

OCS Study
MMS 2002 - 033

P
O
C
K
E
T

G
U
I
D
E

Pipeline Oil Spill Volume Estimator



DISCLAIMER

This Pipeline Oil Spill Volume Estimator known as the "Pocket Guide" was prepared under contract between the Minerals Management Service (MMS) and SINTEF Applied Chemistry. Publication of this Pocket Guide does not necessarily imply that the contents reflect the views and policies of MMS. The discharge volumes derived from this Pocket Guide reflect an estimate and the MMS is not responsible for the accuracy of those estimates. This is merely a tool to be used for estimating oil spill releases from pipeline ruptures. Further, this Pocket Guide does not constitute rulemaking and it must not be used for regulatory compliance.

TABLE OF CONTENTS

Introduction	3
1. Initial estimate of oil release	5
2. Advanced Method	15
Variable Description and Unit Conversion	27

LIST OF TABLES

TABLE 1.1:	VOLUME ESTIMATE OF PIPELINE	7
TABLE 1.2:	AMBIENT PRESSURE, P_{AMB}	10
TABLE 1.3:	MAXIMUM RELEASED VOLUME FRACTION, F_{REL}	11
TABLE 1.4:	GOR REDUCTION FACTORS, F_{GOR}	11

INTRODUCTION

The Pipeline Oil Spill Volume Estimator includes two methods that can be used to calculate the amount of oil that will escape from a leaking pipeline. The Pocket Guide and an associated computer model were developed by SINTEF and Well Flow Dynamics under a contract funded by the Minerals Management Service.

The “Initial” volume calculation method is intended to be a first best guess on the amount of oil that has been released so that spill responders can mobilize adequate equipment to the spill site. It is to be used when data on the event are limited and quick decisions on response strategy are mandatory to minimize spill impacts.

The “Advanced” method allows for the refinement of the spill volume estimate as the spill response proceeds. More variables are required, but the refined estimate will provide a more realistic volume for assisting in developing response strategies and revising incident action plans.

Both the “Initial” and “Advanced” methods assume:

- A single horizontal pipeline segment;
- A full pipeline break or rupture.

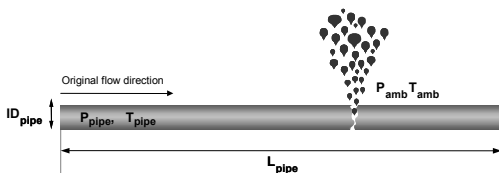
These methods are therefore not applicable to pinhole leaks or other small pipeline fractures.

The computer model removes the limitations found in the “Initial” and “Advanced” methods by allowing the user to input pipeline leak hole size, fluid properties, and variable water depths. The users can also create a pipeline network that may contain many pipeline segments. Model output includes reports that show pipeline leakage rates versus time and cumulative leak rates with reports being in both tabular and graphic formats.

Additionally, the model includes a near field module that produces an estimate of the partitioning of released oil between the water and the surface, as well as an estimate of the distribution of oil thickness in the surface slick.

The computer model can be downloaded from the MMS website at <http://www.mms.gov>. The website also contains a User's Manual on model operations.

The figure below defines the simplified problem graphically.



1. INITIAL ESTIMATE OF OIL RELEASE

1.1 Introduction

This initial approach will give a quick estimate of the total oil released if a pipeline rupture occurs.

1.2 Required data

This calculation procedure requires the following data:

- Pipeline internal diameter, ID_{pipe} [in]
- Pipeline length, L_{pipe} [ft]
- Pipeline pressure, P_{pipe} [psi]
- Gas-oil-ratio, GOR [scf/stb]
- Water depth at rupture location, d [ft]
- Pipeline flow rate, Q [stb/d]
- Time before shut-in, t [min]

For unit conversion, please refer to Page 27.

1.3 Calculation procedure

1.3.1 Simple equation

The total released volume of oil, V_{rel} , is found from Equation 1.1

$$V_{\text{rel}} = 0.1781 \cdot V_{\text{pipe}} \cdot f_{\text{rel}} \cdot f_{\text{GOR}} + V_{\text{pre-shut}} \quad \text{Eq. 1.1}$$

where,

- V_{rel} - Total volume released [bbls]
- V_{pipe} - Volume of pipeline [ft³], see section 1.3.3, Page 6
- f_{rel} - Maximum release volume fraction [-]
Dimensionless, see section 1.3.4, Page 8
- f_{GOR} - GOR reduction factor [-], see section 1.3.5, Page 11
- $V_{\text{pre-shut}}$ - Volume of oil released prior to pipe shut-in, [bbls]

1.3.2 Volume of oil released prior to pipe shut-in, $V_{pre-shut}$

The oil volume released before shut-in can be calculated by using Equation 1.2.

$$V_{pre-shut} = \frac{Q \cdot t}{1440} \quad [\text{bbls}] \quad \text{Eq. 1.2}$$

where,

- Q - Pipeline flow rate [stb/d]
- t - Time before shut-in [min]

1.3.3 Pipeline volume

The pipeline volume can be calculated by using Equation 1.3. Alternatively Table 1.1 can be used. Table 1.1 is meant to be used when a calculator is not available.

$$\text{Volume of pipe} = \left(\frac{\text{Internal Diameter of pipe}}{24} \right)^2 \cdot \text{Length} \cdot 3.14$$

$$V_{pipe} = \left(\frac{ID_{pipe}}{24} \right)^2 \cdot L_{pipe} \cdot \pi \quad \text{Eq. 1.3}$$

where,

- V_{pipe} - volume of pipeline [ft^3]
- ID_{pipe} - internal diameter of pipeline [in]
- L_{pipe} - pipeline length [ft]

Table 1.1: Volume estimate of pipeline

Internal Diameter ID _{pipe} [in]	Volume per 1000 ft [ft ³]
2	21.8
4	87.3
6	196
8	349
10	545
12	785
14	1069
16	1396
20	2180
22	2640
24	3142
28	3403

Example:

A 10,000 ft 12" ID pipeline has ruptured.
Find the volume of the pipeline.

Solution alternative 1:

A calculator is not available \Rightarrow Table 1.1 is used.

Internal Diameter ID _{pipe} [in]	Volume per 1000 ft [ft ³]
8	349
10	545
12	785
15	1230
17	1580

Look in Table 1.1 and find the internal diameter of your pipe, 12". Find the volume per 1000 ft. **785ft³**.

You have now found the volume of 1000 ft pipe. Your pipe is 10,000 ft.

$$\text{Result: } \frac{785\text{ft}^3}{1000\text{ft}} \cdot 10,000\text{ft} = 785\text{ft}^2 \cdot 10\text{ft} = \underline{\underline{7850\text{ft}^3}}$$

Solution alternative 2:

A calculator is available \Rightarrow Equation 1.3 is used.

$$\text{Inserting pipe data: } V_{\text{pipe}} = \left(\frac{12}{24}\right)^2 \cdot 10,000 \cdot 3.14 = \underline{\underline{7850\text{ft}^3}}$$

1.3.4 Release volume fraction, f_{rel}

The maximum release fraction, f_{rel} , represents the maximum ratio of oil released relative to the volume of the pipeline.

To find the release volume fraction, the relative pressure difference over the leak point has to be known. The relative pressure ratio, $\square P_{\text{rel}}$, is found from Equation 1.4.

$$\Delta P_{\text{rel}} = \frac{P_{\text{pipe}}}{P_{\text{amb}}} \quad \text{Eq. 1.4}$$

The ambient pressure P_{amb} can be found from Equation 1.5 or from Table 1.2.

$$P_{\text{amb}} = 0.446533 \cdot d \quad \text{Eq. 1.5}$$

where

P_{amb} - pressure outside leakage [psi]

d - water depth at leak point [ft]

Use Table 1.3 to find the maximum release fraction, f_{rel} , and the G_{max} . G_{max} is used in section 1.3.5 to find the GOR reduction factor (f_{GOR}).

Example:

The pipeline pressure is 950 psi. The gas-oil-ratio (GOR) of the fluid in the pipeline is 450 scf/stb. A rupture occurs at a water depth of 100 ft. Find the maximum release volume fraction, f_{rel} .

Solution*Step 1*

Find ambient pressure at leak point, 100 ft water depth.

There are two alternative methods to find the ambient pressure.

A calculator is not available \Rightarrow use Table 1.2.

For 100 ft water depth, the corresponding ambient pressure is 44.65 psi.

A calculator is available \Rightarrow use equation 1.5

The ambient pressure at 100 ft water depth is:

$$P_{amb} = 0.446533 \cdot 100 = \underline{44.65 \text{ psi}}$$

Step 2

Find the relative pressure ratio.

Use Equation 1.4:
$$\Delta P_{rel} = \frac{P_{pipe}}{P_{amb}} = \frac{950}{44.65} = \underline{21}$$

Step 3

Find the maximum release volume fraction and the G_{max}

Use Table 1.3. The value of ΔP_{rel} has been found to be 21.

Look in Table 1.3 and pick the f_{rel} and G_{max} corresponding to this value. Result: $f_{rel} = 0.71$ and $G_{max} = 168 \text{ scf/stb}$.

Table 1.2: Ambient pressure, P_{amb}

Sea depth [ft]	Pressure [psi]
0	0.00
25	11.16
50	22.33
75	33.49
100	44.65
150	66.98
200	89.31
250	111.6
300	134.0
400	178.6
500	223.3
600	267.9
700	312.6
800	357.2
900	401.9
1000	446.5
1100	491.2
1300	580.5
1500	669.8
1700	759.1
1900	848.4
2100	937.7
2300	1027
2500	1116
2700	1206
2900	1295
3100	1384
3300	1474
3500	1563
3700	1652
3900	1741
4100	1831
4300	1920
4500	2009

Table 1.3: Maximum released volume fraction, f_{rel}

Relative pressure ratio ΔP_{rel} [-]	Maximum release fraction f_{rel} [-]	Maximum Release occurs for a GOR of G_{max} [scf/stb]
1	0.0	not applicable (no leakage)
1.1 - 1.2	0.08	140
1.2 - 1.5	0.17	225
1.5 - 2	0.30	337
2 - 3	0.40	449
3 - 4	0.47	505
4 - 5	0.50	560
5 - 10	0.55	505
10 - 20	0.64	337
20 - 30	0.71	168
30-50	0.74	140
50 - 200	0.76	112
>200	0.77	112

1.3.5 GOR reduction factor, f_{GOR}

The total released volume of oil is strongly connected to the the gas-oil-ratio of the oil. The table below gives the volume reduction factor to be used in Equation 1.1 as function of the GOR.

In Table 1.4 columns two and three give reduction factors. Column two is used if GOR of the pipeline fluid is less than the G_{max} . The maximum G_{max} that can be found from Table 1.3 is 561 scf/stb. If the GOR of the fluid is higher than this value, the GOR will always be higher than G_{max} . Column three is used for GOR higher than G_{max} . G_{max} is found in Table 1.3.

Table 1.4: GOR reduction factors, f_{GOR}

GOR [scf/stb]	GOR reduction factors, f_{GOR} [-]	
	GOR < G_{max}	GOR > G_{max}
0-225	$f_{GOR} = \frac{GOR}{G_{max}}$	1
225-280		0.98
280-340		0.97
340-420		0.95
420-560		0.9
560-1100	Will not occur	0.85
1100-1700		0.82
1700-2800		0.63
2800-5600		0.43
5600-11300		0.26

Example Fluid 1:

The Gas-oil ratio (GOR) of the fluid in the pipeline is 450 scf/stb. Find the GOR reduction factor, f_{GOR} . All the other data are the same as in the examples above.

Solution:

The release volume fraction, f_{rel} and G_{max} has been found to be: $f_{rel} = 0.71$ and $G_{max} = 168$ scf/stb.

GOR [scf/stb]	GOR reduction factors, f_{GOR} [-]	
	GOR < G_{max}	GOR > G_{max}
0-225	$f_{GOR} = \frac{GOR}{G_{max}}$	1
225-280		0.98
280-340		0.97
340-420		0.95
420-560		0.9
560-1100	Will not occur	0.85
1100-1700		0.82
1700-2800		0.63
2800-5600		0.43
5600-11300		0.26

GOR > G_{max}

↓ Table 1.3

$f_{GOR} = 0.9$

Example Fluid 2:

The Gas-oil ratio (GOR) of the fluid in the pipeline is 150 scf/stb. Find the GOR reduction factor, f_{GOR} . All the other data are the same as in the examples above.

Solution:

The release volume fraction, f_{rel} and G_{max} has been found to be: $f_{rel} = 0.71$ and $G_{max} = 168$ scf/stb.

GOR [scf/stb]	GOR reduction factors, f_{GOR} [-]	
	GOR < G_{max}	GOR > G_{max}
0-225	$f_{GOR} = \frac{GOR}{G_{max}}$	1
225-280		0.98
280-340		0.97
340-420		0.95
420-560		0.9
560-1100	Will not occur	0.85
1100-1700		0.82
1700-2800		0.63
2800-5600		0.43
5600-11300		0.26

$$GOR < G_{max}$$

↓ Table 1.3

$$f_{GOR} = \frac{GOR}{G_{max}} = \frac{150}{168} = \underline{\underline{0.89}}$$

Example Fluid 3:

The Gas-oil ratio (GOR) of the fluid in the pipeline is 700 scf/stb. Find the GOR reduction factor, f_{GOR} . All the other data are the same as in the examples above.

Solution:

The release volume fraction, f_{rel} and G_{max} has been found to be: $f_{rel} = 0.71$ and $G_{max} = 168$ scf/stb.

GOR [scf/stb]	GOR reduction factors, f_{GOR} [-]	
	GOR < G_{max}	GOR > G_{max}
0-225	$f_{GOR} = \frac{GOR}{G_{max}}$	1
225-280		0.98
280-340		0.97
340-420		0.95
420-560		0.9
560-1100	Will not occur	0.85
1100-1700		0.82
1700-2800		0.63
2800-5600		0.43
5600-11300		0.26

$$GOR < G_{max}$$

↓ Table 1.3

$$f_{GOR} = 0.85$$

1.3.6 General Trends Regarding the Reduction Factors (Tables 2.3 and 2.4)

- An increase in the pressure difference between the pipe pressure, P_{pipe} , and the ambient pressure at the leak point, P_{amb} , will result in an increased oil release.
- An increase in the fluid Gas-Oil-Ratio, GOR, will result in reduced oil release as long as $\text{GOR} > G_{\text{max}}$. If $\text{GOR} < G_{\text{max}}$, the oil release will increase.
- Higher pipe volume V_{pipe} will result in a higher amount of oil released.

Example:

A 10,000 ft 12" ID pipeline is shut-in with a pressure of 950 psi. The Gas-oil ratio (GOR) of the fluid in the pipeline is 450 scf/stb. A rupture occurs at a water depth of 100 ft. Calculate the total oil release. The pipeline is shut-in 2 minutes after the leakage occurred. The oil is transported at a rate of 18000 stb/d.

Solution:

1. Volume released prior to shut-in

$$V_{\text{pre-shut}} = \frac{Q \cdot t}{1440} = \frac{18000 \cdot 2}{1440} = 25 \text{ bbls}$$

2. Total pipeline volume is 7850 ft³ (from Table 1.1)
3. Ambient pressure at leak point is 44.65 psi (from Table 1.2).
4. Relative pressure difference is
950 psi / 44.65 psi = 21
5. From Table 1.3 f_{rel} is **0.71** and
 G_{max} is 168 scf/stb.
6. From Table 1.4 f_{GOR} is **0.9** since $\text{GOR} > G_{\text{max}}$

Total release of oil from Equation 1.1:

$$V_{\text{rel}} = 0.1781 \cdot 7850 \text{ [ft}^3\text{]} \cdot 0.71 \cdot 0.9 + 25 = \underline{\underline{918 \text{ bbls}}}$$

2. ADVANCED METHOD

2.1 Introduction

The calculation approach presented in this Chapter is a more advanced method than the "Initial" approach presented in Chapter 1. To be able to follow this advanced method, a calculator is needed. This method is based on the principle of conservation of mass and the equilibrium of the oil fluid.

The fluid calculation equations presented in section 2.4 are based on experience and observations from a limited quantity of representative data and should be used with proper caution.

- These fluid calculation equations should not be used for very light crude oil or gas condensates.

The method presented in this Chapter assumes:

- A single horizontal pipeline segment.
- A full pipeline break or rupture (not applicable to pinhole leaks or other small pipeline fractures).

2.2 Required data

Following data are required to perform the calculations:

- Pipeline internal Diameter, ID_{pipe} [in]
- Pipeline length, L_{pipe} [ft]
- Pipeline Pressure, P_{pipe} [psi]
- Pipeline Temperature, T_{pipe} [°F]
- Ambient pressure, P_{amb} [psi]
- Ambient temperature, T_{amb} [°F]
- Gas-oil ratio at standard conditions, GOR [scf/stb]
- Oil density at standard conditions, γ_{API} [-] (API gravity, dimensionless), ρ_1^{stc} [lb/ft³] and γ_o [-] (specific gravity, dimensionless)
- Gas density at standard conditions, ρ_g^{stc} [lb/ft³], γ_g [-] (Specific gravity, dimensionless)
- Pipeline flow rate, Q [stb/d]
- Time before shut-in, t [min]

For unit conversion, please refer to Page 27.

2.3 Step by step procedure

1. Calculate total volume of pipe, V_{pipe} :

$$V_{\text{pipe}} = \left(\frac{ID_{\text{Pipe}}}{24} \right)^2 \cdot \pi \cdot L_{\text{pipe}} \quad [\text{ft}^3]$$

2. Calculate the oil and gas densities at initial operational conditions, ρ_o^{initial} and ρ_g^{initial} (Use procedure given in Section 2.4). Units: $[\text{lb}/\text{ft}^3]$
3. Calculate oil volume fraction at initial operational conditions ($P_{\text{pipe}}, T_{\text{pipe}}$), $X_{\text{ovf}}^{\text{initial}}$ (Use procedure given in Section 2.4). Dimensionless.

4. Calculate the initial mass in the pipeline:

$$m_{\text{tot}}^{\text{initial}} = \left(\rho_o^{\text{initial}} \cdot V_{\text{pipe}} \cdot X_{\text{ovf}}^{\text{initial}} \right) + \left(\rho_g^{\text{initial}} \cdot V_{\text{pipe}} \cdot (1 - X_{\text{ovf}}^{\text{initial}}) \right) \quad [\text{lb}]$$

5. Calculate the oil and gas densities at ambient pressure and temperature, ρ_o^{amb} and ρ_g^{amb} (Use procedure given in Section 2.4). Units: $[\text{lb}/\text{ft}^3]$
6. Calculate oil volume fraction at ambient pressure and temperature ($P_{\text{amb}}, T_{\text{amb}}$), $X_{\text{ovf}}^{\text{amb}}$ (Use procedure given in section 2.4). Dimensionless.

7. Calculate the total mass in the pipeline when pressure in pipeline has reached ambient pressure:

$$m_{\text{tot}}^{\text{amb}} = (\rho_o^{\text{amb}} \cdot V_{\text{pipe}} \cdot X_{\text{ovf}}^{\text{amb}}) + (\rho_g^{\text{amb}} \cdot V_{\text{pipe}} \cdot (1 - X_{\text{ovf}}^{\text{amb}})) \quad [\text{lb}]$$

8. Calculate the total mass released

$$m_{\text{tot_rel}} = m_{\text{tot}}^{\text{initial}} - m_{\text{tot}}^{\text{amb}} \quad [\text{lb}]$$

9. Calculate the gas mass fraction at **standard conditions**. Dimensionless.

$$X_{\text{gmf}}^{\text{stc}} = \frac{1}{1 + \frac{\rho_L^{\text{stc}} \cdot 5.614583}{(\text{GOR} \cdot \rho_g^{\text{stc}})}} \quad [-]$$

10. Calculate the volume of oil releases prior to shut-in.

$$V_{\text{pre-shut}} = \frac{Q \cdot t}{1440} \quad [\text{bbbls}]$$

11. Calculate the volume of oil released, **standard conditions**.

$$V_{\text{rel}}^{\text{stc}} = 0.1781 \cdot \frac{m_{\text{rel}} (1 - X_{\text{gmf}}^{\text{stc}})}{\rho_o^{\text{stc}}} + V_{\text{pre-shut}} \quad [\text{bbbls}]$$

2.4 Fluid Calculations

This section gives a procedure to calculate fluid properties at a given pressure and temperature (P, T). The gas and oil densities at standard conditions (60°F, 14.7psi) and the GOR of the fluid have to be known.

Find constants needed to calculate gas solubility:

<i>Coefficient</i>	$\gamma_{API} \leq 30$	$\gamma_{API} > 30$
C ₁	0.0362	0.0178
C ₂	1.09	1.19
C ₃	25.7	23.9

Calculate gas gravity at 100 psi

$$\gamma_{g100} = \gamma_g (1.0 - 3.1126 \cdot 10^{-3} \gamma_{API})$$

Calculate gas solubility

$$R_s = C_1 \gamma_{g100} p^{C_2} \cdot \exp \left[C_3 \frac{\gamma_{API}}{T + 460} \right]$$

Find coefficients needed to calculate bubble point pressure

<i>Coefficient</i>	$\gamma_{API} \leq 30$	$\gamma_{API} > 30$
K ₁	27.62	56.18
K ₂	0.9143	0.8424
K ₃	11.13	10.39

Calculate coefficient needed to calculate bubble point pressure

$$a = \frac{-K_3 \gamma_{API}}{T + 460}$$

Calculate bubble point pressure

$$P_b = \left[\left(\frac{K_1 GOR}{\gamma_{g100}} \right) 10^a \right]^{K_2}$$

Find coefficients needed to calculate formation volume factor

Coefficient	$\gamma_{API} \leq 30$	$\gamma_{API} > 30$
X_1	$4.677 \cdot 10^{-4}$	$4.670 \cdot 10^{-4}$
X_2	$1.751 \cdot 10^{-5}$	$1.100 \cdot 10^{-5}$
X_3	$-1.811 \cdot 10^{-8}$	$1.337 \cdot 10^{-9}$

Calculate the formation volume factor, B_o

If pressure is below bubble point pressure, P_b , then

$$B_o = 1.0 + X_1 R_s + (T - 60) \cdot \left(\frac{\gamma_{API}}{\gamma_{g100}} \right) \cdot (X_2 + X_3 R_s)$$

If pressure is above bubble point pressure, P_b , then

Calculate the isothermal compressibility of oil

$$c_o = \frac{6.83 \cdot 10^{-6}}{P} \cdot R_s^{0.5} \cdot \gamma_{API}^{0.36} \cdot T^{0.77} \cdot \gamma_{g100}^{-0.0355}$$

Calculate the B_o factor

$$B'_o = 1.0 + X_1 \text{GOR} + (T - 60) \left(\frac{\gamma_{\text{API}}}{\gamma_{\text{g100}}} \right) (X_2 + X_3 \text{GOR})$$

$$B_o = B'_o \exp[-c_o(P - P_b)]$$

If $B_o < 1$ then $B_o = 1$

Calculate specific gravity of dissolved gas in the oil phase

$$\gamma_{\text{gd}} = (-3.57 \cdot 10^{-6} \cdot \gamma_{\text{API}} - 2.86 \cdot 10^{-9}) \cdot R_s + 0.02\gamma_{\text{API}} + 0.25$$

If $\gamma_{\text{gd}} < 0.56$ Then $\gamma_{\text{gd}} = 0.56$

If $\gamma_{\text{gd}} < \gamma_g$ Then $\gamma_{\text{gd}} = \gamma_g$

Calculate specific gravity of free gas

$$\gamma_{\text{gf}} = \frac{\text{GOR} \cdot \gamma_g - R_s \gamma_{\text{gd}}}{\text{GOR} - R_s}$$

If $\gamma_{\text{gf}} < 0.56$ Then $\gamma_{\text{gf}} = 0.56$

If $\gamma_{\text{gf}} > \gamma_g$ Then $\gamma_{\text{gf}} = \gamma_g$

Calculate the oil density

If pressure below bubble point pressure

$$\rho_o = \frac{62.4\gamma_o + 0.0136R_s\gamma_{\text{gd}}}{B_o} \quad [\text{lb/ft}^3]$$

If pressure above bubble point pressure

$$\rho_o = \left[\frac{62.4\gamma_o + 0.0136\text{GOR}\gamma_{\text{gd}}}{B_o} \right] \cdot e^{c_o(P - P_b)} \quad [\text{lb/ft}^3]$$

Calculate pseudocritical temperature [$^{\circ}$ R]

$$T_{pc} = 187 + 330\gamma_g - 71.5\gamma_g^2$$

Calculate reduced temperature, T_{pr}

$$T_{pr} = \frac{T + 460}{T_{pc}}$$

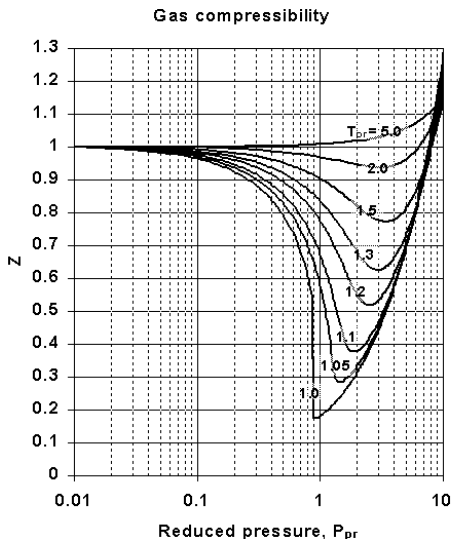
Calculate pseudocritical pressure [psi]

$$P_{pc} = 706 - 51.7\gamma_g - 11.1\gamma_g^2$$

Calculate reduced pressure, P_{pr}

$$P_{pr} = \frac{P}{P_{pc}}$$

Pick gas compressibility factor Z from the chart below



Calculate the gas density

$$\rho_g = \frac{2.7 \cdot \gamma_{gf} \cdot P}{Z(T + 460)} \quad [\text{lb/ft}^3]$$

Calculate the gas mass fraction of free gas.

$$R_{\text{sfree}} = \text{GOR} - R_s$$

Calculate the gas mass fraction

$$X_{\text{gmf}} = \frac{1}{1 + \frac{\rho_L^{\text{stc}} \cdot 5.615}{(R_{\text{sfree}} \cdot \rho_g^{\text{stc}})}} \quad \text{if } X_{\text{gmf}} < 0 \Rightarrow X_{\text{gmf}} = 0$$

Calculate the volume fraction of oil

$$X_{\text{ovf}} = \frac{(1 - X_{\text{gmf}}) \cdot \rho_g}{X_{\text{gmf}} \cdot \rho_o + (1 - X_{\text{gmf}}) \cdot \rho_g}$$

Example:

A 10 000 ft 12" ID pipeline is shut-in with a pressure of 3000 psi and a operational temperature of 80°F. The Gas-oil ratio (GOR) of the fluid in the pipeline is 450 scf/stb. The oil and gas densities at standard conditions are 65 lb/ft³ and 0.05 lb/ft³ respectively. A rupture occurs at a water depth of 100 ft. The seabed temperature is 65°F. Calculate the total oil release. The pipeline is shut-in 2 minutes after the leakage occurs. The oil is transported at a rate of 18000stb/d.

Solution:Unit Conversion*Gas density*

0.05 lb/ft³, In the fluid calculation equations, the gas density has to be known in gas gravity. To convert from lb/ft³ to gas gravity, multiply by 12.98408. Result: $\gamma_g = 0.649$ (gas gravity)

Oil density

50 lb/ft³, In the fluid calculation equations the gas density has to be known in specific gravity and in API gravity. From lb/ft³ to specific gravity multiply by 0.016018. Result: $\gamma_o = 0.8009$ (specific gravity)

From specific gravity to API gravity, the following formula

must be used:
$$\frac{141.5}{\text{specific gravity}} - 131.5 = \frac{141.5}{0.8009} - 131.5$$

= 45.18 API gravity

1. Calculate total volume of pipe, V_{tot} :

$$V_{\text{pipe}} = \left(\frac{\text{ID}_{\text{pipe}}}{24} \right)^2 \cdot \pi \cdot L_{\text{pipe}} = \left(\frac{12}{24} \right)^2 \cdot 3.14 \cdot 10000 = 7850$$

2. Calculate the oil and gas densities at initial operational conditions (Use procedure given in section 2.4).

γ_{g100}	0.5579
R_s	251.7
a	-0.87
P_b	1548
B_o	1.14
γ_{gd}	1.11
γ_{gf}	0.56
ρ_o	47.4
T_{pc}	371
T_{pr}	1.45
P_{pc}	668
P_{pr}	1.42
Z	0.81
ρ_g	3.28

Oil density, ρ_o^{initial} : 47.4 lb/ft³

Gas density, ρ_g^{initial} : 3.28 lb/ft³

3. Calculate oil volume fraction at initial operational conditions (Use procedure given in section 2.4).

$R_{s\text{free}}$	198.3
X_{gmf}	0.03411
X_{ovf}	0.6628

Volume fraction of oil, $X_{ovf}^{\text{initial}} = 0.729$ (Dimensionless)

4. Calculate the initial mass in the pipeline:

$$m_{\text{tot}}^{\text{initial}} = (\rho_o^{\text{initial}} \cdot V_{\text{pipe}} \cdot X_{ovf}^{\text{initial}}) + (\rho_g^{\text{initial}} \cdot V_{\text{pipe}} \cdot (1 - X_{ovf}^{\text{initial}}))$$

$$m_{\text{tot}}^{\text{initial}} = (47.4 \text{ lb/ft}^3 \cdot 7850 \text{ ft}^3 \cdot 0.6628) + (3.28 \text{ lb/ft}^3 \cdot 7850 \text{ ft}^3 \cdot (1 - 0.6628))$$

$$m_{\text{tot}}^{\text{initial}} = \underline{2.55 \cdot 10^5 \text{ lb}}$$

5. Calculate the oil and gas densities at ambient pressure and temperature (Use procedure given in section 2.4).

γ_{g100}	0.5579
R_s	7.1
a	-0.90
P_b	1475
B_o	1.008
γ_{gd}	1.15
γ_{gf}	0.64
ρ_o	49.7
T_{pc}	371.1
T_{pr}	1.14
P_{pc}	668
P_{pr}	0.067
Z	0.99
ρ_g	0.149

Oil density, ρ_o^{end} : 49.7 lb/ft³

Gas density, ρ_g^{end} : 0.149 lb/ft³

6. Calculate oil volume fraction at ambient pressure and temperature (Use procedure given in section 2.4).

$R_{s\text{free}}$	442.9
X_{gmf}	0.073
X_{ovf}	0.037

Volume fraction of oil, $X_{\text{ovf}}^{\text{end}}$: 0.037 (Dimensionless)

7. Calculate the total mass in the pipeline when pressure in pipeline has reached ambient pressure:

$$m_{\text{tot}}^{\text{end}} = (\rho_o^{\text{end}} \cdot V_{\text{pipe}} \cdot X_{\text{ovf}}^{\text{end}}) + (\rho_g^{\text{end}} \cdot V_{\text{pipe}} \cdot (1 - X_{\text{ovf}}^{\text{end}}))$$

$$m_{\text{tot}}^{\text{end}} = (49.7 \text{ lb/ft}^3 \cdot 7850 \text{ ft}^3 \cdot 0.037) + (0.149 \text{ lb/ft}^3 \cdot 7850 \text{ ft}^3 \cdot (1 - 0.037))$$

$$m_{\text{tot}}^{\text{end}} = \underline{15561 \text{ lb}}$$

8. Calculate the total mass released

$$m_{\text{tot_rel}}^{\text{released}} = m_{\text{tot}}^{\text{initial}} - m_{\text{tot}}^{\text{end}}$$

$$m_{\text{tot_rel}}^{\text{released}} = 2.55 \cdot 10^5 \text{ lb} - 15561 \text{ lb} = 239439 \text{ lb}$$

9. Calculate the gas mass fraction at **standard conditions**. Dimensionless.

$$X_{\text{gmf}}^{\text{stc}} = \frac{1}{1 + \frac{\rho_{\text{L}}^{\text{stc}} \cdot 5.614583}{(\text{GOR} \cdot \rho_{\text{g}}^{\text{stc}})}} = \frac{1}{1 + \frac{50 \cdot 5.614583}{(450 \cdot 0.05)}} = 0.0742$$

10. Calculate the volume of oil releases prior to shut-in.

$$V_{\text{pre-shut}} = \frac{Q \cdot t}{1440} = \frac{18000 \cdot 2}{1440} = 25 \quad [\text{bbls}]$$

11. Calculate the total volume released, **standard conditions**

$$V_{\text{rel}}^{\text{stc}} = 0.1781 \cdot \frac{m_{\text{tot_rel}}^{\text{released}} (1 - X_{\text{gmf}}^{\text{stc}})}{\rho_{\text{o}}^{\text{stc}}} + V_{\text{pre_shut}}$$

$$V_{\text{rel}}^{\text{stc}} = 0.1781 \frac{239439 \text{ lb} \cdot (1 - 0.0742)}{50 \text{ lb / ft}^3} + 25$$

$$V_{\text{rel}}^{\text{stc}} = \underline{\underline{815 \text{ bbls}}}$$

APPENDIX A

VARIABLE DESCRIPTION AND UNIT CONVERSION

Pipeline Length, L_{pipe}

This is the length of the pipeline including risers.

Units

The unit of the length has to be in ft when used in the further studies.

The conversion factors to use are listed below:

To convert from	To	Multiply by
M	Ft	3.2808

Pipeline Internal Diameter, ID_{pipe}

This is the inside diameter of the pipeline.

Units

The unit of the diameter has to be in *in* when used in the further studies.

The conversion factors to use are listed below:

To convert from	To	Multiply by
M	In	39.37
Ft	In	12

Pipeline Pressure, P_{pipe}

The operational pressure of the pipeline has to be known to get an estimate of the total amount of oil released.

Units

The unit of the operational pressure has to be in *Psi* when used in the further studies.

The conversion factors to use are listed below:

To convert from	To	Multiply by
Bar	Psi	14.503774

Pipeline Temperature, T_{pipe}

This is an average temperature inside the pipe during transportation.

Units

The unit of the operational temperature has to be in $^{\circ}F$ when used in the further studies.

The conversion factors to use are listed below:

To convert from	To	Conversion formula
$^{\circ}C$	$^{\circ}F$	$T_f = \frac{9}{5} T_c + 32$

Water Depth at Rupture Location, d

The water depth at rupture location is used to calculate the ambient pressure.

Units

The unit of the water depth has to be in *ft* when used in the further studies.

The conversion factors to use are listed below:

To convert from	To	Multiply by
m	Ft	3.2808

Ambient Pressure, P_{amb}

This is the pressure outside the pipe at the location of the rupture.

This pressure is a function of the sea depth:

$$P = \text{Water depth [ft]} * 0.446686 \quad [\text{psi}]$$

Units

The unit of the ambient pressure has to be in *Psi* when used in the further studies.

The conversion factors to use are listed below:

To convert from	To	Multiply by
Bar	Psi	14.503774

Ambient Temperature, T_{amb}

This is the temperature outside the pipe at the location of the rupture.

A typical value for the sea bottom temperature is 35°F

Units

The unit of the ambient temperature has to be in °F when used in the further studies.

The conversion factors to use are listed below:

To convert from	To	Conversion formula
°C	°F	$T_f = \frac{9}{5} T_c + 32$

Gas-oil ratio, GOR

This is the Gas-oil ratio of the pipeline fluid at standard conditions.

Units

The unit of the GOR has to be in *scf/stb* when used in the further studies.

The conversion factors to use are listed below:

To convert from	To	Multiply by
Sm ³ / Sm ³	Scf/stb	5.6146

Oil Density, γ_{API} , ρ_I^{stc}

This is the density of the oil phase at standard conditions.

Units

For further calculation, the unit of the oil density has to be known in API gravity, γ_{API} , and lb/ft^3 , ρ_I^{stc} .

The conversion factors to use are listed below:

To convert from	To	Multiply by
lb/ft^3	Specific gravity [-]	0.016018
kg/m^3	lb/ft^3	0.062428
kg/m^3	Specific gravity [-]	0.001
Specific gravity [-]	API gravity [-]	$\frac{141.5}{\text{specific gravity}} - 131.5$

Gas Density, γ_g , ρ_g^{stc}

This is the density of the gas phase at standard conditions.

Units

For further calculation, the unit of the gas density has to be known in gas gravity, γ_g , and lb/ft^3 , ρ_g^{stc} .

The conversion factors to use are listed below:

To convert from	To	Multiply by
lb/ft^3	Gas gravity [-]	12.984
kg/m^3	lb/ft^3	0.06243
kg/m^3	Gas gravity [-]	$\frac{1}{1.2337}$

List of conversion factors

<i>To convert from</i>	<i>To</i>	<i>Multiply by</i>
Length		
M	Ft	3.2808
M	In	39.37
Ft	In	12
Volume		
ft ³	Bbls	0.1781
Bbls	Ft ³	5.615
Pressure		
Bar	Psi	14.503774
Water depth(h), m	Psi	0.446533
Temperature		
°C	°F	$T_f = \frac{9}{5} T_C + 32$
°F	°R	$T_r = T_f + 460$
Gas-oil ratio, GOR		
Sm ³ / Sm ³	Scf/stb	5.6146
Density		
lb/ft	Gas gravity [-]	12.984
kg/m ³	Lb/ft	0.06243
kg/m ³	Gas gravity [-]	$\frac{1}{1.2337}$
lb/ft ³	Specific gravity [-]	0.016018
kg/m ³	Specific gravity [-]	0.001
Specific gravity [-]	API gravity [-]	$\frac{141.5}{\text{specific gravity}} - 131.5$