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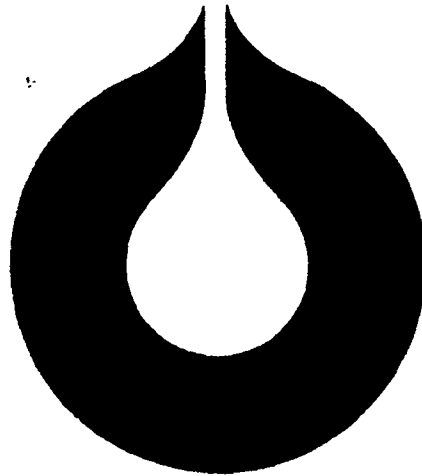
 **STATOIL**

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PVT Study on
Recombined sample
from
Well 1-9-6, Tommeliten Field,
Drillstem test nr. 3A

**STATOIL
EXPLORATION & PRODUCTION
LABORATORY**

Otto Rogne


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Title

PVT Study on
Recombined sample
from
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1. INTRODUCTION

The present report gives the experimental results of the PVT study on samples from well 1/9-6, Tommeliten field, drillstem test nr. 3A, Tor formation. Two set of separator samples from the low rate flow, and one set from the high rate flow, were analysed for sample validity and molecular composition. One of the set from the low rate flow was recombined for PVT analysis at 129C.

1.1 SUMMARY AND MAIN RESULTS

The main results for the sample selected for complete PVT analysis are:

Dew pt. pressure Pd at 129C : 463 barg
 Compressibility factor z at Pd: 1.243
 Density at Pd : 0.350 g/cm³
 Gas gravity at Pd : 1.076
 Maximum liquid dropout, const. mass : 21.0% at 180 barg
 const. volume: 18.5% at 220 barg

Reservoir fluid composition

Component	mol%	molecular weight	Density g/cm ³
Nitrogen	0.12		
Carbondioxide	2.49		
Methane	76.36		
Ethane	7.45		
Propane	3.11		
iso-Butane	0.59		
n-Butane	1.21		
iso-Pentane	0.50		
n-Pentane	0.59		
Hexanes	0.79	85.5	0.682
Heptanes	0.95	93.6	0.721
Octanes	1.08	105	0.746
Nonanes	0.78	121	0.771
Decanes+	<u>3.98</u>	218	0.824
	100.00		

2. SEPARATOR SAMPLES

2.1 Sample Description

Surface samples from DST nr. 3A, Tor formation, were collected by FLOPETROL (report nr. 82/2301/37) with

perforations at: 3523.5 - 3550.9 m MD
3560.1 - 3569.2 m MD
3578.4 - 3587.5 m MD

Set nr. 1, low rate flow

separator conditions: 66.2 barg, 44C.
field GOR: 1008 Sm³/m³ sep. oil
oil sample, bottle nr. 1116/359
gas sample, bottle nr. A-13191

Set nr. 2, low rate flow

separator conditions: 66.2 barg, 46C
field GOR: 1198 Sm³/m³ sep. oil
oil sample, bottle nr. 1116/323
gas sample, bottle nr. A-13127

Set nr. 3, high rate flow

separator conditions: 65.5 barg, 50.5C
field GOR: 1367 Sm³/m³ sep. oil
oil sample, bottle nr. 1110/458
gas sample, bottle nr. A-13226

Set nr. 1 recombined for PVT analysis

2.2 Bubble point of separator liquid samples

- 1) Set nr. 1, bottle nr. 1116/359
Bubble point at 45C = 60.0 barg
- 2) Set nr. 2, bottle nr. 1116/323
Bubble point at 46C = 60.5 barg
- 3) Set nr. 3, bottle nr. 1116/458
Bubble point at 50C = 60.5 barg

Bubble Point Determination of Separator Liquids

Set nr. 1
bottle nr. 1116/359

P/barg	Volume/cm ³
23.7	128.94
32.2	99.09
43.5	79.09
53.5	69.08
60.8	64.45
Pb = 60.0	
79.6	64.29
106.9	64.05
156.8	63.64
202.1	63.29

Set nr. 2
bottle nr. 1116/323

P/barg	Pump reading/cm ³
29.9	91.402
34.9	100.185
43.7	110.596
53.5	117.638
58.8	120.372
Pb = 60.5	
69.8	121.002
97.7	121.594
148.4	122.275
197.7	122.789

Set nr. 3
bottle nr. 1116/458

P/barg	Pump reading/cm ³
50.8	20.000
53.6	40.000
55.7	55.000
57.5	65.000
59.5	76.000
60.2	79.465
Pb = 60.5	
65.7	80.470
79.4	81.730
104.0	83.843
132.3	86.150
150.0	87.592
182.0	89.980

2.3 FLASH OF SEPARATOR LIQUID TO STOCK TANK CONDITIONS
(Molecular composition)

Set nr. 1, bottle nr. 1116/359

Component	Stock tank oil		Evolved gas mol%	Recombined sep. liquid mol%
	weight%	mol%		
Nitrogen	--	--	0.01	0.01
Carbondioxide	--	--	3.72	1.35
Methane	--	--	51.92	18.84
Ethane	0.03	0.18	16.60	6.14
Propane	0.27	0.96	12.44	5.12
iso-Butane	0.27	0.72	2.83	1.49
n-Butane	0.92	2.49	5.81	3.69
iso-Pentane	1.07	2.32	1.91	2.17
n-Pentane	1.54	3.35	2.02	2.87
Hexanes	3.75	6.89	1.44	4.91
Heptanes	6.09	10.16	0.83	6.77
Octanes	8.62	12.79	0.41	8.30
Nonanes	7.53	9.77	0.04	6.24
Decanes plus	<u>69.91*</u>	<u>50.37</u>	<u>0.02</u>	<u>32.10</u>
	100.00	100.00	100.00	100.00

Density of stock tank oil at 15C: 0.794 g/cm³
Molecular weight : 157
GOR : 68.1 Sm³/m³
Shrinkage factor of sep. liq. : 0.7855 Sm³/m³
Liberated gas gravity (air = 1) : 1.063
*Molecular weight : 218

2.3 FLASH OF SEPARATOR LIQUID TO STOCK TANK CONDITIONS
(Molecular composition)

Set nr. 2, bottle nr. 1116/323

Component	Stock tank oil		Evolved gas mol%	Recombined sep. liquid mol%
	weight%	mol%		
Nitrogen	--	--	--	--
Carbondioxide	--	--	3.04	1.10
Methane	--	--	53.10	19.24
Ethane	0.05	0.27	16.94	6.31
Propane	0.33	1.17	12.49	5.27
iso-Butane	0.30	0.81	2.81	1.54
n-Butane	1.00	2.73	5.71	3.81
iso-Pentane	1.12	2.45	1.84	2.23
n-Pentane	1.60	3.50	1.83	2.90
Hexanes	3.80	7.02	1.25	4.93
Heptanes	6.06	10.19	0.67	6.74
Octanes	6.55	10.05	0.25	6.50
Nonanes	7.46	9.74	0.04	6.23
Decanes plus	<u>71.73*</u>	<u>52.07</u>	<u>0.03</u>	<u>33.20</u>
	100.00	100.00	100.00	100.00

Density of stock tank oil at 15C: 0.794 g/cm³
Molecular weight : 158
GOR : 67.6 Sm³/m³
Shrinkage factor of sep. liq. : 0.8150 Sm³/m³
Liberated gas gravity (air = 1) : 1.042
*Molecular weight : 218

2.3 FLASH OF SEPARATOR LIQUID TO STOCK TANK CONDITIONS
(Molecular composition)

Set nr. 3, bottle nr 1116/458

Component	Stock tank oil		Evolved gas mol%	Recombined sep. liquid mol%
	weight%	mol%		
Nitrogen	--	--	0.02	0.01
Carbondioxide	--	--	2.82	1.01
Methane	--	--	54.12	19.43
Ethane	0.02	0.12	16.41	5.97
Propane	0.28	0.95	12.09	4.95
iso-Butane	0.30	0.77	2.76	1.49
n-Butane	1.06	2.71	5.63	3.76
iso-Pentane	1.24	2.56	1.84	2.30
n-Pentane	1.80	3.71	1.86	3.05
Hexanes	4.42	7.69	1.31	5.40
Heptanes	7.24	11.47	0.76	7.62
Octanes	10.33	14.54	0.32	9.44
Nonanes	9.26	11.41	0.05	7.33
Decanes plus	<u>64.05*</u>	<u>44.07</u>	<u>0.01</u>	<u>28.24</u>
	100.00	100.00	100.00	100.00

Density of stock tank oil at 15C: 0.782 g/cm³
Molecular weight : 149
GOR : 69.5 Sm³/m³
Shrinkage factor of sep. liq. : 0.8117
Liberated gas gravity (air = 1) : 1.038
*Molecular weight : 218

2.4 MOLECULAR COMPOSITION OF FIELD SEPARATOR GASES

Component	Composition/mol %		
	Set nr. 1	Set nr. 2	Set nr. 3
	Bottle nr.	Bottle nr.	Bottle nr.
	A-13191	A-13127	A-13226
Nitrogen	0.13	0.13	0.13
Carbondioxide	2.65	2.61	2.82
Methane	84.50	84.00	84.74
Ethane	7.64	7.77	7.66
Propane	2.83	2.90	2.76
iso-Butane	0.46	0.48	0.43
n-Butane	0.86	0.91	0.77
iso-Pentane	0.26	0.29	0.21
n-Pentane	0.27	0.31	0.21
Hexanes	0.20	0.27	0.14
Heptanes	0.13	0.19	0.08
Octanes	0.06	0.08	0.04
Nonanes	0.01	0.04	0.01
Decanes plus	<u>0.00</u>	<u>0.02</u>	<u>0.00</u>
	100.00	100.00	100.00
Molecular weight	19.81	20.09	19.64
Gravity (air=1)	0.684	0.694	0.678

3. RECOMBINATION OF SEPARATOR SAMPLE

- 1) Samples used: Set nr. 1, oil bottle 1116/359
gas bottle A-13191

- 2) Field data : GOR = 1033 Sm³/m³ sep. oil
(average value over sampling period)

 Gas gravity (air=1) = 0.689

 Compressibility factor z = 0.870

- 3) Lab data : Gas gravity = 0.684

 Compressibility factor z = 0.864

- 4) Corrected GOR = $1033 \times \sqrt{\frac{0.689 \times 0.870}{0.684 \times 0.864}}$ = 1040

- 5) Physical recombination: Samples were recombined in the ratio of 1040 Sm³ separator gas per m³ separator oil.

4.1 MOLECULAR COMPOSITION OF RESERVOIR FLUID

Set nr. 1, oil bottle 1116/359
gas bottle A-13191

Component	Separator	Separator	Reservoir fluid		
	liq. mol%	gas mol%	mol%	molecular weight ¹⁾	Density g/cm ³ ²⁾
Nitrogen	0.01	0.13	0.12		
Carbondioxide	1.35	2.65	2.49		
Methane	18.84	84.50	76.36		
Ethane	6.14	7.64	7.45		
Propane	5.12	2.83	3.11		
iso-Butane	1.49	0.46	0.59		
n-Butane	3.69	0.86	1.21		
iso-Pentane	2.17	0.26	0.50		
n-Pentane	2.87	0.27	0.59		
Hexanes	4.91	0.20	0.79	85.5	0.682
Heptanes	6.77	0.13	0.95	93.6	0.721
Octanes	8.30	0.06	1.08	105	0.746
Nonanes	6.24	0.01	0.78	121	0.771
Decanes plus	<u>32.10</u>	<u>0.00</u>	<u>3.98</u>	218	0.824
	100.00	100.00	100.00		
Molecular weight	111.2		19.81	31.17	
Gravity (air=1)	--		0.684	1.076	

1) For reservoir fluid, see methods for details

2) at 15C, from TBP distillation

4.2 Extended Molecular Composition of Recombined Fluid

Compound	Mol %	molecular ¹⁾ weight	Density ¹⁾ g/cm ³ at 15C
N ₂	0.12		
CO ₂	2.49		
C ₁	76.36		
C ₂	7.45		
C ₃	3.11		
i-C ₄	0.59		
n-C ₄	1.21		
i-C ₅	0.50		
n-C ₅	0.59		
C ₆	0.79	85	0.682
C ₇	0.95	94	0.721
C ₈	1.08	106	0.746
C ₉	0.78	118	0.771
C ₁₀	0.58	133	0.781
C ₁₁	0.49	147	0.777
C ₁₂	0.40	160	0.782
C ₁₃	0.40	178	0.800
C ₁₄	0.32	198	0.815
C ₁₅	0.29	211	0.816
C ₁₆	0.21	225	0.824
C ₁₇	0.21	238	0.823
C ₁₈	0.15	249	0.831
C ₁₉	0.15	261	0.837
C ₂₀₊	0.78	378	0.872
	<u>100.00</u>		

1) Values from TBP distillation

4.3 TBP - Distillation of Stock Tank Liquid obtained from Flash of Separator Liquid to 1 atm of 15C.**

HC Group	Boiling range oC	Cumulative distilled % by weight	Density of fraction gcm ⁻³ at 15C	Molecular weight of fraction
gass		0.34	0.496*	45*
C ₅	<36.5	6.22	0.621*	69*
C ₆	36.5 - 69.2	8.68	0.682	85*
C ₇	69.2 - 98.9	16.6	0.721	94*
C ₈	98.9 - 126.1	25.0	0.746	106*
C ₉	126.1 - 151.3	33.3	0.771	118
C ₁₀	151.3 - 174.6	39.1	0.781	133
C ₁₁	174.6 - 196.4	44.5	0.777	147
C ₁₂	196.4 - 216.8	49.3	0.782	160
C ₁₃	216.8 - 235.9	54.7	0.800	178
C ₁₄	235.9 - 253.9	59.2	0.815	189
C ₁₅	253.9 - 271.1	63.8	0.816	211
C ₁₆	271.1 - 287.3	67.3	0.824	225
C ₁₇	287.3 - 303	71.1	0.823	238
C ₁₈	303 - 317	73.8	0.831	249
C ₁₉	317 - 331	76.6	0.837	261
C ₂₀₊		100	0.872	378

* Calc. value from GC - analysis

** Data from distillation, report no. LAB.82.55

5. CONSTANT MASS EXPANSION AT 129C

Pressure (barg)	Relative Volume (V/Vd)	Compressib. factor ($z=PV/nRT$)	Viscosity ¹⁾ (cP)	Retrograde liquid (% of dew p.volume)
735	0.8590	1.693	0.0658	
695	0.8730	1.628	0.0637	
653	0.8897	1.559	0.0610	
604	0.9109	1.477	0.0581	
553	0.9370	1.391	0.0548	
520	0.9575	1.336	0.0524	
493	0.9766	1.291	0.0506	
468	0.9958	1.252	0.0488	
463	1.0000	1.243	0.0486	0
461	1.001			0.2
451	1.011			1.33
442	1.020			2.79
428	1.034			5.04
412	1.053			7.08
384	1.091			10.4
353	1.144			13.5
322	1.207			16.2
292	1.289			18.7
260	1.399			19.9
230	1.542			20.5
198	1.748			20.9
162	2.115			20.9
128	2.635			20.5
98	3.460			19.8
52	6.537			18.1

1) Calculated

6.1 CONSTANT VOLUME DEPLETION AT 129C

Pressure barg	Retrograde liq. % of dew p.vol.	Cumulative mol produced, % of initial	$z = PV/nRT$ of well stream	Viscosity of Vapour Phase CP	Gas gravity (air=1)	Density of retrograde liq. g/cm ³	Viscosity of retrograde liq. liquid CP
P = 463	0	0	1.243	0.0486	1.076		
436	3.71	2.37	1.178	0.0438	1.017	0.72	0.16
395	10.0	7.25	1.077	0.0398	0.9574	0.52	0.18
352	14.4	13.4	0.9981	0.0349	0.8963	0.51	0.20
302	17.1	22.3	0.9089	0.0306	0.8452	0.48	0.22
252	18.3	31.7	0.8586	0.0202	0.8079	0.50	0.24
201	18.4	44.9	0.8186	0.0222	0.7641	0.51	0.27
152	18.1	58.5	0.8115	0.0191	0.7540	0.52	0.30
98.7	16.9	75.2	0.8400	0.0164	0.7630	0.52	0.34
47.0	15.4	89.4	0.9306	0.0144	0.7682	0.697	0.39

1) Calculated

6.1 CONSTANT VOLUME DEPLETION AT 129C.

(Flash of reservoir gas at T and p to 15 (1atm))

P/barg	Formation vol. factor ¹ of gas condensate Bgc.	GOR ²
436	8.67	2160
395	10.4	2600
352	13.7	3320
302	22.9	5300
252	42.6	8680
201	194	17300
152	243 ³	32000 ³
98.7	534 ³	45000 ³
47	1500 ³	54000 ³

1) $\frac{\text{m}^3 \text{ reservoir gas}}{\text{m}^3 \text{ STO at 15C}}$	2) $\frac{\text{m}^3 \text{ gas at 15C, 1atm}}{\text{m}^3 \text{ STO at 15C}}$	3) Estimated
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6.2 CONSTANT VOLUME DEPLETION AT 129C

Molecular Composition of Produced Well stream, mol %

Pressure (barg):	463	436	395	352	302	252	201	152	98.7	47.0
N ₂	0.12	0.10	0.10	0.10	0.10	0.11	0.09	0.09	0.10	0.14
CO ₂	2.49	2.43	2.46	2.48	2.49	2.50	2.53	2.54	2.46	3.17
C ₁	76.36	76.76	77.94	79.28	80.61	81.40	82.50	81.95	81.31	80.41
C ₂	7.45	7.90	7.94	7.64	7.25	7.14	7.13	7.66	7.70	7.80
C ₃	3.11	3.34	3.25	3.18	2.98	2.93	2.88	3.09	3.20	3.36
i-C ₄	0.59	0.64	0.60	0.61	0.56	0.55	0.53	0.57	0.60	0.64
n-C ₄	1.21	1.33	1.24	1.23	1.14	1.11	1.07	1.13	1.30	1.31
i-C ₅	0.50	0.55	0.50	0.50	0.46	0.45	0.42	0.44	0.55	0.52
n-C ₅	0.59	0.65	0.59	0.56	0.54	0.53	0.48	0.50	0.65	0.59
C ₆	0.79	0.84	0.73	0.68	0.68	0.68	0.58	0.59	0.70	0.68
C ₇	0.95	0.94	0.80	0.66	0.76	0.77	0.59	0.58	0.68	0.64
C ₈	1.08	1.04	0.79	0.64	0.75	0.76	0.54	0.48	0.45	0.46
C ₉	0.78	0.65	0.55	0.46	0.41	0.31	0.20	0.14	0.12	0.10
C ₁₀	3.98	2.84	2.50	1.98	1.27	0.75	0.45	0.24	0.18	0.16
Molecular weight	31.17	29.45	27.73	25.96	24.48	23.40	22.13	21.84	22.10	22.25
Molecular wt. C ₁₀ ⁺	220	220	219	207	200	200	179	173	169	166

6.3 CONSTANT VOLUME DEPLETION AT 129C

Flash of remaining liquid from 47barg
to stock tank conditions.

Component	Stock tank oil mol %	Evolved gas mol %	Liquid at 47 barg, 129C mol %
Nitrogen	-	0.11	0.02
Carbondioride	-	2.49	0.54
Methane	-	63.23	13.74
Ethane	0.12	15.23	3.40
Propane	0.64	9.62	2.59
iso-Butane	0.45	1.96	0.78
n-Butane	1.51	3.77	2.00
iso-Pentane	1.38	1.18	1.33
n-Pentane	1.99	1.15	1.81
Hexanes	4.46	0.80	3.64
Heptanes	7.61	0.37	5.67
Octanes	11.06	0.07	8.03
Nonanes	9.66	0.00	7.14
Decanes plus	61.12*	0.02	49.31

Density of stock tank oil at 15C : 0.808 g/cm³

Molecular weight : 204

GOR : 26.0 Sm³/m³

Shrinkage factor : 0.8337 Sm³/m³

Liberated gas gravity (air=1) : 0.907

* Molecular weight : 271

7. METHODS AND EQUIPMENT

7.1 Compositional analysis

Component analysis are performed using a Hewlett Packard 5880 gas chromatographic systems. For gas analysis, non hydrocarbons are determined on a poropak R 1/8" x 3 m steel column with TC detector, and hydrocarbons in chromapack Cp tm Sil 550 m x 0.22 mm quartz capillary column with FI detector. Oil analysis are performed on a gas chromatograph fitted with chromapack Cp tm Sil 525 m x 0.22 mm quartz capillary column and FI detector. Molecular weight is determined by freezing point depression of benzene, density by Paar DMA 602 frequency densiometer.

Molecular weights for C₆, C₇ and C₈ in gas and STO are calculated as average values from the molecular composition of the groups. Molecular weights for the C₆, C₇ and C₈ groups in the reservoir fluid are calculated from the above values, the molecular composition of gas and liquid and the GOR.

Molecular weight of C₉ is taken as 121 (Katz and Firoozabadi, JPT, 1649 (1978) whereas that of C₁₀₊ is measured directly during TBP distillation.

7.2 PVT analysis

PVT analysis was performed in an Elf designed gas condensate cell of the sloane type (ACB, Nanntes). Total cell volume is about 4 dm³ with a minimum liquid readability of about 0.1 cm³.

Constant volume depletion was carried out differentially with the pressure reduced in discrete steps. After each step the cell volume is brought back to the original (dew point) volume while removing equilibrium vapour phase material at constant pressure.

The vapour removed is flashed to standard conditions where the gas and liquid are measured separately.

Gas viscosities are calculated from gas density (Lee et.al. J.Pet. Techn., 1966, 997)

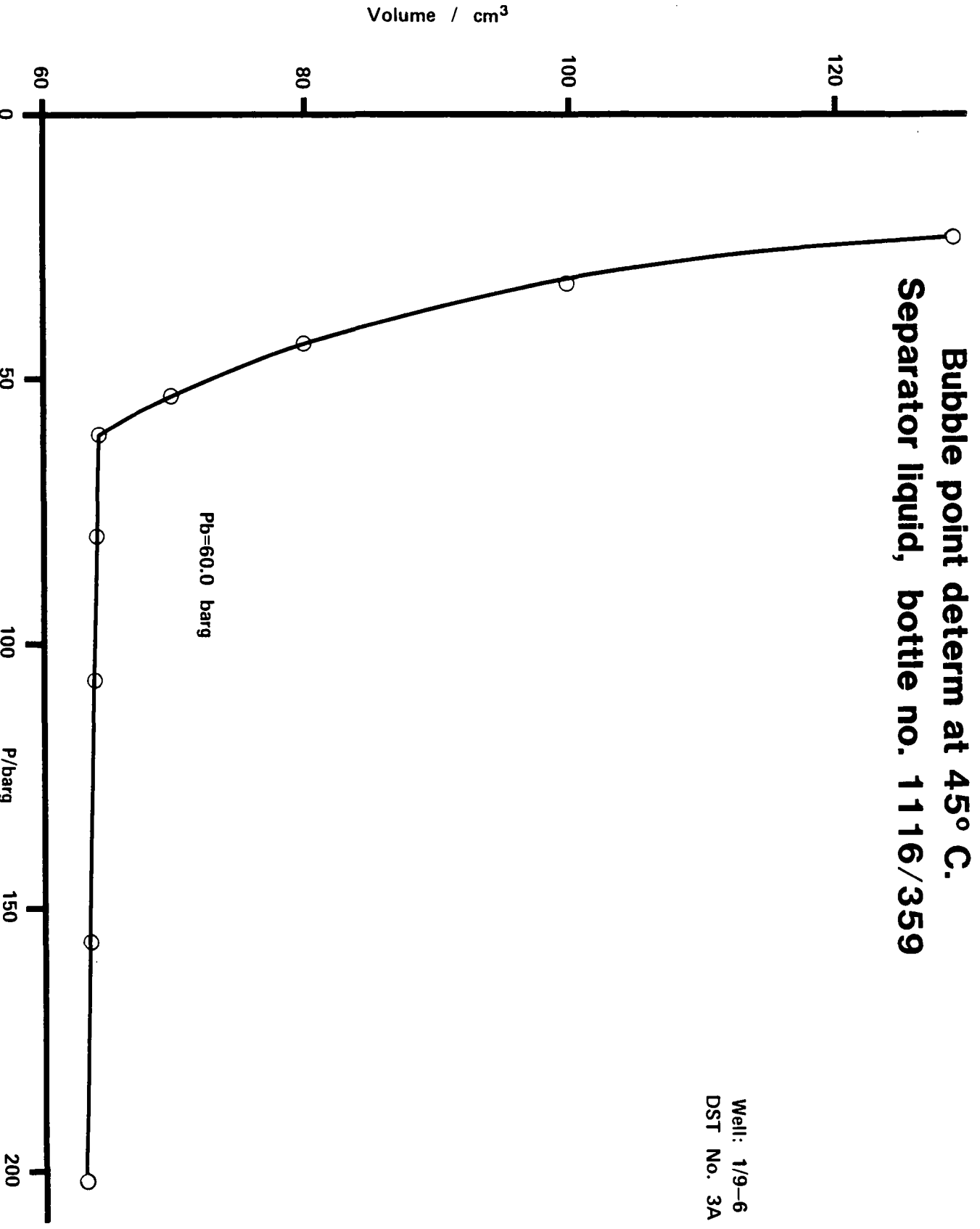
Liquid densities are calculated according to Fredenslund et.al. (Thermodynamics of Petroleum mixtures, SEP 8207, Institutt for Kjemiteknikk, DTH, Lyngby, Danmark.

Standard conditions, gas = 15C, 1 atm.

oil = 15C, atmospheric pressure.

Fig 1

Bubble point determ at 45° C.
Separator liquid, bottle no. 1116/359



Well: 1/9-6
DST No. 3A

Fig 2

Bubble point determ. at 46° C
Separator liquid, bottle no. 1116/323

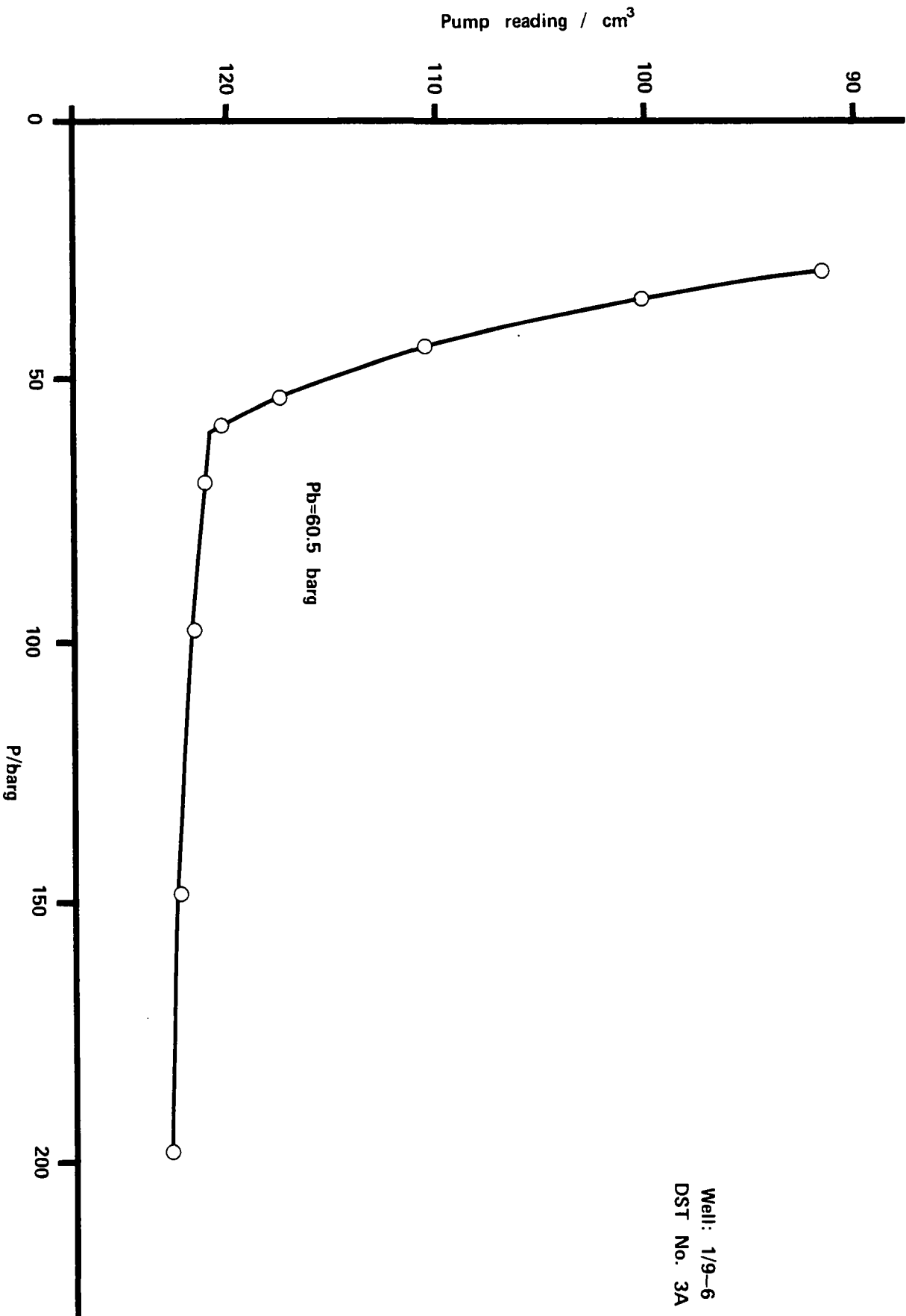


Fig 3

Bubble point determination at 50° C
Separator liquid, bottle no. 1116/458

Well: 1/9-6
DST No. 3A

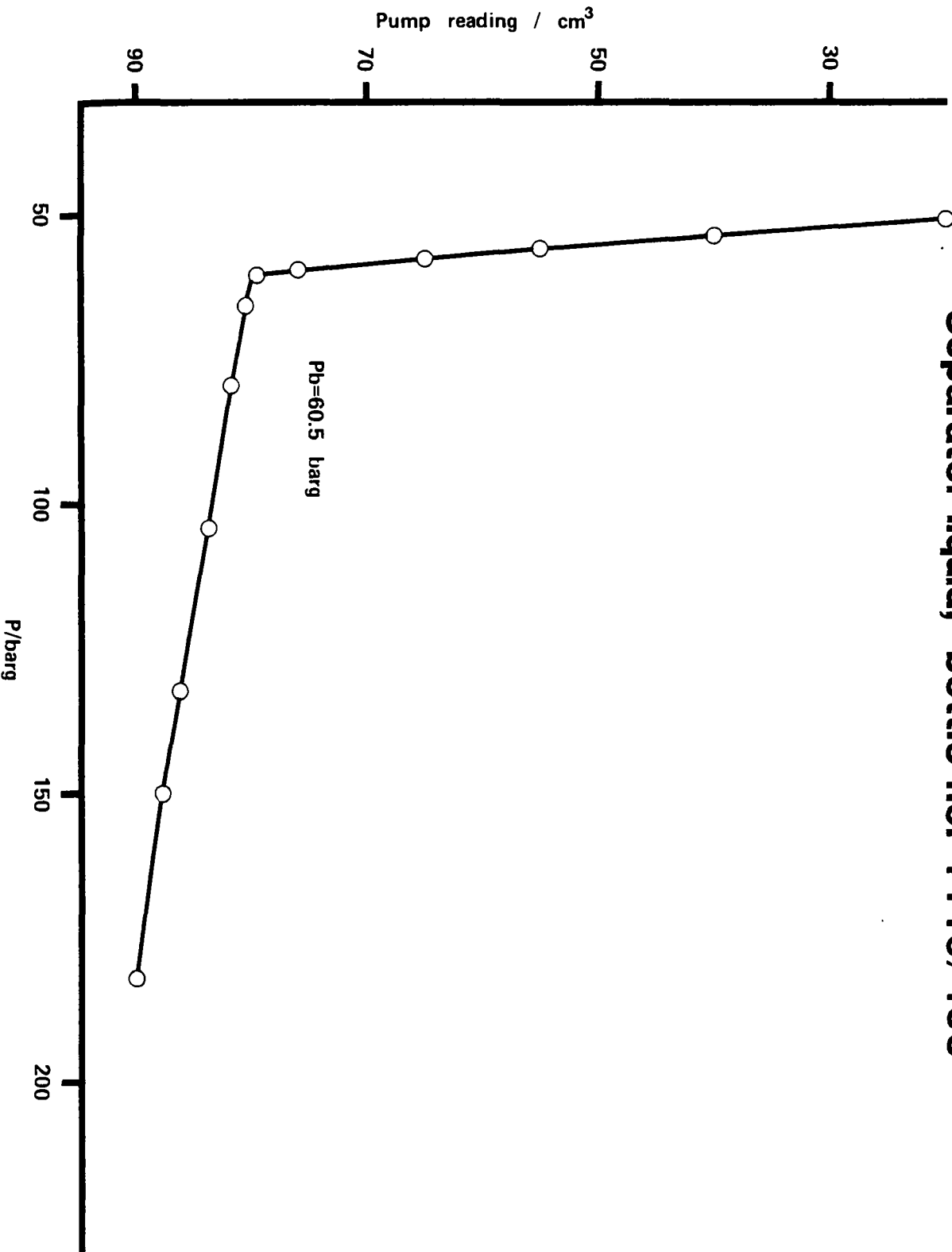


Fig 4
Retrograde liquid at 129° C

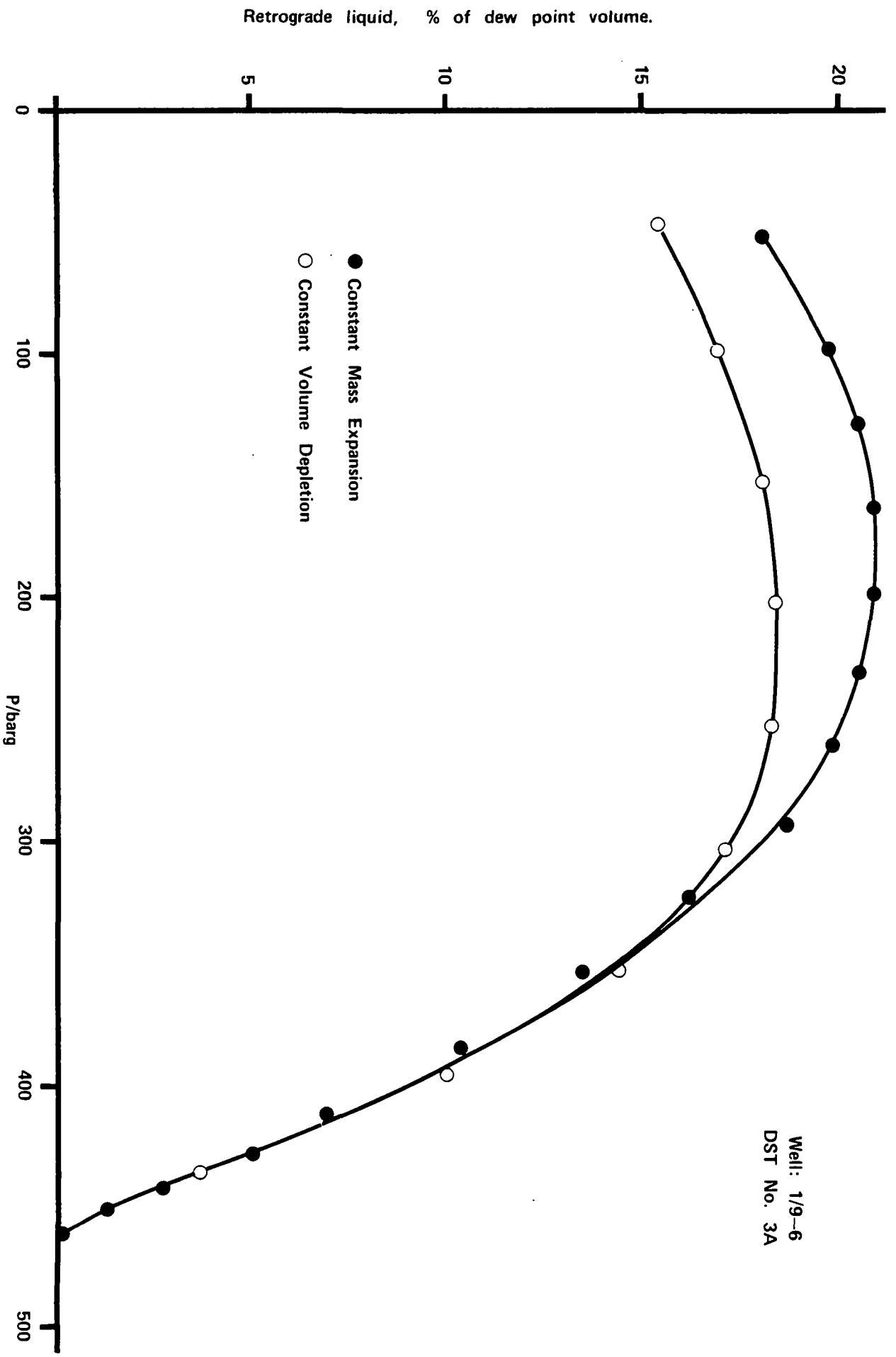


Fig 5

Constant Volume Depletion at 129° C Well stream compressibility factor

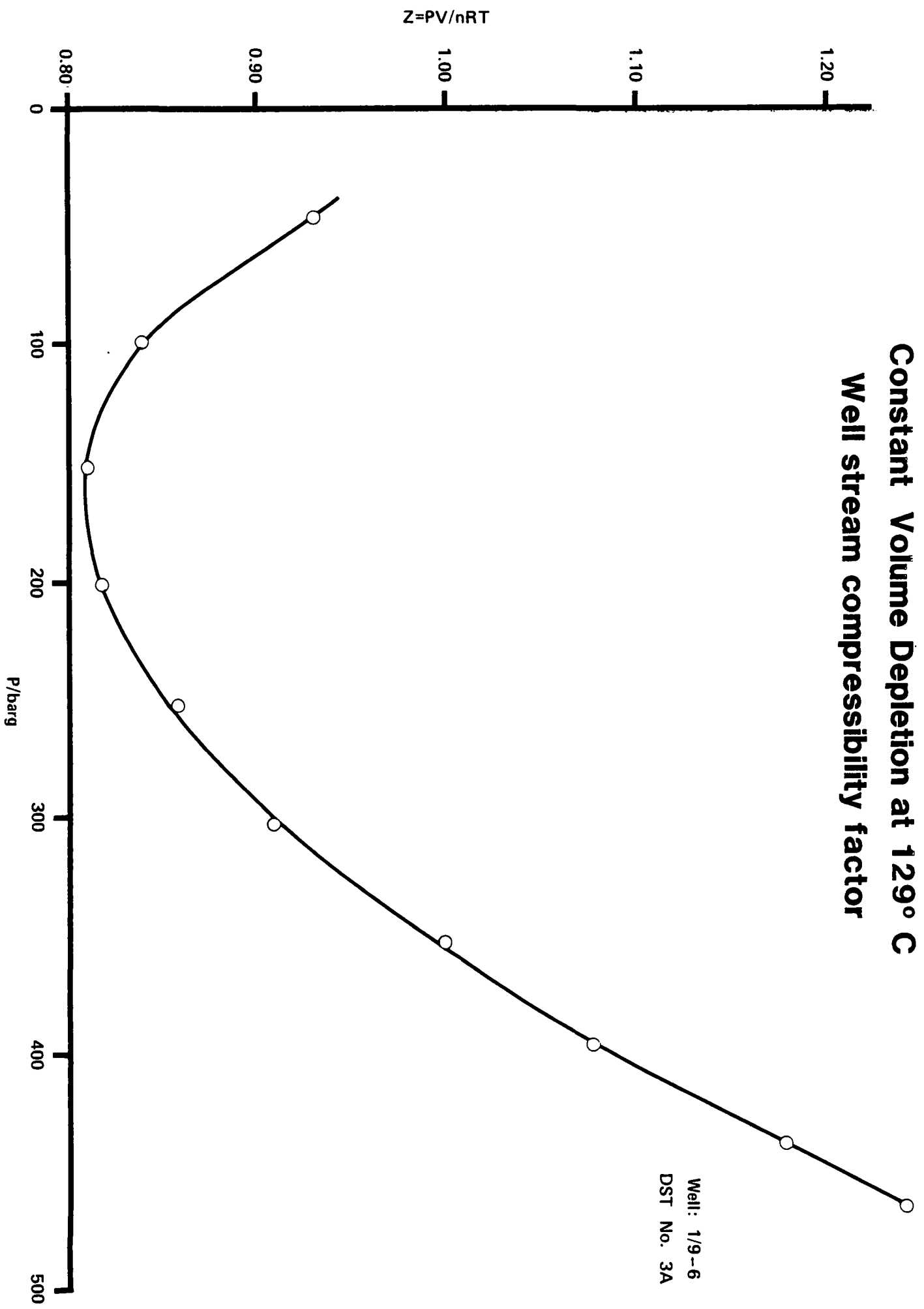


Fig 6

Constant Volume Depletion at 129° C
Viscosity of Vapour Phase

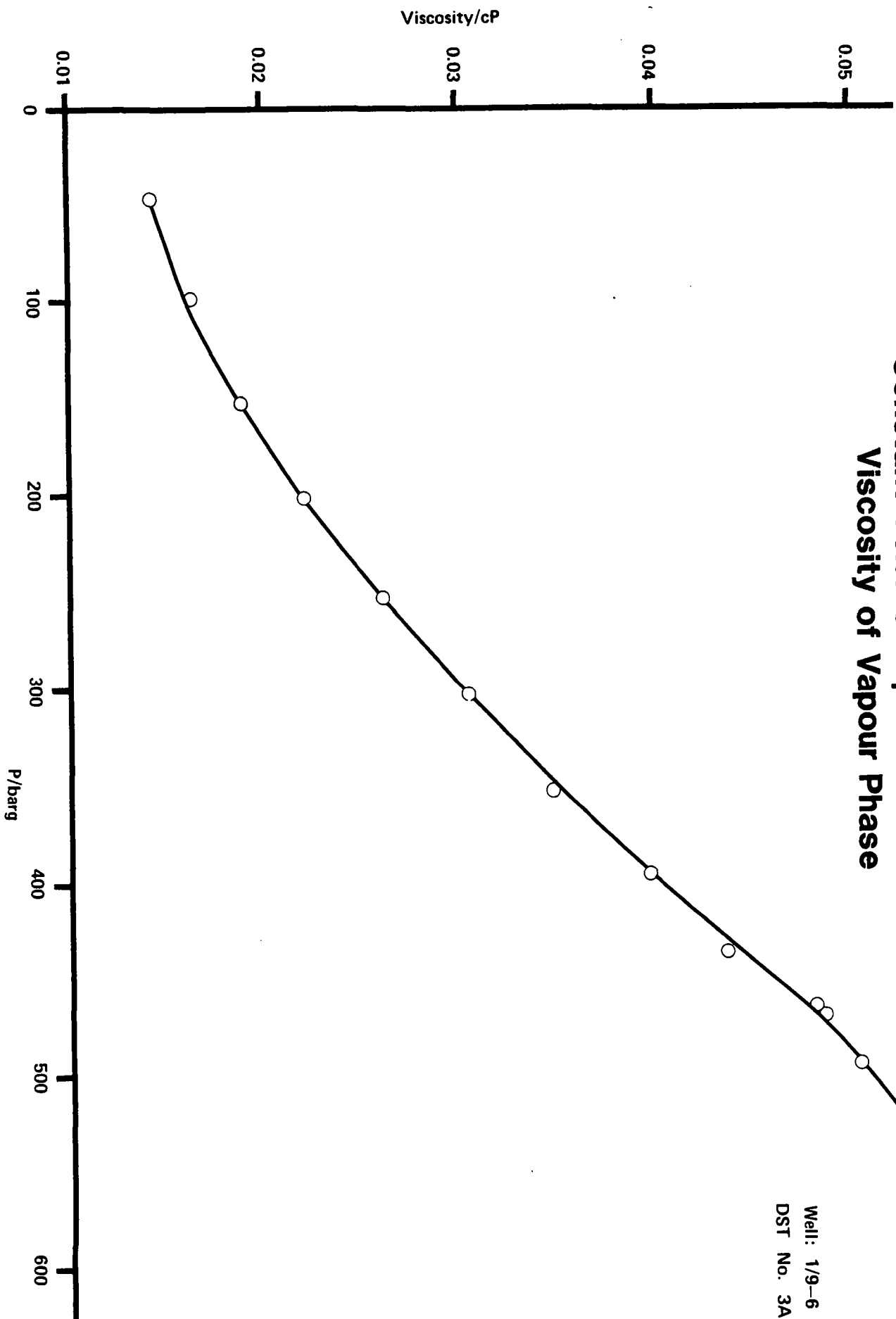


Fig 7

Constant Volume Depletion at 129° C
Cumulative mol produced, % of initial.

Well: 1/9-6
DST No. 3A

