DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2001/11

Special Core Analysis For DONG A/S

Cap rock test on Stenlille-19

Christian Høier and Niels Springer

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF ENVIRONMENT AND ENERGY

G E U S

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GEUS

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1. Introduction

By request of DONG Naturgas A/S, GEUS Core Laboratory has carried out special core analysis on the well Stenlille 19.

The experimental programme was specified by Mr. Karsten Bonde. The following analytical programme has been carried out:

- Liquid permeability at reservoir conditions
- Gas treshold pressure at reservoir conditions.

This study is carried out under contract R-625/00. Several preliminary reports have been forwarded to DONG A/S in the time period December 2000 – January 2001.

2. Sampling and analytical procedure

GEUS Core Laboratory received a total of 6 stk. 1½"Ø plugs for special core analysis covering the interval 1631 – 1633 meter measured depth in the Gassum formation zone 6 from the Stenlille 19 well.

2.1 Preparation

The 6 plugs were trimmed to a length of 20 – 25 mm and saturated in brine using vacuum. The bulk volume was measured using Archimedes technique.

2.2 Experimental setup

The experimental setup contained a 3 cylinder Quizix pump, which was used to control the overburden pressure and the flowrate. A gas reservoir was used maintain a stable radial overburden pressure. The sample was placed in a Hoek cell, which is a biaxial compaction cell. The outlet of the Hoek cell was monitored by a Mettler balance and the data was recorded by a computer each minute.

In the gas treshold pressure experiment an additional 300 ml gas reservoir containing N_2 was used see figure 2.2. In the liquid permeability experiment the gas reservoir was by passed.

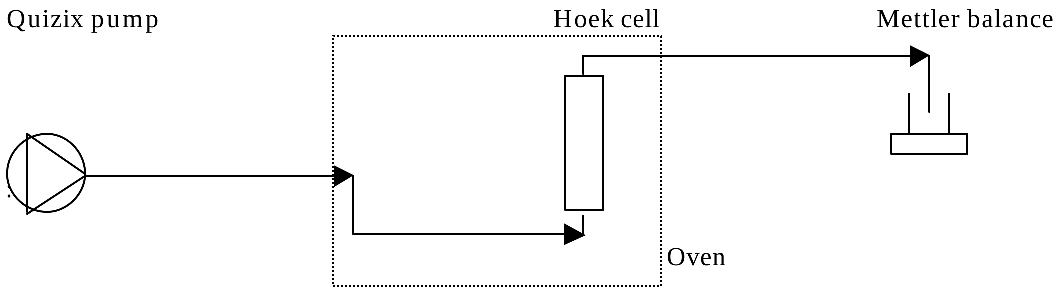


Figure 2.1 – The liquid permeability setup.

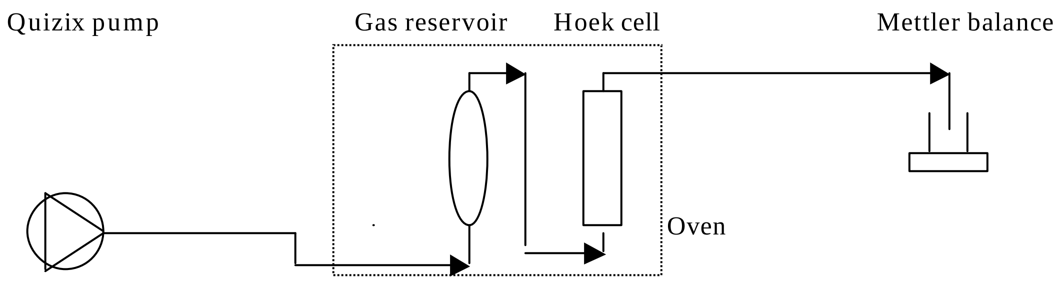
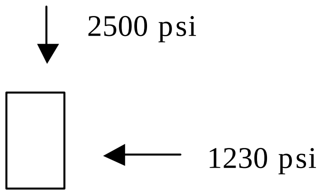


Figure 2.2 – The gas treshold pressure setup.

2.3 Reservoir conditions

The vertical overburden pressure was given to 2500 psi and from the Poisson ration the radial overburden was calculated to 1230 psi.

Poisson ration (υ): 0.29 – 0.33 ~ 0.33
$\sigma_3 = \upsilon * \sigma_1 / (1-\upsilon) = 1230$ psi
Temperature: 50^o C



The vertical and radial overburden pressure were raised from room to reservoir condition continuously during 3 – 5 hours . The System was given 15 – 20 hours to stabilise at reservoir conditions and meanwhile the creep curve was measured. The system maintained the given reservoir overburden pressure during the liquid permeability and the gas treshold pressure test. When unloading the reservoir overburden pressure was decreased from reservoir to room conditions continuously during 3 – 5 hours.

2.4 Liquid permeability

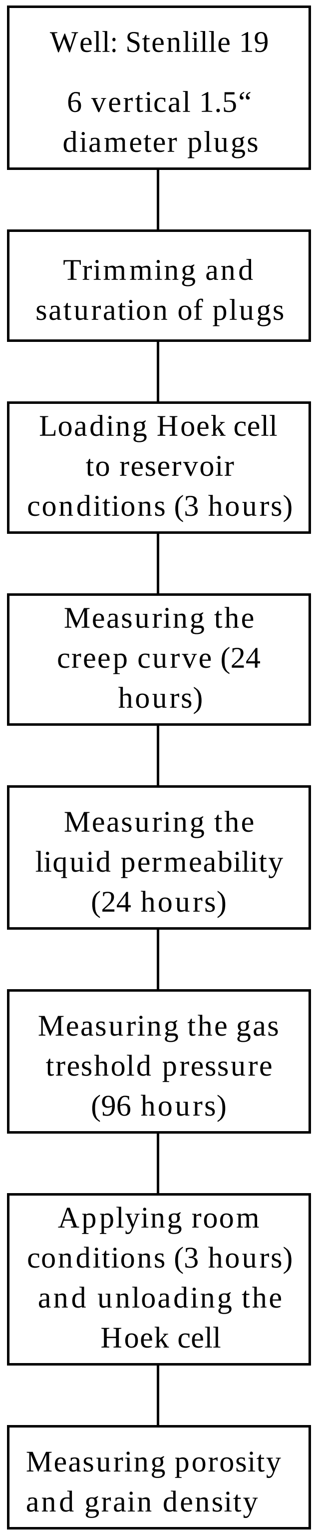
The liquid permeability was measured at reservoir condition. A constant differential pressure of 150 psi was applied across the sample for 24 hours. The flow rate was calculated using the volume of brine injected into the sample.

2.5 Gas treshold pressure

The gas treshold pressure was measured by increasing the gas pressure on the sample continuously from 30 psi to 300 psi over 48 hours and recording the output. This was done by pumping brine into the bottom of a 300 ml gas reservoir containing N_2 at 20 – 40 psi. The flow rate was controlled by the Quizix pump that ensured a steady increase in the upstream pressure. From the Quizix pump the flow rate, the injected brine and upstream pressure were recorded. The outlet was recorded by a computer monitoring a Mettler balance.

The gas pressure was maintained at 300 psi for 24 hours and then the gas pressure was lowered to 0 psi and monitored for another 24 hours. This was done to distinguish a production curve due to the gas break-through from a creep curve.

3. Flow chart of the analytical procedure



4. Analytical methods

The following is a short description of the methods used by the GEUS Core Laboratory. For a more detailed description of methods, instrumentation and principles of calculation the reader is referred to API recommended practice for core analysis procedure (API RP 40, 1998).

4.1 He-porosity and grain density

The porosity is measured on cleaned and dried samples. The porosity is determined by subtraction of the measured grain volume and the measured bulk volume. The Helium technique, employing Boyle's Law, is used for grain volume determination, applying a double chambered Helium porosimeter with digital readout, whereas bulk volume is measured by submersion of the plug in a mercury bath using Archimedes principle. Grain density is calculated from the grain volume measurement and the weight of the cleaned and dried sample.

4.2 Stress conversion in laboratory overburden tests for biaxial cell

The stress conditions prevailing in a reservoir rock can be expressed by Terzaghi's equation:

$$\sigma_{eff} = \sigma_{tot} - \sigma_{res} \qquad (1)$$

σ_{eff} : effective confining stress - ECS (= net overburden pressure).
σ_{tot} : total confining stress due to the overburden load.
σ_{res} : reservoir fluid pore pressure.

When a rock is compressed under uniaxial compression conditions, not only will it “shorten” along the loading direction, it will also expand in the lateral directions due to Poisson’s effect. This will result in a horizontal stress. In a basin not subjected to tectonic forces the horizontal stress will be the same in every direction. If the reservoir has been gently laid down between very stiff lateral boundaries (in which case lateral strain is constrained to be zero), then the horizontal stress is found from:

$$s_h = \left(\frac{u}{1-u}\right) s_v \qquad (2)$$

σ_h : Horizontal stress
σ_v : Vertical stress
υ : Poisson’s ratio

5. Results

The following data are listed:

- Conventional core analysis data
- Liquid permeability data
- Gas treshold pressure data shown in plots

5.1 Conventional core analysis data

The bulk volume, pore volume, grain density and porosity was measured after the gas treshold pressure test.

Plug no.	Depth meter	Length mm	Diameter mm	Bulk vol. ml	Pore vol. ml	Grain density g/ml	Porosity %
1	1631.58	23.23	37.67	25.30	3.12	2.706	12.32
2	1631.70	20.62	37.55	22.55	2.58	2.694	11.46
3	1631.81	27.28	37.42	30.62	4.01	2.687	13.08
4	1632.07	21.62	37.63	23.80	2.74	2.705	11.52
5	1632.30	25.67	37.59	28.53	3.36	2.689	11.76
6	1632.45	27.24	37.70	30.06	3.00	2.676	9.99

Table: 5.1 – Conventional core analysis data.

The wet weight of the plug before and after experiment a shown in table 5.2. The weight loss after experiment is influenced by the compaction of the plug, gas breakthrough and evaporation during unloading. To compensate for the compaction and evaporation, the plugs were left in brine for 5 days to allow them to decompress.

Plug no.	Depth meter	Wet weight Before experiment (g)	Wet weight Right after experiment (g)	Wet weight 5 days after experiment (g)	Difference W_b-W_{5d} (g)
1	1631.58	64.16	63.55	63.97	0.19
2	1631.70	56.76	-	56.62	0.14
3	1631.81	76.01	-	76.21	-0.20
4	1632.07	60.13	59.87	60.16	-0.03
5	1632.30	70.96	-	70.45	0.51
6	1632.45	75.71	-	75.34	0.37

Table: 5.2 – Wet weight of plugs before and after the gas treshold pressure experiment.

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5.2 Liquid permeability data

The measured permeabilities and flow rates are shown in table 5.3. The flow rate was calculated from the volume of injected brine over a time period of 12 – 52 hours.

Plug no.	Depth meter	Flow rate ml/h	Differential pressure psi	Permeability mD
1	1631.58	0.0121	150	$5.98*10^{-5}$
2	1631.70	0.0135	150	$5.96*10^{-5}$
3	1631.81	0.0034	150	$1.97*10^{-5}$
3	1631.81	0.0071	300	$2.09*10^{-5}$
4	1632.07	0.0270	150	$1.24*10^{-4}$
5	1632.30	0.0065	150	$3.58*10^{-5}$
6	1632.45	0.0078	150	$4.52*10^{-5}$

Table 5.3 – Brine permeability measured at reservoir conditions

The properties of the simulated brine is listed in table 5.4 and table 5.5

Component	Concentration [mg/l]
Cl^-	109960
Na^+	60000
Ca^{2+}	8600
Mg^{2+}	1640
K^+	370

Table 5.4 - Chemical composition of simulated formation brine.

Formation brine	Temperature at 24 °C	Temperature at 50 °C
Density (g/ml)	1.120	-
Viscosity (cP)	1.45	0.87

Table 5.5 - Physical parameters for the simulated formation brine.

5.3 Gas treshold pressure data

The results from the gas treshold pressure experiments are shown in the figures. Three variables are shown on each diagram:

The blue trace **[ml]** shows the volume of brine injected in the gas reservoir to build up the upstream pressure. The logarithmic view is caused by the gas compressing as the pressure is increasing. At gas breakthrough an increase in volume will occur to maintain the given pressure or pressure step.

The green trace **[psi]** shows the upstream pressure. The upstream pressure is the controlling factor in the experiments and therefor almost identical in all the figures.

The red trace **[mg]*10** shows the outlet collected at the balance. The mass is measured in [g], but given as [mg]*10 to be shown on the same figure. The mass is constantly increasing due to the compaction of the plug under reservoir conditions. At gas breakthrough an additional increase in mass will occur.

The figures are shown on page 10 - 15.

5.3.1 Discussion

The red trace **[mg]*10** on figure 1, 3, 5 and 6 seams to be independent of the upstream pressure and therefor the mass increase on the balance is only caused by compaction of the plug.

The red trace **[mg]*10** on figure 2 bends downwards after 47 hours. This behaviour can be caused by brine in the inlet of the Hoek cell that needs to be drained off before the gas can contact the sample. When the gas reach the sample the liquid flow stops and the rest of the trace is a creep curve.

The red trace **[mg]*10** on figure 4 bends upwards after 14 hours and increases until 27.5 hours, when it stabilise. This is caused by a gas breakthrough at 14 hours and brine is produced until 27.5 hours. At 27.5 hours the gas reach the balance and the mass on the balance becomes constant as the gas is not recorded. The 2 spikes on the plot at 30 and 47 hours is caused by refilling the outlet tubing with brine and re-zeroing the balance. The level at 713 mg*10 is identical with the dead volume of the outlet tubing. The gas breakthrough at 14 hours corresponds to a pressure of 110 psi at the green trace **[psi]**.

5.3.2 Conclusion

There is only registered gas breakthrough at plug no. 4 at 110 psi, but the gas breakthrough was caused by fractures in the plugs, which occured during testing. The red trace **[mg]*10** showed that the produced brine was derived from the outlet tubing and not from plug matrix as the produced volume equals the dead volume of the outlet tubeing.

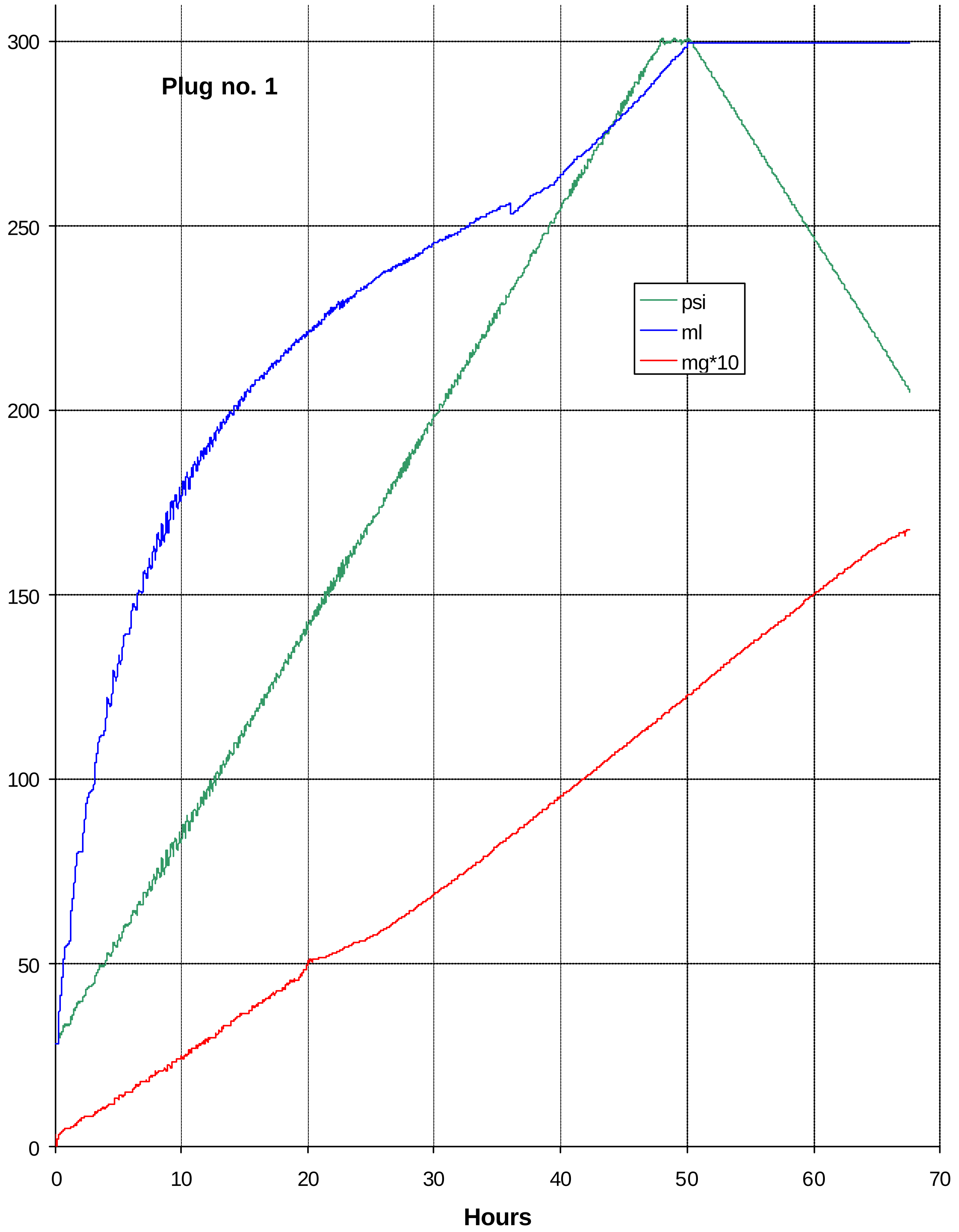

Plug no. 1
psi
ml
mg*10
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
Hours

Figure 5.1 – Gas treshold pressure data on plug 1

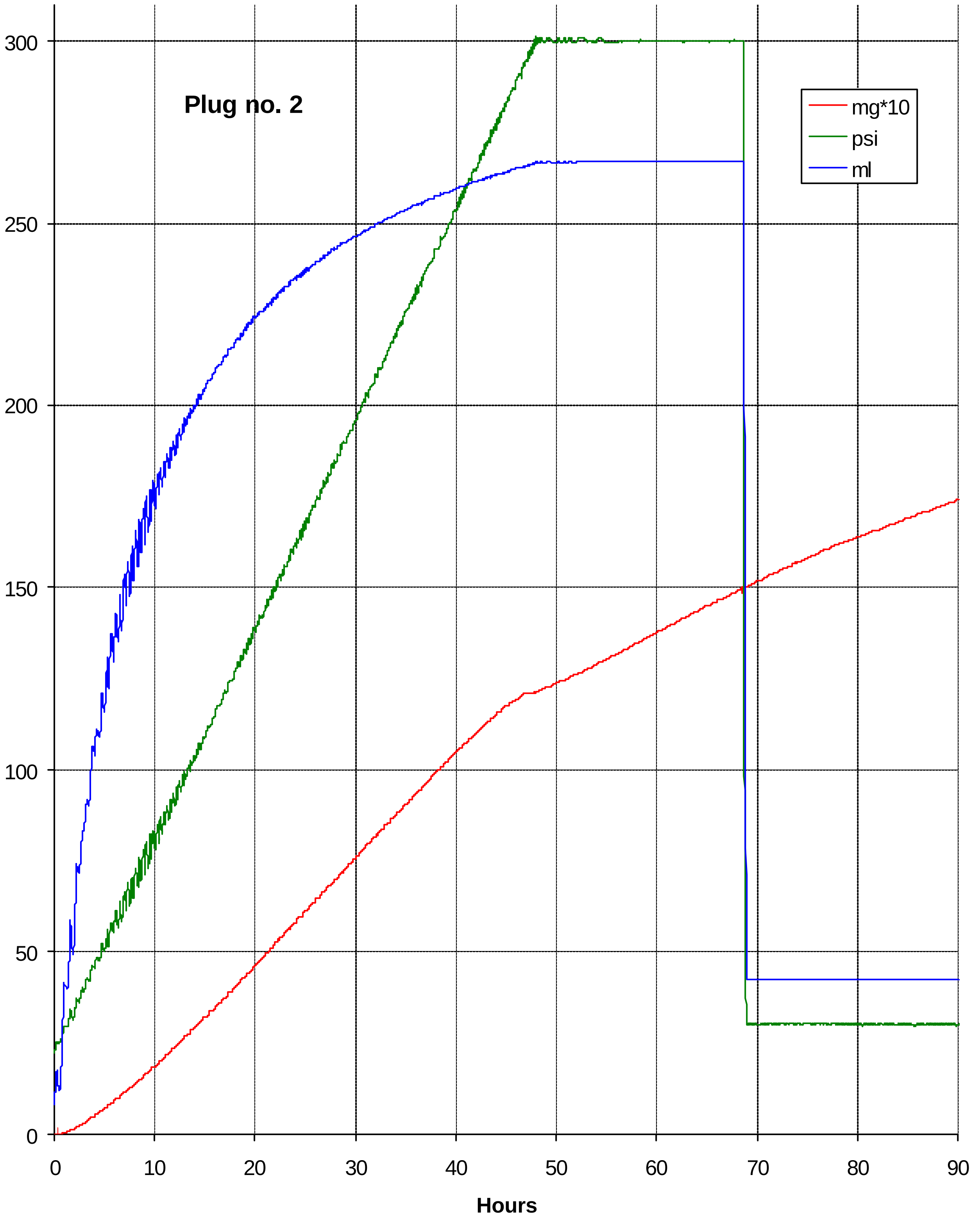

Plug no. 2
mg*10
psi
ml
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
Hours

Figure 5.2 – Gas treshold pressure data on plug 2

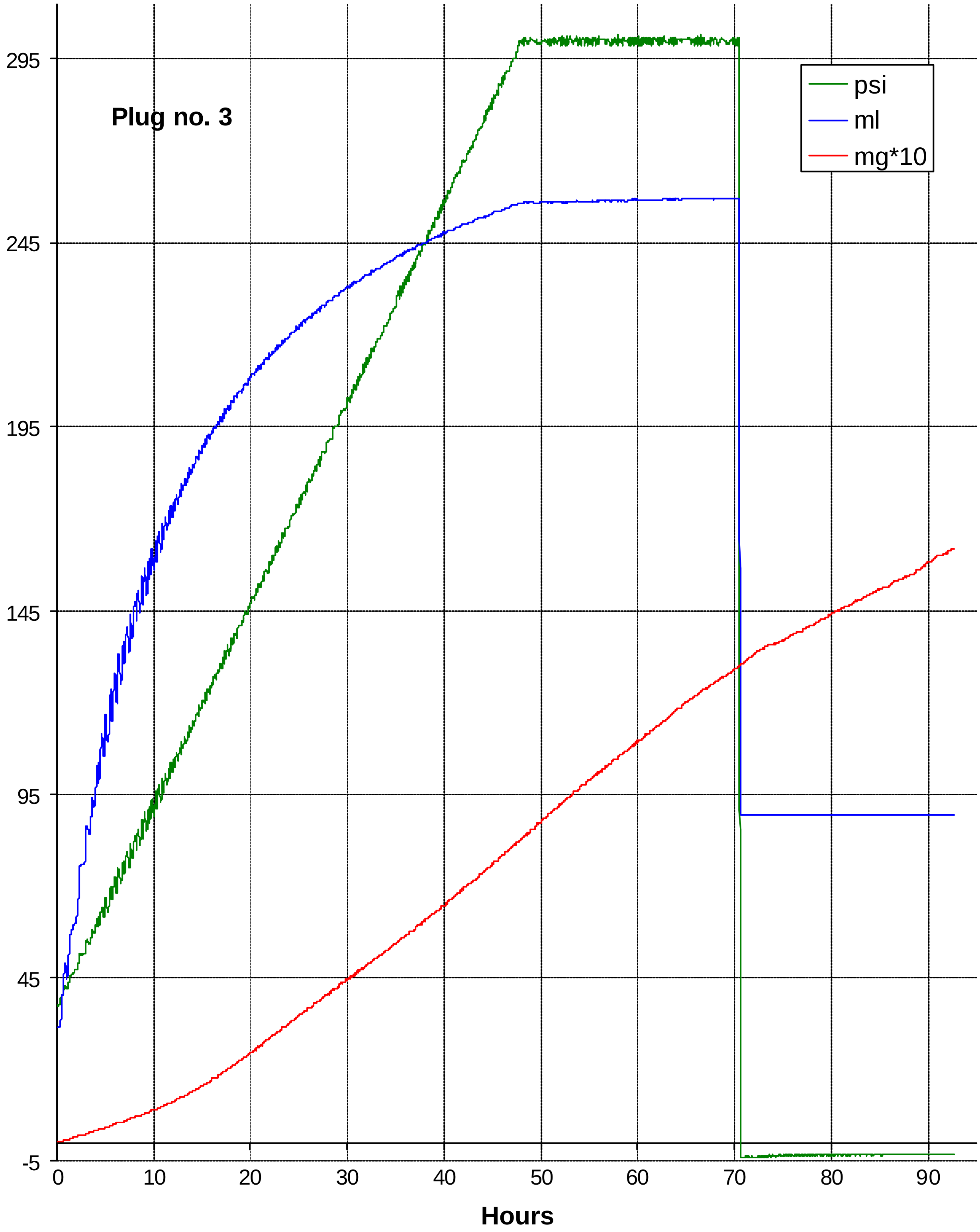
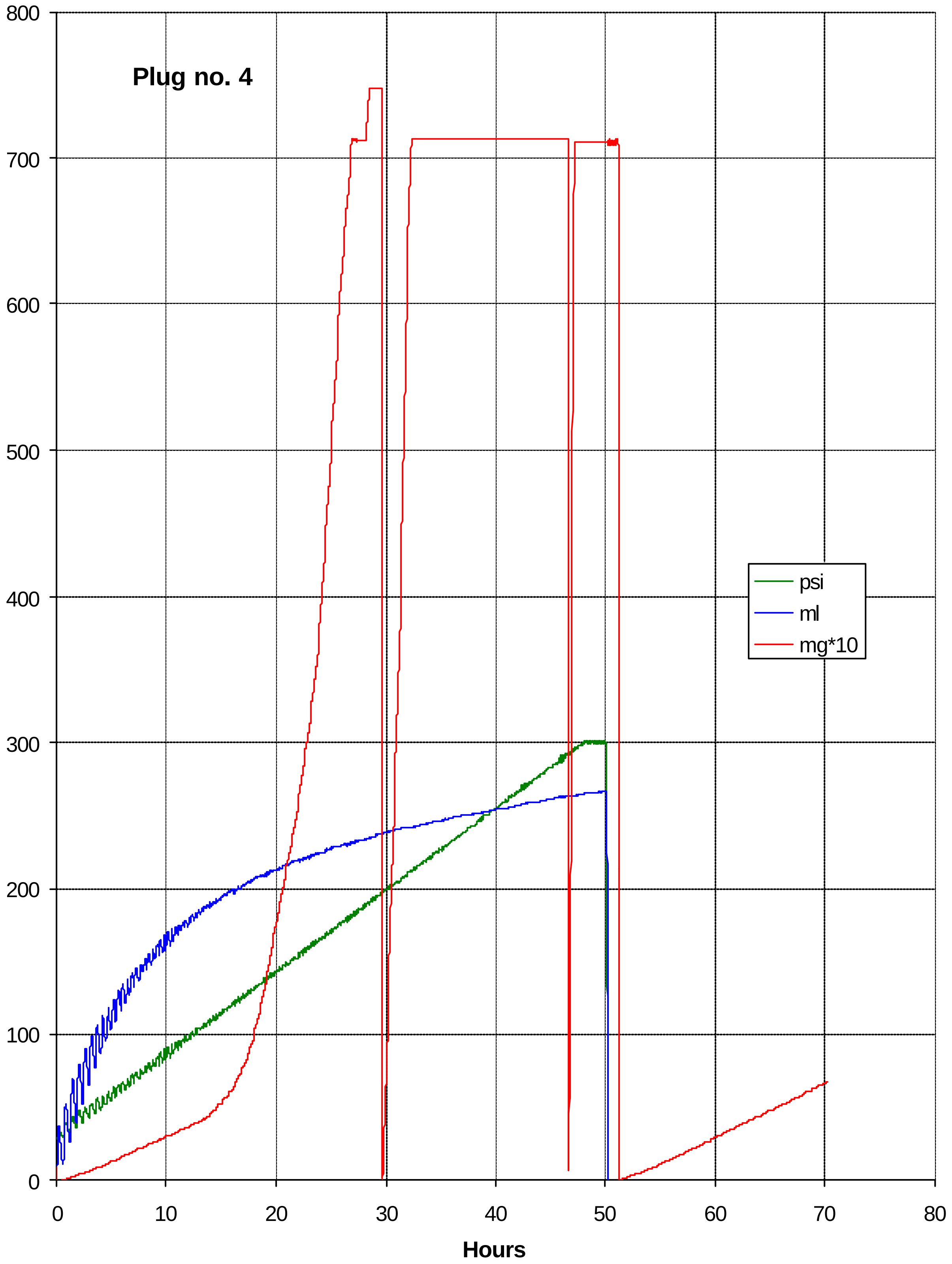

Plug no. 3
psi
ml
mg*10
295
245
195
145
95
45
-5
0
10
20
30
40
50
60
70
80
90
Hours

Figure 5.3 – Gas treshold pressure data on plug 3



Plug no. 4
psi
ml
mg*10
Hours
0
100
200
300
400
500
600
700
800
0
10
20
30
40
50
60
70
80

Figure 5.4 – Gas treshold pressure data on plug 4

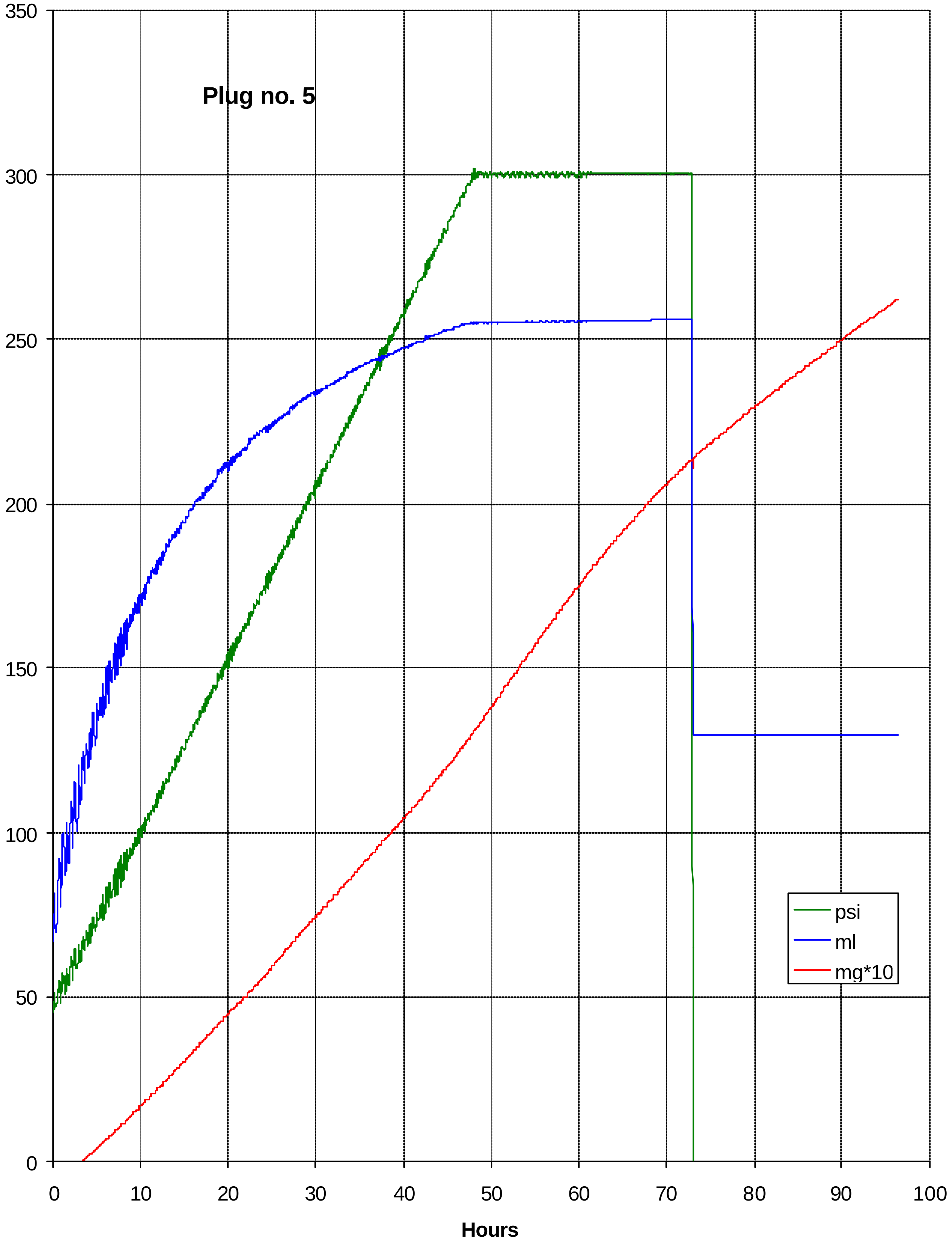

Plug no. 5
350
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
100
Hours
psi
ml
mg*10

Figure 5.5 – Gas treshold pressure data on plug 5

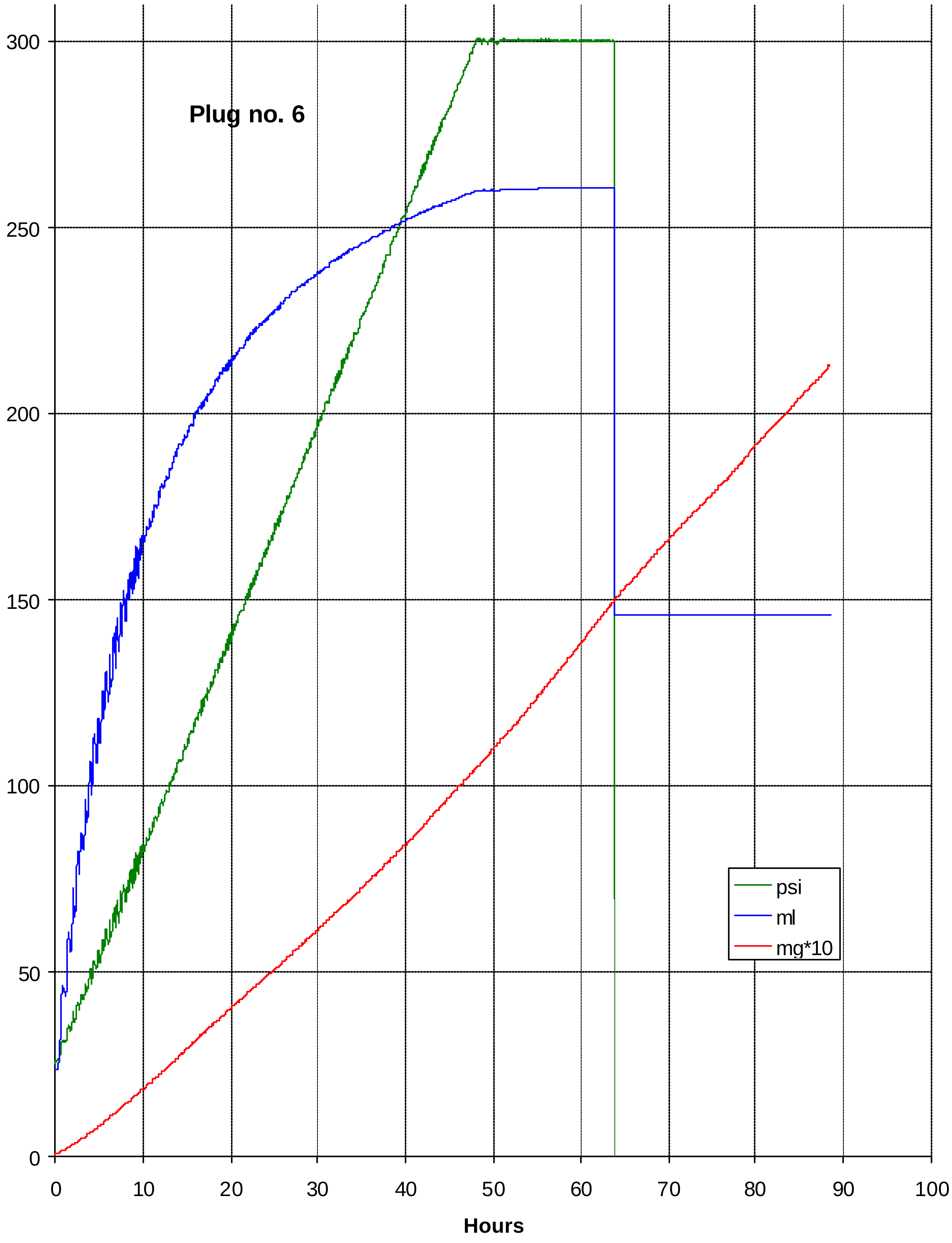

Plug no. 6
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
100
Hours
psi
ml
mg*10

Figure 5.6 – Gas treshold pressure data on plug 6