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Outgassing of Booster dipole chamber

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OUTGASSING OF BOOSTER DIPOLE CHAMBER

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INTRODUCTION

The average pressure inside the Booster vacuum chamber is proportional to the outgassing of the vacuum chamber, which in turn varies exponentially with the temperature of the chamber. Due to eddy current heating during fast-cycle proton acceleration, the temperature of the dipole chamber could reach as high as 100°C. The outgassing and the resulted pressure will certainly be higher than those at 25°C and was the subject of our present study.

In our study, the outgassing and the ultimate pressure of a "straight" dipole chamber fabricated of 316L stainless steel has been measured at different temperature (regulated by external heaters). The results and its implication are summarized here.

DESCRIPTION OF TEST SETUP

This dipole chamber was cleaned at NSLS, vacuum fired (950°C x 4 hrs) at CERN and insitu baked (200°C x 40 hrs) before testing. It was pumped by a modified Isabelle pump station. This UHV pump station has a nominal pumping speed of ~ 1000 l/s for hydrogen (the real pumping speed of this particular station was later estimated to be only 200 l/s!). Three ion gauges (G1, G2 and G3) and one quadrupole residual gas analyzer (RGA) were used to monitor the vacuum at the chamber and at the pump station. A schematic of the setup is shown in Figure 1.

To measure the outgassing rate, an orifice plate with a conductance C of 0.6 l/s and 2.4 l/s for N_2 and H_2, respectively, was installed between the chamber and the station. The total chamber outgassing Q and the unit outgassing q then can be derived from the measured pressures P (N_2 equivalent), the conductance C and the surface area of the chamber A; such that

$$Q = [P\,(G2) - P\,(G3)]*C \qquad \text{Torr.l/s}$$
$$q = Q/A \qquad \text{Torr.l/s.cm}^2$$

In the other study, the ultimate pressures of the chamber and of the pump station at different temperature were measured when the orifice plate was removed.

OUTGASSING VS TEMPERATURE

One week after insitu bake, the outgassing rate q was about 5×10^{-13} Torr. l/s. cm^2 with hydrogen being more than 90% of the residual gas. It decreased to about 3×10^{-13} level in a month. This level does meet the Booster design requirements although as low as 1×10^{-13} Torr. l/s.cm^2 was achieved in ISABELLE project.[1]

Outgassing rates between 30 and 180°C are summarized in Figure 2. Since hydrogen was the dominant gas and its source is the diffusion from the stainless bulk, the outgassing rate should follow the Fick's law of diffusion and

$$Q(T) = q_o \times \exp - (\Delta E/RT) \qquad (1)$$

This is indeed the case for T > 60°C as shown in Figure 2 when Log q was plotted against 1/T. The energy of diffusion ΔE derived from the slope is about 8.5 Kcal/mole and is consistent with the previously measured value[1] of 10 ± 1 Kcal/mole for 304 LN stainless steel. The constant q_o, which is proportional to the concentration of the dissolved hydrogen in the bulk, is about 1.5×10^{-7} Torr.l/s.cm^2 for this chamber.

ULTIMATE PRESSURE VS TEMPERATURE

At room temperature, the maximum pressure (measured at G1) along this dipole chamber is about 3×10^{-11} Torr one week after insitu bake; and reached to about 2×10^{-11} Torr after one month. A significant fraction (~ 1×10^{-11} Torr) of this pressure was due to gauge outgassing.

At higher temperature, the pressure at G1 and G2 can be expressed by

$$P(G1) = P_o + 0.5 \times q\,(T) \times u \times (L/S + L^2/4C) \qquad (2)$$
$$P(G2) = P_o + 0.5 \times q\,(T) \times u \times L/S \qquad (3)$$

here q(T) is given by Eqn. (1) using the derived ΔE and q_o

L/2 is the length of the dipole chamber = 240 cm
C is the linear conductance of the chamber = 7200 l.cm/sec
u is the perimeter of the chamber = 45 cm
S is the pumping speed in l/s
P_o is the blankoff pressure of the pump <1×10^{-11} Torr

The measured P(G1) and P(G2) are plotted against 1/T and compared with the calculated values in Figure 3. Here P(G1)' and P(G2)' are calculated from Eqs. (2) and (3) when S=200 l/s and, P(G1)" is when S = 1000 l/s.

The slopes of the measured P and the calculated P agree well with each other, suggesting that again hydrogen diffusion is the pressure dominating step at higher temperature. This is also confirmed by our residual gas spectra. The speed of this pump station was probably less than 200 l/s since P(G1) is higher than P(G1)'.

The average pressure in the Booster standard half cell can be expressed by

$$P_{avg} = P_o + q(T) \times u \times (L/S + L^2/12C)$$

and will be near that of P(G1)" even with the presence of the PUE elements, since the pumping speed will be about 1000 l/s for hydrogen, L be shorter and C of quadrupole chamber be larger.

SUMMARY

At room temperature, the outgassing rate and the ultimate pressure (N_2 equivalent) of this dipole chamber has met the designed values of 5×10^{-13} Torr. l/s. cm^2 and 3×10^{-11} Torr, respectively. During heavy ion acceleration, the eddy current heating power amounts to 2-3 watts/m and will not give any noticeable increase in outgassing.

At higher temperature, hydrogen diffusion from the stainless bulk will dominate the outgassing and the ultimate pressure. Our measurements agree well with the prediction of the Fick's law of diffusion. With 100 watt/m heating power during proton acceleration, the chamber might reach to 100°C (depending on the amount of insulation). The average pressure will be less than 2×10^{-10} Torr and is tolerable to the operation of titanium sublimation pump. No extra chamber cooling is required.

The pressure decay half-time from 100°C is about 2-3 hours (i.e. 1.5×10^{-10} Torr to 7×10^{-11} Torr). Fast switching (less than one hour) from proton to heavy ion (Au^{+33}) operation is unlikely if we want to keep the beam loss to a minimum.

The duration between sublimating the titanium filament (48 A x 7 minutes) is about 2 weeks during proton operation. The lifetime of the three filaments is about 10 years. For easy maintenance in the future, the pump body will be flanged to vacuum chamber.

ACKNOWLEDGE

We would like to thank B. McDowell for design, fabrication, cleaning and vacuum firing of this dipole chamber which guarantees the success of our testing.

REFERENCE

1. H.C. Hseuh and E. F. Gauget, IEEE, NS-28, No. 3, 3295, (1981).

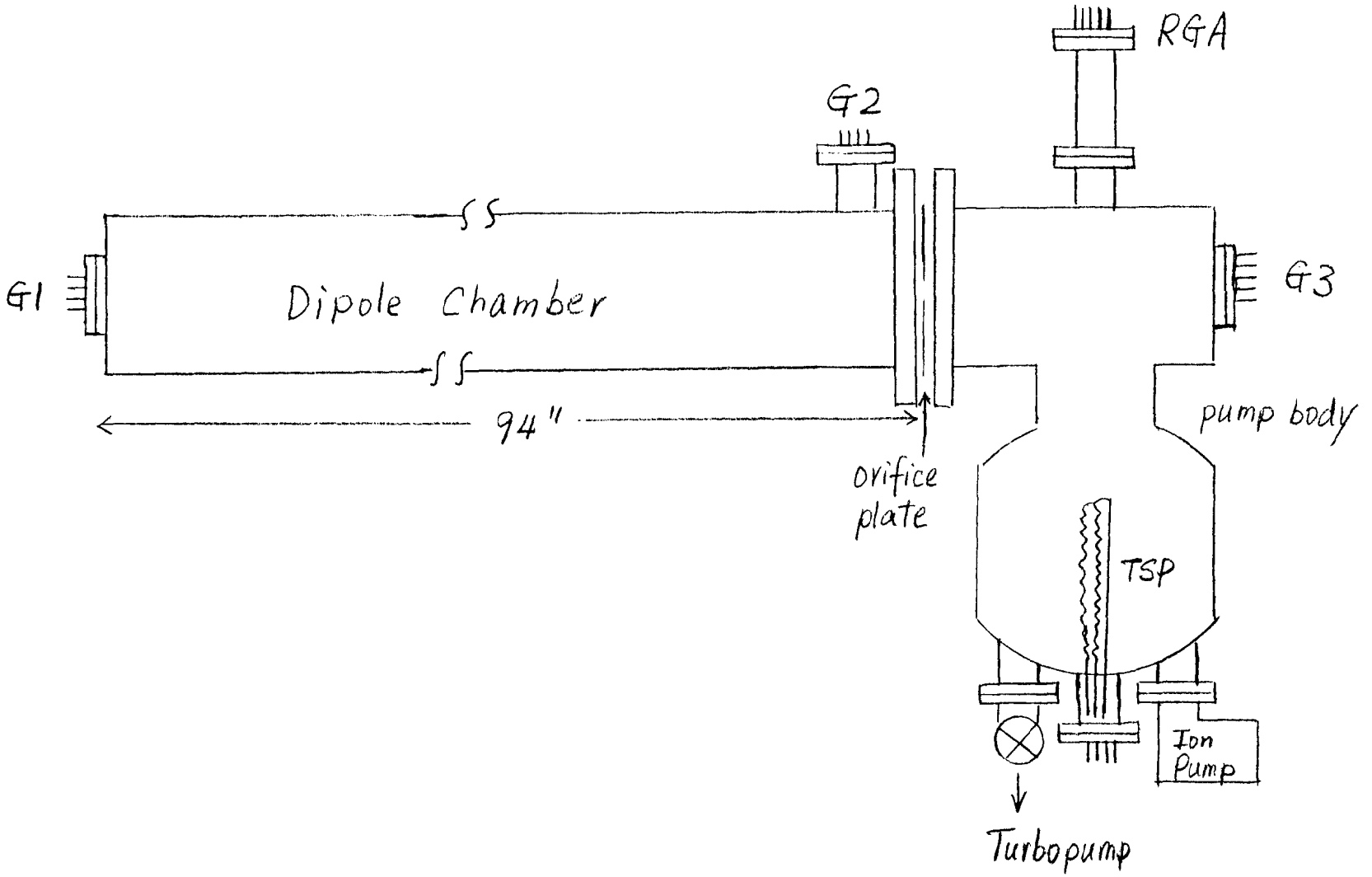
RGA
G2
SS
G1
Dipole Chamber
G3
SS
94"
pump body
orifice
plate
TSP
Ion
Pump
Turbopump

Figure 1

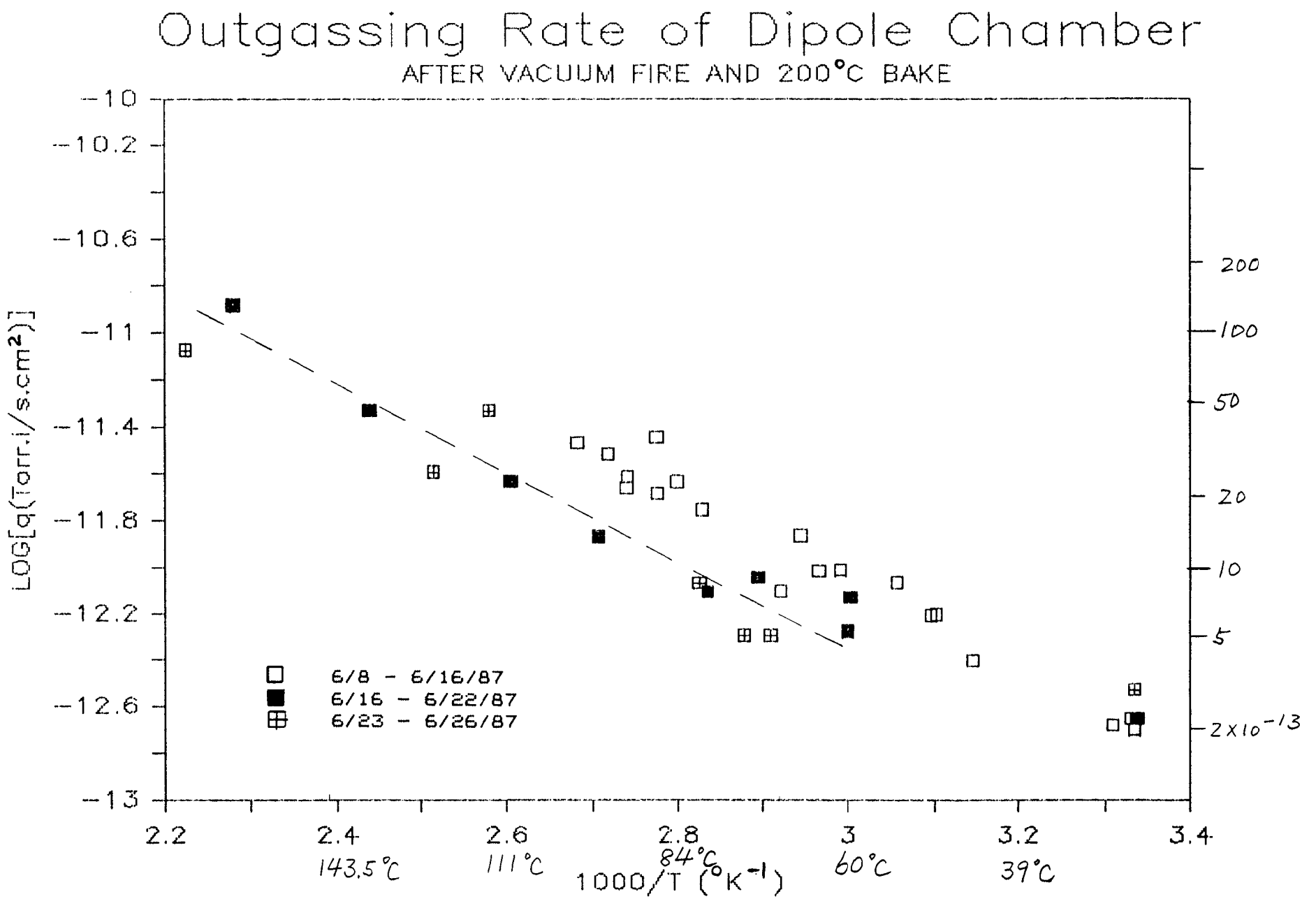
Outgassing Rate of Dipole Chamber
AFTER VACUUM FIRE AND 200°C BAKE
LOG[q(Torr.l/s.cm²)]
-10
-10.2
-10.6
-11
-11.4
-11.8
-12.2
-12.6
-13
200
100
50
20
10
5
2X10⁻¹³
6/8 - 6/16/87
6/16 - 6/22/87
6/23 - 6/26/87
2.2
2.4
2.6
2.8
3
3.2
3.4
143.5°C
111°C
84°C
60°C
39°C
1000/T (°K⁻¹)

Figure 2

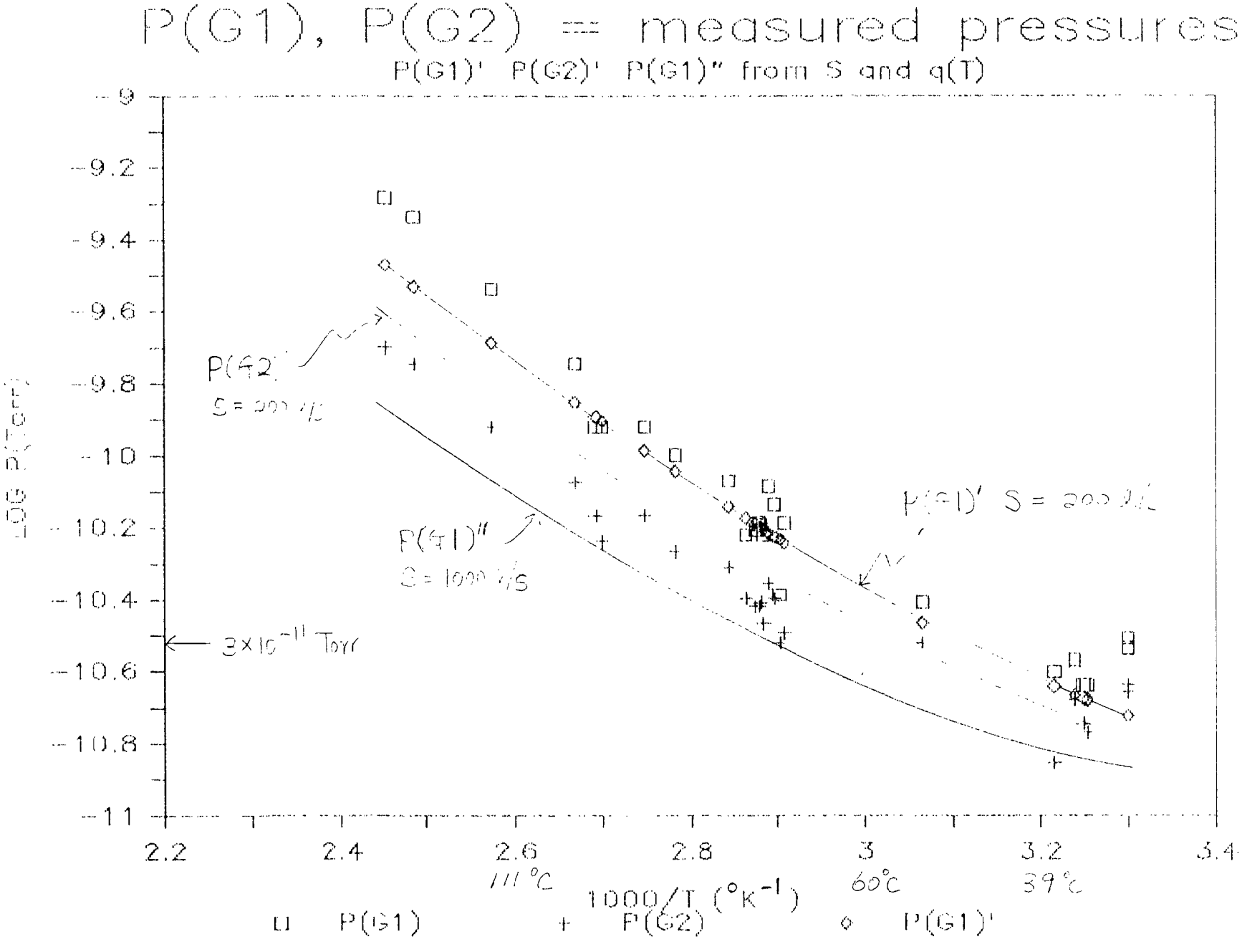
P(G1), P(G2) == measured pressures
P(G1)' P(G2)' P(G1)" from S and q(T)
LOG P (Torr)
-9
-9.2
-9.4
-9.6
-9.8
-10
-10.2
-10.4
-10.6
-10.8
-11
P(G2)'
S = 200 l/s
P(G1)"
S = 1000 l/s
P(G1)' S = 200 l/s
3×10⁻¹¹ Torr
2.2
2.4
2.6
2.8
3
3.2
3.4
111 °C
60°C
39°C
1000/T (°K⁻¹)
P(G1)
P(G2)
P(G1)'

Figure 3