Separation

Separation efficiency is dominated by **separator size**. For a given separator, factors that affect separation of liquid and gas phases include:

1. **Separator operating pressure**
2. **Separator operating temperature**
3. **Fluid stream composition**

Changes in any of these factors will change the amount of gas and liquid leaving the separator. An increase in operating pressure or a decrease in operating temperature generally increases the liquid covered in a separator

The operator can control operating pressure to some extent by use of backpressure valves. Indirect heater can be used to increase temperature.

Gas Capacity

The following empirical equations proposed by Souders-Brown are widely used for calculating gas capacity of oil/gas separators:

$$v = K\sqrt{\frac{\rho_L - \rho_g}{\rho_g}} \quad (4.1)$$

A = total cross-sectional area of separator, ft^2
v = superficial gas velocity based on total cross-sectional area A, ft/sec
q = gas flow rate at operating conditions, ft^3/sec
ρ_L = density of liquid at operating conditions, lb_m/ft^3
ρ_g = density of gas at operating conditions, lb_m/ft^3
K = empirical factor

and

$$q = Av \quad (4.2)$$

Table 4-1 presents *K*-values for various types of separators. Also listed in the table are *K*-values used for other designs such as mist eliminators and trayed towers in dehydration or gas sweetening units.

Table 4-1 K *Values Used for Selecting Separators*

Separator type	*K*	*Remarks*
Vertical separators	0.06–0.35	
Horizontal separators	0.40–0.50	
Wire mesh mist eliminators	0.35	
Bubble cap trayed columns	0.16	24-in. spacing

Substituting equation (4.1) into equation (4.2) and applying real gas law gives

$$q_{st} = \frac{2.4 D^2 K p}{z(T + 460)} \sqrt{\frac{\rho_L - \rho_g}{\rho_g}} \qquad (4.3)$$

q_{st}	= gas capacity at standard conditions, MMscfd
D	= internal diameter of vessel, ft
p	= operation pressure, psia
T	= operating temperature, ºF
z	= gas compressibility factor

It should be noted that Eq. (4.3) is empirical. Height differences in vertical separators and length differences in horizontal separators are not considered. Field experience has indicated that additional gas capacity can be obtained by increasing height of vertical separators and length of horizontal separators.

Liquid Capacity

Retention time of the liquid within the vessel determines liquid capacity of a separator. Adequate separation requires sufficient time to obtain an equilibrium condition between the liquid and gas phase at the temperature and pressure of separation.

The liquid capacity of a separator relates to the retention time through the settling volume:

$$q_L = \frac{1440 V_L}{t} \qquad (4.4)$$

q_L = liquid capacity, bbl/day
V_L = liquid settling volume, bbl
t = retention time, min

Table 4-2 presents *t*-values for various types of separators tested in fields. It is shown that temperature has a strong impact on three-phase separations at low pressures.

Table 4-2 *Retention Time Required Under Various Separation Conditions*

Separation condition	*T* (°F)	*t* (min)
Oil/gas separation		1
High-pressure oil/gas/water separation		2–5
Low-pressure oil/gas/water separation	>100	5–10
	90	10–15
	80	15–20
	70	20–25
	60	25–30

Tables 4-3 through 4-8 present liquid-settling volumes with the conventional placement of liquid-level controls for typical oil/gas separators.

Table 4.3 *Settling Volumes of Standard Vertical High-Pressure Separators (230–2,000 psi working pressure)*

	V_L (bbl)	
Size (D × H)	*Oil/Gas separators*	*Oil/Gas/Water separators*
16″ × 5′	0.27	0.44
16″ × 7½′	0.41	0.72
16″ × 10′	0.51	0.94
20″ × 5′	0.44	0.71
20″ × 7½′	0.65	1.15
20″ × 10′	0.82	1.48
24″ × 5′	0.66	1.05
24″ × 7½′	0.97	1.68
24″ × 10′	1.21	2.15
30″ × 5′	1.13	1.76
30″ × 7½′	1.64	2.78
30″ × 10′	2.02	3.54
36″ × 7½′	2.47	4.13
36″ × 10′	3.02	5.24
36″ × 15′	4.13	7.45
42″ × 7½′	3.53	5.80
42″ × 10′	4.29	7.32
42″ × 15′	5.80	10.36
48″ × 7½′	4.81	7.79
48″ × 10′	5.80	9.78
48″ × 15′	7.79	13.76
54″ × 7½	6.33	10.12
54″ × 10′	7.60	12.65
54″ × 15′	10.12	17.70
60″ × 7½′	8.08	12.73
60″ × 10′	9.63	15.83
60″ × 15′	12.73	22.03
60″ × 20′	15.31	27.20

Table 4-4: Settling Volumes of Standard Vertical Low-Pressure Separators (125 psi working pressure)

Table 4.4 *Settling Volumes of Standard Vertical Low-Pressure Separators (125 psi working pressure)*

	V_L (bbl)	
Size (D × H)	*Oil/Gas separators*	*Oil/Gas/Water separators*
24′ × 5′	0.65	1.10
24′ × 7½′	1.01	1.82
30′ × 10′	2.06	3.75
36′ × 5′	1.61	2.63
36′ × 7½′	2.43	4.26
36′ × 10′	3.04	5.48
48′ × 10′	5.67	10.06
48′ × 15′	7.86	14.44
60′ × 10′	9.23	16.08
60′ × 15′	12.65	12.93
60′ × 20′	15.51	18.64

Table 4-5: Settling Volumes of Standard Horizontal High-Pressure Separators (230 psi to 2,000 psi working pressure)

Table 4.5

Settling Volumes of Standard Horizontal High-Pressure Separators (230–2,000 psi working pressure)

Size (D × L)	V_L (bbl)		
	½ *Full*	⅓ *Full*	¼ *Full*
12¾″ × 5′	0.38	0.22	0.15
12¾″ × 7½′	0.55	0.32	0.21
12¾″ × 10′	0.72	0.42	0.28
16″ × 5′	0.61	0.35	0.24
16″ × 7½′	0.88	0.50	0.34
16″ × 10′	1.14	0.66	0.44
20″ × 5′	0.98	0.55	0.38
20″ × 7½′	1.39	0.79	0.54
20″ × 10′	1.80	1.03	0.70
24″ × 5′	1.45	0.83	0.55
24″ × 7½′	2.04	1.18	0.78
24″ × 10′	2.63	1.52	1.01
24″ × 15′	3.81	2.21	1.47
30″ × 5′	2.43	1.39	0.91
30″ × 7½′	3.40	1.96	1.29
30″ × 10′	4.37	2.52	1.67
30″ × 15′	6.30	3.65	2.42
36″ × 7½	4.99	2.87	1.90
36″ × 10′	6.38	3.68	2.45
36″ × 15′	9.17	5.30	3.54
36″ × 20′	11.96	6.92	4.63
42″ × 7½′	6.93	3.98	2.61
42″ × 10′	8.83	5.09	3.35
42″ × 15′	12.62	7.30	4.83
42″ × 20′	16.41	9.51	6.32
48″ × 7½′	9.28	5.32	3.51
48″ × 10′	11.77	6.77	4.49
48″ × 15′	16.74	9.67	6.43
48″ × 20′	21.71	12.57	8.38
54″ × 7½′	12.02	6.87	4.49
54″ × 10′	15.17	8.71	5.73
54″ × 15′	12.49	12.40	8.20
54″ × 20′	27.81	16.08	10.68
60″ × 7½′	15.05	8.60	5.66
60″ × 10′	18.93	10.86	7.17
60″ × 15′	26.68	15.38	10.21
60″ × 20′	34.44	19.90	13.24

Table 4-6: Settling Volumes of Standard Horizontal Low-Pressure Separators (125 psi working pressure)

Table 4.6 *Settling Volumes of Standard Horizontal Low-Pressure Separators (125 psi working pressure)*

Size (D × L)	V_L (bbl) ½ Full	⅓ Full	¼ Full
24″ × 5′	1.55	0.89	0.59
24″ × 7½′	2.22	1.28	0.86
24″ × 10′	2.89	1.67	1.12
30″ × 5′	2.48	1.43	0.94
30″ × 71/2′	3.54	2.04	1.36
30″ × 10′	4.59	2.66	1.77
36″ × 10′	6.71	3.88	2.59
36″ × 15′	9.76	5.66	3.79
48″ × 10′	12.24	7.07	4.71
48″ × 15′	17.72	10.26	6.85
60″ × 10′	19.50	11.24	7.47
60″ × 15′	28.06	16.23	10.82
60″ × 20′	36.63	21.21	14.16

Table 4-7: Settling Volumes of Standard Spherical High-Pressure Separators (230 psi to 3,000 psi working pressure)

Table 4.7 *Settling Volumes of Standard Spherical High-Pressure Separators (230–3,000 psi working pressure)*

Size (OD)	V_L (bbl)
24″	0.15
30″	0.30
36″	0.54
42″	0.88
48″	1.33
60″	2.20

Table 4-8: Settling Volumes of Standard Spherical Low-Pressure Separators (125 psi)

Table 4.8 *Settling Volumes of Standard Spherical Low-Pressure Separators (125 psi)*

Size (OD)	V_L (bbl)
41″	0.77
46″	1.02
54″	1.60

Example Problem 4-1:

Calculate the minimum required size of a standard oil/gas separator for the following conditions. Consider both vertical and horizontal separators.

Gas flow rate:	5.0 MMscfd
Gas-specific gravity:	0.7
Condensate flow rate:	20 bbl/MMscf
Condensate gravity:	60 ^{o}API
Operating pressure:	800 psig
Operating temperature:	80 ^{o}F

Solution:

The total required liquid flow capacity is (5)(20) = 100 bbl/day. Assuming a 20” × 7-$^{1/2}$’ vertical separator, Table 4-1 suggests an average *K*-value of 0.205. The spreadsheet program Hall-Yarborogh-z.xls gives z = 0.8427 and ρ_g = 3.38 lb_m/ft^3 at 800 psig and 80 ^oF. Liquid density is calculated as:

$$\rho_L = 62.4\frac{141.5}{131.5 + 60}$$

$$= 46.11\ lb_m/ft^3$$

Equation (4.3) gives:

$$q_{st} = \frac{2.4D^2Kp}{z(T+460)}\sqrt{\frac{\rho_L - \rho_g}{\rho_g}}$$

$$q_{st} = \frac{(2.4)(20/12)^2(0.205)(800)}{(0.8427)(80+460)}\sqrt{\frac{46.11-3.38}{3.38}}$$

= 8.70 MMscfd

From Table 4-3, a 20-in × 7-1/2-ft separator will handle the following liquid capacity:

$$q_L = \frac{1440V_L}{t}$$

$$q_L = \frac{1440(0.65)}{1.0}$$

= 936 bbl/day

which is much higher than the liquid load of 100 bbl/day.

Consider a 16-in × 5-ft horizontal separator and equation (4.3) gives:

$$q_{st} = \frac{(2.4)(16/12)^2(0.45)(800)}{(0.8427)(80+460)}\sqrt{\frac{46.11-3.38}{3.38}}$$

= 12.22 MMscfd

If the separator is one-half full of liquid, it can still treat 6.11 MMscfd of gas. From Table 4-5, a 16-in × 5-ft horizontal separator will handle

$$q_L = \frac{1440(0.61)}{1.0}$$

= 878 bbl/day

which again is much higher than the liquid load of 100 bbl/day.

This example illustrates a case of high gas/oil ratio well streams where the gas capacity is the controlling factor for separator selection. It suggests that a smaller horizontal separator would be required and would be more economical. The selected separator should have at least a 1,000 psig working pressure.