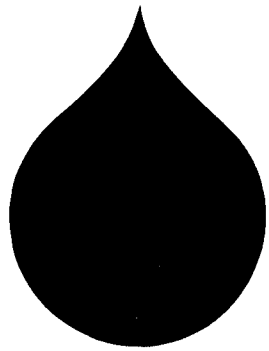
# RESERVOIR FLUID STUDY



FOR

## STATOIL

DEN NORSKE STATS OLJESELSKAP A/S

Stavanger, Norway

BOTTOM HOLE SAMPLE

OIL WELL NO 34/10–2

DST NO 3a




**SINTEF**

**PETROLEUM ENGINEERING DIVISION**

THE FOUNDATION OF SCIENTIFIC AND INDUSTRIAL RESEARCH AT THE UNIVERSITY OF TRONDHEIM

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ABSTRACT

This report presents the results from a PVT-analysis performed on a bottom hole sample from 34/10-2.

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## INTRODUCTION

The present report presents the results of laboratory studies on a bottom hole sample from 34/10-2.

In the laboratory the reservoir fluid gave a bubble point pressure of 356.5 bar-g at 126.7°C respectively 341.3 bar-g at 35°C.

The gas-oil ratio from a single flash of the reservoir fluid in conjunction with the measured composition of the separator products was used to calculate the composition of the well stream fluid. These data are reported in Table 10.

Differential gas liberation test gave 167.4 standard cubic meter of vapor per cubic meter of residual oil. The corresponding relative volume factor was found to be 1.533 cubic meter of fluid at saturation pressure per cubic meter of residual oil.

A one-stage test separation resulted in a total GOR of 173.0 standard cubic meter of vapor per cubic meter of stock tank oil. The formation volume factor measured was 1.543 cubic meter of fluid at saturation pressure per cubic meter of stock tank oil. See Table 9 for details.

The viscosity of the liquid phase decreased form a value of 0.528 mPa·s at 540 bar, through a minimum of 0.403 mPa·s at saturation pressure and increased to a maximum of 1.560 mPa·s at atmospheric pressure during differential depletion. This is shown graphically in Figure 3.

Results from destillation of stock tank oil are found in table 11.

Table 1 presents a summary of reservoir fluid properties from these studies.

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Table 1. Summary of Fluid Properties

| | | |
|---|---|---|
| 1. | Bubble point pressure | 356.5 bar-g at 126.7°C<br>341.3 bar-g at 35°C |
| 2. | Density of bubble point oil | 0.670 g/cm$^3$ |
| 3. | Viscosity of bubble point oil | 0.403 mPa·s |
| 4. | Gas solubility of bubble point oil | |
| | a. Differential gas liberation at 126.7°C | 167.4 m$^3$/m$^3$ Resid. Oil |
| | b. One-stage flash | 173.0 m$^3$/m$^3$ St. Oil |
| 5. | Relative volume factor of bubble point oil, differential test | 1.533 m$^3$/m$^3$ Resid. Oil |
| 6. | Formation volume factor of bubble point oil, one-stage flash | 1.543 m$^3$/m$^3$ St. Oil |
| 7. | Compressibility of undersaturated reservoir oil<br>Varies almost linearly from $1.2885 \cdot 10^{-4}$ bar$^{-1}$ at 500 bar to $2.0533 \cdot 10^{-4}$ bar$^{-1}$ at 360 bar. | |

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## Table 2. Reservoir and Sample Data

### *Well and Formation Data*

| | | | |
|---|---|---|---|
| Producing zone | Statfjord | | |
| Perforation intervals | 3335-3345 m | | |
| Initial pressure | 473.0 | bar-g at | 3331 m |
| Reservoir temperature | 126.7 | °C at | 3325 m |
| Last static pressure | 467.6 | bar-g at | 3331 m |
| Date | 1979-07-29 | | |
| Flowing pressure | 349.7 | bar-g at | 3063 m |
| Rate (oil, water) | - | - | |
| (gas) | - | | |
| Date | | | |
| Tubing size and depth | 3½" D.P. Shoe at 3338 m | | |

### *Sample Data*

| | |
|---|---|
| Data sampled | 1979-07-29 |
| Type of sample(s) | Bottom Hole |
| Separator pressure | |
| Separator temperature | |
| Average flow during sampling | |
| First stage separator gas | |
| Other separator gases | |
| Stocktank oil | |
| Water | |

### *Remarks*

The bottom hole sample bottle was marked 22478-53.

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Table 3. Smoothed Constant-Composition Pressure-Volume Data at 126.7°C

| *Pressure* *bar-g* | *Relative Vol. Fact.* $V_R$ | *Y Factor* | *Compressibility* *($bar^{-1}$)* |
|---|---|---|---|
| 500 | 0.9761 | | 1.2885-04 |
| 480 | 0.9787 | | 1.4008-04 |
| 460 | 0.9816 | | 1.5121-04 |
| 440 | 0.9846 | | 1.6225-04 |
| 420 | 0.9879 | | 1.7317-04 |
| 400 | 0.9915 | | 1.8398-04 |
| 380 | 0.9952 | | 1.9467-04 |
| 360 | 0.9992 | | 2.0523-04 |
| 356.5 | 1.0000 | 4.4989 | |
| 340 | 1.0109 | 4.4119 | |
| 320 | 1.0264 | 4.3062 | |
| 300 | 1.0447 | 4.2006 | |
| 280 | 1.0665 | 4.0949 | |
| 260 | 1.0927 | 3.9892 | |
| 240 | 1.1244 | 3.8836 | |
| 220 | 1.1635 | 3.7779 | |
| 200 | 1.2120 | 3.6722 | |
| 180 | 1.2734 | 3.5666 | |
| 160 | 1.3526 | 3.4609 | |
| 140 | 1.4576 | 3.3552 | |
| 120 | 1.6014 | 3.2496 | |
| 100 | 1.8077 | 3.1439 | |

| *Equations* | *Pressure Range* |
|---|---|
| $Y = 2.61026 + 5.2834(10^{-3})p$ | $100.0 < p < 357.5$ |
| $V_R = 1.11022 - 4.0961(10^{-4})p + 2.8327(10^{-7})p^2$ | $357.5 < p < 500.0$ |
| $V_R = \frac{357.5 + 1.61026p + 5.2834(10^{-3})p^2}{2.61026p + 5.2834(10^{-3})p^2}$ | $100.0 < p < 357.5$ |
| $C_o = \frac{4.0961(10^{-4}) - 5.6654(10^{-7})p}{1.11022 - 4.0961(10^{-4})p + 2.8327(10^{-7})p^2}$ | $357.5 < p < 500.0$ |

Pressures in the above equations are in bar-absolute.

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Table 4. Smoothed Differential Gas Liberation Data at 126.7°C

| *Pressure bar-g* | *Solution Gas-Oil Ratio $m^3/m^3$ Residual Oil* | *Relative Oil Volume $m^3/m^3$ Residual Oil* | *Saturated Oil Density $g/cm^3$* |
|---|---|---|---|
| 356.5 | 165.5 | 1.522 | 0.673 |
| 340 | 156.9 | 1.503 | 0.677 |
| 320 | 146.5 | 1.480 | 0.682 |
| 300 | 136.3 | 1.457 | 0.687 |
| 280 | 126.3 | 1.434 | 0.693 |
| 260 | 116.5 | 1.412 | 0.698 |
| 240 | 106.8 | 1.389 | 0.704 |
| 220 | 97.3 | 1.367 | 0.710 |
| 200 | 87.9 | 1.345 | 0.716 |
| 180 | 78.8 | 1.323 | 0.722 |
| 160 | 69.7 | 1.301 | 0.728 |
| 140 | 60.9 | 1.279 | 0.734 |
| 120 | 52.2 | 1.258 | 0.740 |
| 100 | 43.7 | 1.236 | 0.746 |
| 80 | 35.3 | 1.215 | 0.753 |
| 60 | 27.1 | 1.194 | 0.759 |
| 40 | 19.1 | 1.172 | 0.766 |
| 20 | 11.2 | 1.151 | 0.773 |
| 0 | - | 1.131 | 0.780 |

*Equations*

$$R_S = 3.53606 + 3.80787(10^{-1})p + 2.06287(10^{-4})p^2$$

$$V_{Ro} = 1.13066 + 1.03735(10^{-3})p + 1.70653(10^{-7})p^2$$

$$\rho_o = 7.79743(10^{-1}) - 3.46770(10^{-4})p + 1.29011(10^{-7})p^2$$

Pressures in the above equations are in bar-gage.

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Table 5. Smoothed Liquid and Gas Viscosity Data at 126.7°C

| *Pressure bar-g* | *Liquid Phase Viscosity mPa·s* | *Gas Phase Viscosity mPa·s*)* |
|---|---|---|
| 540 | 0.528 | |
| 520 | 0.514 | |
| 500 | 0.501 | |
| 480 | 0.487 | |
| 460 | 0.474 | |
| 440 | 0.460 | |
| 420 | 0.447 | |
| 400 | 0.433 | |
| 380 | 0.419 | |
| 360 | 0.406 | |
| 356.5 | 0.403 | |
| 340 | 0.427 | 2.4257-02 |
| 320 | 0.446 | 2.3363-02 |
| 300 | 0.469 | 2.2497-02 |
| 280 | 0.495 | 2.1658-02 |
| 260 | 0.524 | 2.0848-02 |
| 240 | 0.556 | 2.0065-02 |
| 220 | 0.591 | 1.9310-02 |
| 200 | 0.630 | 1.8583-02 |
| 180 | 0.671 | 1.7884-02 |
| 160 | 0.715 | 1.7212-02 |
| 140 | 0.763 | 1.6568-02 |
| 120 | 0.814 | 1.5952-02 |

| *Equations* | *Pressure Range* |
|---|---|
| $\mu_o = 1.61755(10^{-1}) + 6.78010(10^{-4})p$ | $356.5 < p < 540$ |
| $\mu_o = 1.18367 - 3.54934(10^{-3})p + 3.89241(10^{-6})p^2$ | $120 < p < 356.5$ |
| $\mu_g = 1.28394(10^{-2}) + 2.17720(10^{-5})p + 3.47303(10^{-8})p^2$ | $120 < p < 356.5$ |

*)Calculated from gas gravity and data of Carr, Kobyashi and Burrows.

Pressures in the above equations are in bar-gage.

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Table 6. Experimental Constant-Composition Pressure-Volume Data at 126.7°C

| *Pressure bar-g* | *Relative Vol.Fact.* $V_R$ | *Y Factor* |
|---|---|---|
| 489.9 | 0.9782 | |
| 445.7 | 0.9845 | |
| 397.7 | 0.9928 | |
| 365.3 | 0.9990 | |
| 356.5 | 1.0000 | |
| 345.7 | 1.0078 | 3.9830 * |
| 320.2 | 1.0275 | 4.1165 * |
| 295.2 | 1.0499 | 4.1465 |
| 270.2 | 1.0782 | 4.0720 |
| 248.6 | 1.1103 | 3.9185 |
| 220.7 | 1.1617 | 3.7894 |
| 197.6 | 1.2172 | 3.6835 |
| 151.0 | 1.3986 | 3.3913 |
| 99.0 | 1.8372 | 3.0758 |

*) Not used in equation fit.

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Table 7. Experimental Liquid Phase Viscosity Data at 126.7°C

| *Pressure* bar-g | *Liquid Phase Viscosity*, mPa·s |
|---|---|
| 494.8 | 0.50 |
| 447.2 | 0.46 |
| 393.3 | 0.43 |
| 365.3 | 0.41 |
| 343.2 | 0.42 |
| 321.2 | 0.46*) |
| 297.6 | 0.48 |
| 270.7 | 0.51 |
| 246.6 | 0.54 |
| 198.1 | 0.63 |
| 150.5 | 0.74 |
| 103.0 | 0.88 |
| 61.8 | 1.02 |
| 34.8 | 1.15 |
| 0 | 1.56 |

*) Not used in equation fit.

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Table 8. Experimental Differential Gas Liberation Data at 126.7°C

| *Pressure* bar-g | *Liberated Gas-Oil Ratio* $m^3/m^3$ *Residual Oil* | *Solution Gas-Oil Ratio* $m^3/m^3$ *Residual Oil* | *Relative Volume* $m^3/m^3$ *Residual Oil* | *Saturated Oil Density* $g/cm^3$ | *Compressibility Factor of Liberated Gas Z* | *Average Gravity of Liberated Gas (air=1)* |
|---|---|---|---|---|---|---|
| 356.5 | - | 167.4 | 1.533 | 0.670 | - | - |
| 318.2 | 21.2 | 146.2 | 1.481 | 0.681 | - | 0.673 |
| 283.9 | 40.9 | 126.5 | 1.429 | 0.695 | 0,952 | 0.671 |
| 252.0 | 56.9 | 110.5 | 1.393 | 0.703 | 0,937 | 0.670 |
| 215.2 | 73.9 | 93.5 | 1.353 | 0.714 | 0,936 | 0.670 |
| 179.0 | 90.0 | 77.4 | 1.315 | 0.725 | 0,920 | 0.670 |
| 143.7 | 102.9 | 64.5 | 1.296 | 0.727 | 0,920 | 0.673 |
| 107.9 | 119.2 | 48.2 | 1.249 | 0.743 | 0,934 | 0.677 |
| 72.1 | 133.2 | 34.2 | 1.218 | 0.753 | 0,948 | 0.686 |
| 35.8 | 148.0 | 19.4 | 1.182 | 0.765 | 1,000 | 0.738 |
| 0 | 167.4 | - | 1.110 | 0.785 | - | 1.362 |
| | | at 15.0°C | 1.000 | | | |

Residual oil specific gravity = 0.871 $g/cm^3$ at 15.0°C

Average gravity of total liberated gas = 0.759

Notes:

(1) Reservoir fluid bubble point pressure is 356.5 bar-g at 126.7°C.

(2) Gas/oil ratios are cubic meter of gas at 1.013 bar and 15.0°C per cubic meter of residual oil at 1.013 bar and 15.0°C.

(3) Relative oil volumes are cubic meter of saturated reservoir oil per cubic meter residual oil at 1.013 bar and 15.0°C.

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Table 9. Separator Tests of Reservoir Fluid Sample

| | *Separator pressure, bar* |
|---|---|
| | 1.013 |
| Separator temperature, $^{o}C$ | 15.0 |
| Separator gas/oil ratio, $m^3/m^3$ | 173.0 |
| Separator gas gravity, air = 1 | 0.690 |
| Stocktank oil gravity, $g/cm^3$ | 0.869 |
| Bubble point formation volume factor, $m^3/m^3$ | 1.543 |

Notes:

(1) Gas and liquid volumes are expressed at standard conditions of 1.013 bar and 15.0$^{o}$C.

(2) Reservoir fluid bubble point pressure is 356.5 bar-g at 126.7$^{o}$C.

(3) Gas/oil ratios are standard cubic meter of gas per cubic meter of stocktank oil.

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Table 10. Analysis of Separator Streams from Single Flash and Calculated Reservoir Fluid Composition

| | *Mole Fraction* | | |
|---|---|---|---|
| *Component* | *Separator Gas* | *Separator Liquid* | *Reservoir Fluid* |
| Carbon dioxide | 0.0220 | | 0.0147 |
| Nitrogen | 0.0025 | | 0.0017 |
| Methane | 0.8359 | | 0.5590 |
| Ethane | 0.0710 | 0.0032 | 0.0485 |
| Propane | 0.0358 | 0.0071 | 0.0263 |
| iso-Butane | 0.0057 | 0.0029 | 0.0048 |
| n-Butane | 0.0103 | 0.0083 | 0.0096 |
| iso-Pentane | 0.0036 | 0.0047 | 0.0040 |
| n-Pentane | 0.0038 | 0.0033 | 0.0036 |
| Hexanes | 0.0038 | 0.0163 | 0.0079 |
| Heptanes | 0.0055 | 0.0438 | 0.0182 |
| Octanes | | 0.0613 | 0.0203 |
| Nonanes | | 0.0341 | 0.0113 |
| Decanes | | 0.0229 | 0.0076 |
| Undecanes plus | | 0.7921 | 0.2625 |
| | 1.0000 | 1.0000 | 1.0000 |

Properties of Heneicosanes plus

| | |
|---|---|
| Molecular weight | 276.7 |
| Specific gravity | 0.886 |

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Table 11. Destillation of Stocktank Oil and Analysis of $C_{11+}$-fraction

The stock tank oil from single flash was destilled down to $C_{11+}$ -fraction (equivalent boiling point 174.6°C at 1.013 bar).

Results:

| | |
|---|---|
| Weight-% $C_{11+}$ of total stock tank oil: | 91.3 |
| Weight-% of total mixture of $C_{11+}$-fraction (after ASTM D-2549/76): | |
| Paraffines & naphtenes | 72.9 |
| Aromats | 27.1 |
| Sum: | 100.0 |
| Weight-% of asphaltenes in $C_{11+}$ - fraction determined by method proposed by STATOIL (letter of 1979-10-29) | 1.94 % |
| Density of $C_{11+}$ - fraction, g/cm$^3$ | 0.882 |
| Molecular weight of $C_{11+}$ - fraction | 278.8 |

Anfar C10 MW = 133

⇓

C10+ MW = 274.7

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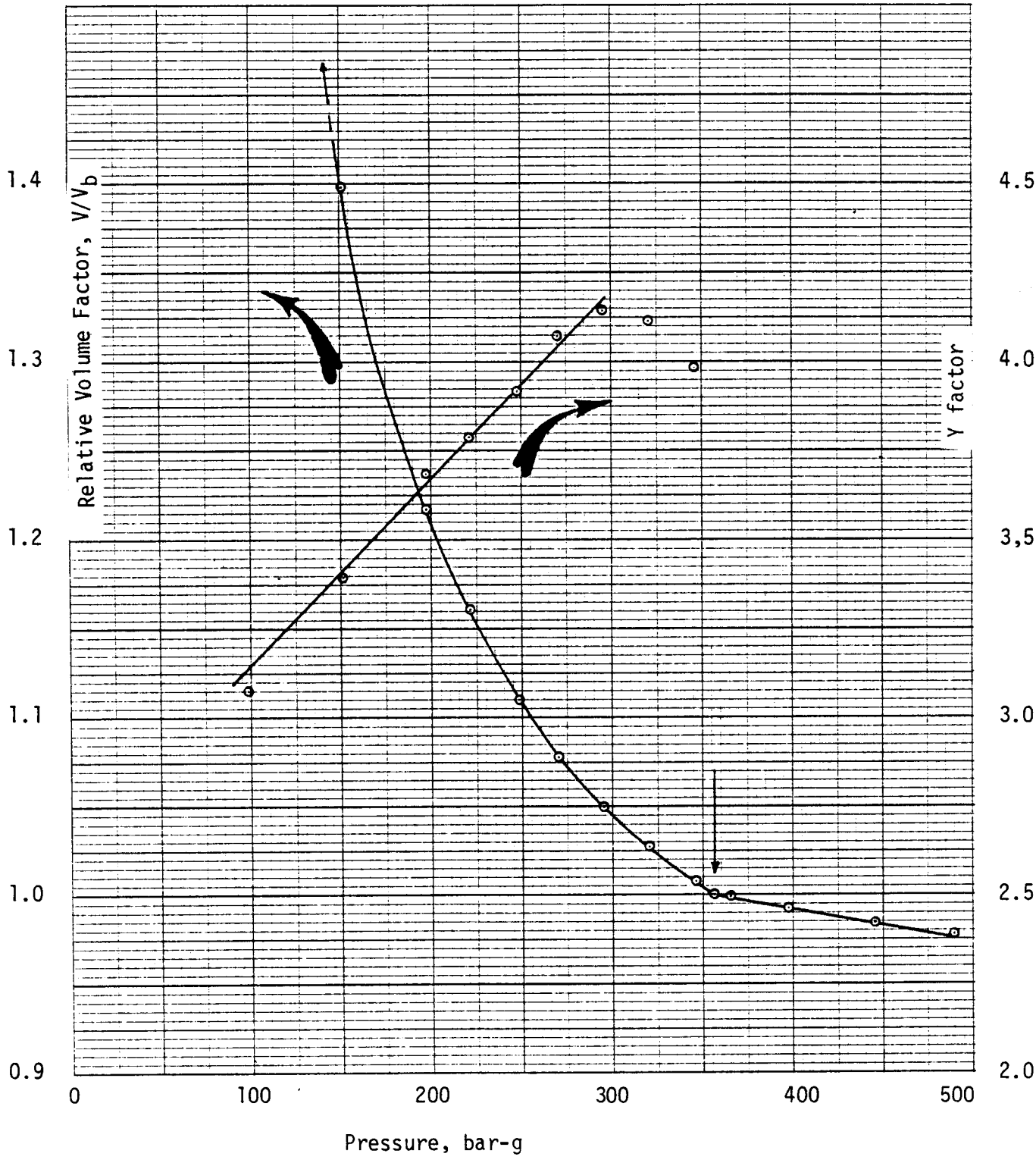


Figure 1. Experimental constant - composition pressure-volume and Y factor vs. pressure. Temperature 126,7°C.

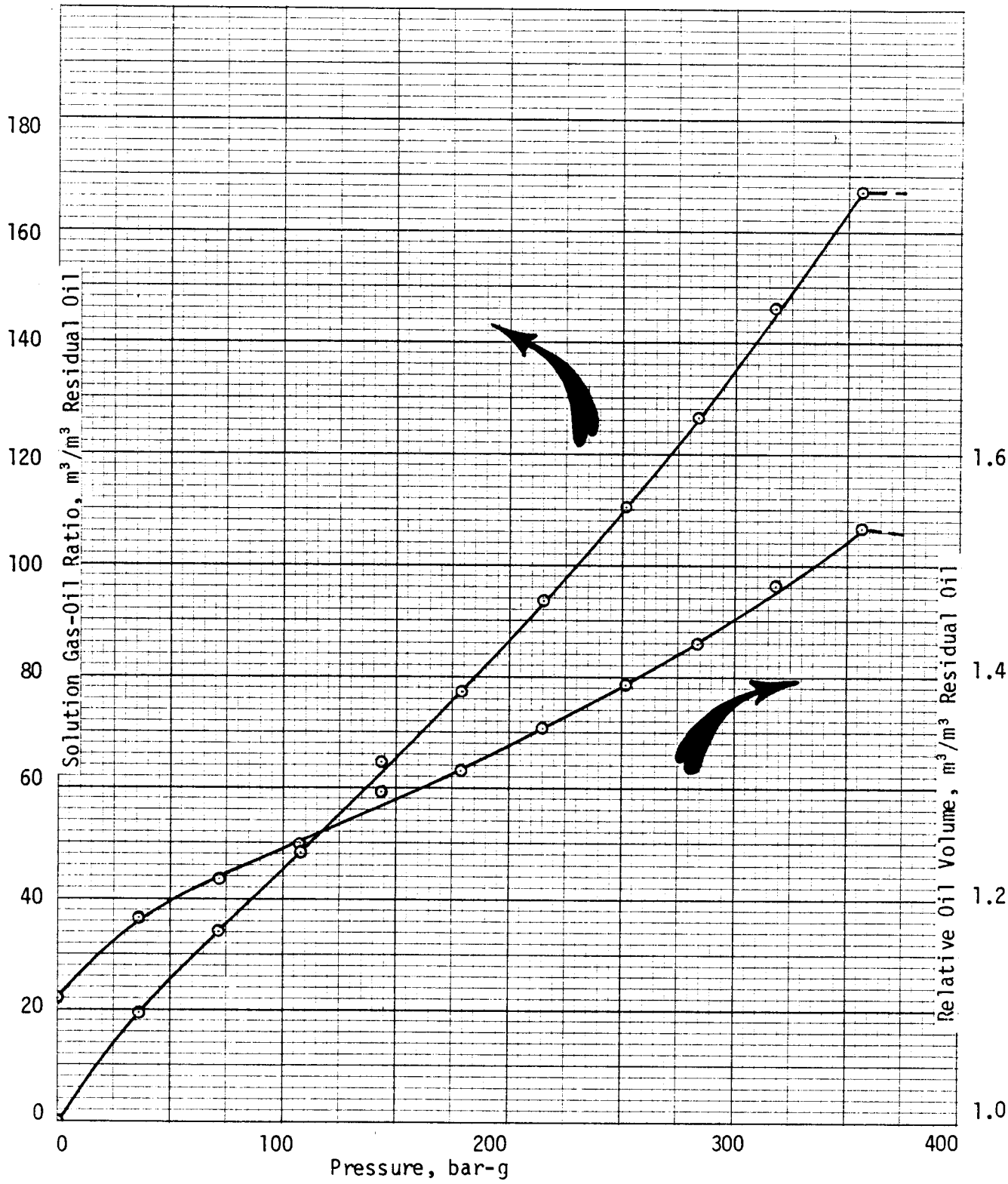


Figure 2. Experimental gas solubility and relative oil volume data vs. pressure. Differential gas liberation process. Temperature 126.7°C.

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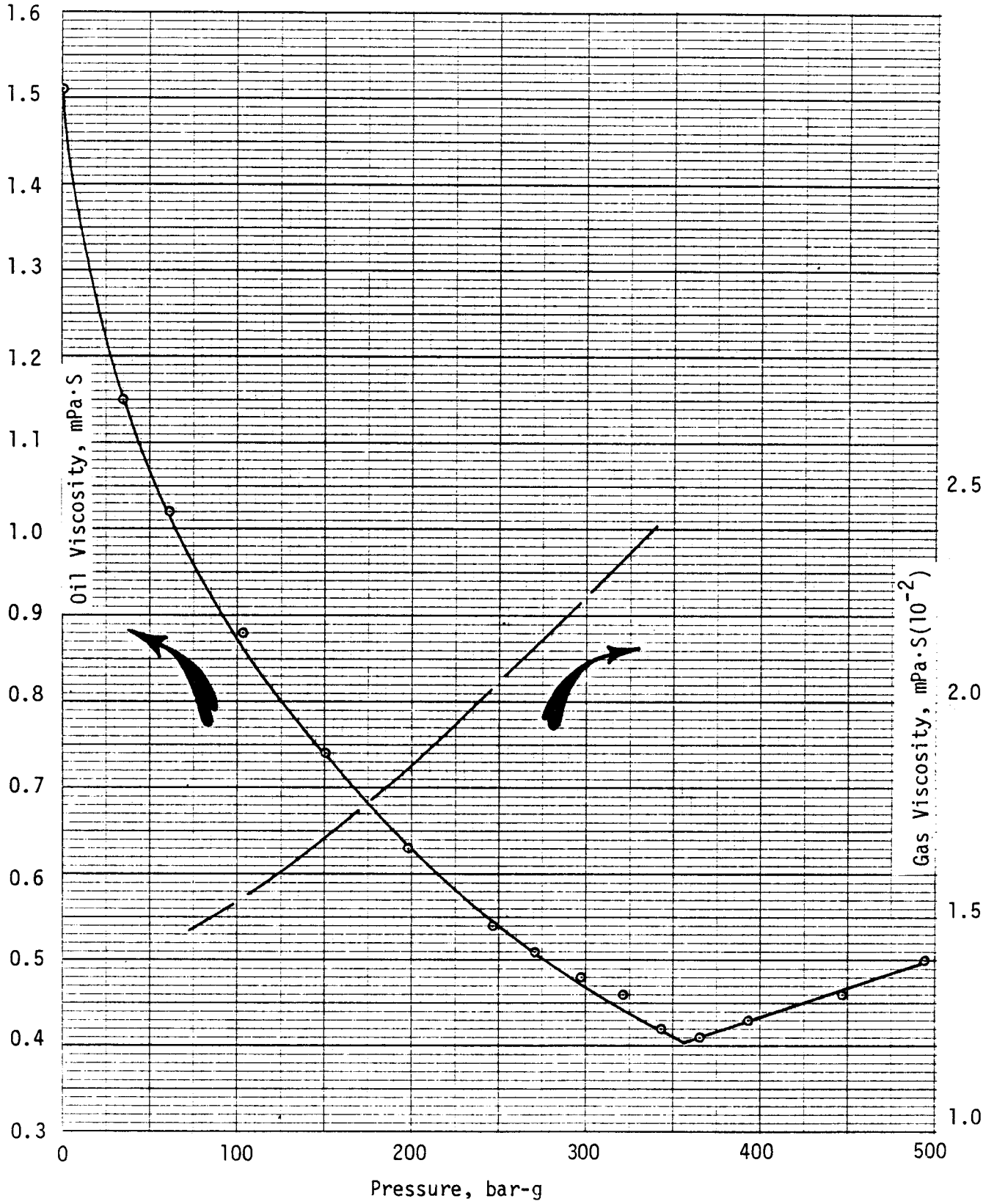


Figure 3. Experimental oil viscosity and calculated gas viscosity vs. pressure. Temperature 126.7°C.