Evaluation of the TiSP3

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Abstract

The purpose of this project was to evaluate the performance and capabilities of the TiSP3, a titanium sublimation pump located at three meters from the interaction point of CESR. Maximum pumping speed obtainable, the optimal number of filament flashes, and the pumping capabilities of a nitrogen-saturated chamber were investigated.

Introduction

The Cornell Electron Storage Ring (CESR) stores a clockwise positron beam and a counter-clockwise electron beam and allows the beams to collide at the interaction point within the CLEO detector. Once the beams are transferred to CESR, they must be stored there for several hours before the collision can take place. This puts very strict demands on the quality of the vacuum. The residual gas molecules in the paths of the beam particles must be many billion times less dense than in the normal atmosphere. Vacuum pumps distributed around the ring create and maintain this ultra high vacuum.

TiSP3 is the titanium sublimation pump located at 3 meters from the interaction point of CESR. It is the closest pump to the interaction point, so it is responsible for maintaining the ultra high vacuum needed throughout the detector and surrounding beam pipe. By capturing gas molecules on its inner surfaces, the TiSP3 maintains the vacuum by preventing the molecules from circulating back into the beam chamber.

The Apparatus

The TiSP3 is a circular stainless steel chamber around the central beam line tunnel. It houses five cartridges of three titanium filaments each and gains its pumping capabilities only after these filaments are flashed. Flashing is the process of heating up the filaments by applying 50 amps for a duration of two minutes. The filaments sublimate titanium molecules, which then cover the inner surfaces of the chamber to form a sticky surface. Gas molecules are then adsorbed onto this surface, thus removing them from circulation and improving the vacuum.

For the duration of testing, several additional components were attached to the chamber. At the top of the chamber, a Residual Gas Analyzer (RGA) ionized gas molecules and then sorted the resulting ions by mass in order to determine the identity and quantity of gases present. Partial pressures were found by identifying molecules with dominant atomic masses. Two cold cathode gauges (CCG) were also connected to the chamber, one located at the upper part of the chamber and one near the beam line to get a more relevant pressure reading. They measured voltage, from which pressure could be obtained using equation 1

$$P = 10^{aV-b}, \qquad (1)$$

where a and b were constants determined from initial data fits. The chamber CCG gave a different pressure reading than the beam line CCG because the central beam line tunnel was open to the rest of the chamber only through a series of pumping slots. The conductance of these slots limited the minimum pressure attainable at the beam line. One end of the chamber was attached to a mechanical turbo molecular pump. After accounting for the hoses that connected the turbo pump to the chamber, it had an effective pumping speed of 3 l/s. The other end of the chamber was connected to a gas manifold containing two calibrated leaks, N_2 and CO. The known leak rates of these bottles were then used to study the pumping characteristics of titanium subject to differing conditions.

Experiment Chronology

The chamber was initially baked-out at 150 ^{o}C in order to remove any residual gases, mainly nitrogen and water. After the chamber had cooled, the filaments were flashed once and the N_2 leak was introduced, primarily to determine the RGA sensitivity calibration. In order to investigate the pumping characteristics of nitrogen-saturated titanium, the first CO leak (CO-2) was introduced without flashing. After this saturation, a local power failure caused the system to be exposed to air. Another bake-out was omitted in order to observe the effects of a contaminated system on pumping characteristics. The filaments were then flashed once before the next CO leak (CO-3) was introduced. In order to investigate the effects of increasing the number of flashes, the filaments were flashed twice before introducing the fourth CO leak (CO-4), and then flashed three times before the fifth CO leak (CO-5).

Results

Pumping Speeds

Evaluation of the pumping characteristics of TiSP3 was best done using pumping speeds. Pumping speed was calculated by taking the constant calibrated gas leak rate and dividing by the pressure, as shown in equation 2.

$$S = (dQ/dt)/P \qquad (2)$$

Figure 1 shows pumping speeds as each of the CO saturations proceeded. As the titanium saturated and pressures rose, pumping speeds dropped to that of the turbo pump alone. A large initial difference between chamber and beam line pumping speeds was also observable. Slot conductance limited the maximum beam line pumping speed, but the maximum pumping speed at the chamber was not affected.

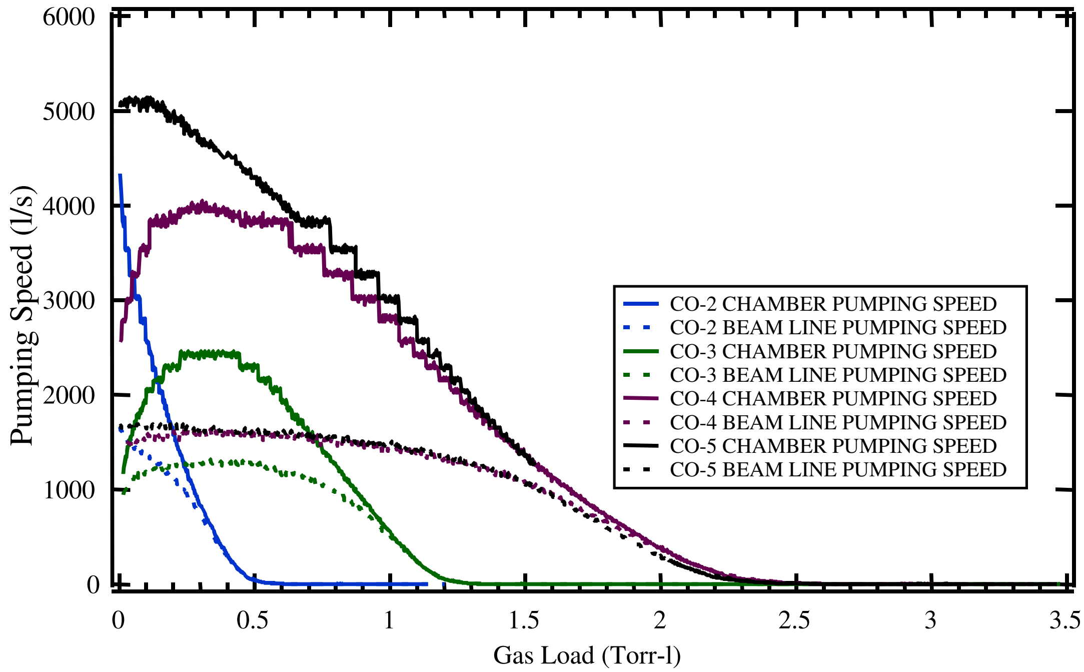

Figure 1. Comparison of Pumping Speeds from CO Saturations CO-2 through CO-5

The differences between maximum pumping speeds are quantized in Table I. The maximum beam line pumping speed of 1701.9 l/s is notable.

Table I. Maximum Pumping Speeds

	CO-2 S_{max} (l/s)	CO-3 S_{max} (l/s)	CO-4 S_{max} (l/s)	CO-5 S_{max} (l/s)
Chamber	4334.5	2462.1	4048.9	5139.5
Beam Line	1663.1	1320.2	1651.6	1701.9

Gas Load Values at Saturation

Another interesting property of titanium pumping we wished to investigate was the gas load at which the titanium became saturated. Gas load was defined as the product of the gas leak rate and the elapsed time since the gas leak was opened, as shown in equation 3.

$$Q = (dQ/dt)*t \qquad (3)$$

The definition of where Q_{sat} occurred was quite ambiguous, so the method of calculation varied. The first method used stated that the titanium saturated at ten times the initial (or minimum in some cases) pressure. This resulted in two values of Q_{sat} for each saturation, one that used the chamber pressure and another that used the pressure at the beam line. RGA data could also be used to calculate Q_{sat} as ten times the initial partial pressure calculated from 28 AMU, or the mass of a CO molecule. Another method to calculate the gas load at which the system saturated was to determine where the ratio of beam line to chamber pressure equaled one.

At this point, the beam line and chamber pressures equalized, and it was safe to assume that the titanium was saturated.

One of the goals of this project was to ascertain the number of flashes required to create optimal pumping conditions. Q_{sat} values were used to determine this, as seen in Figure 2. The four methods for calculating Q_{sat} are all represented in the graph. The Q_{sat} values from RGA data were lower because here we were considering only the partial pressure due to 28 AMU, rather than the total pressure as found from CCG data. TiSP3 pumping capacity was doubled by the increase of flashes from one to two. However, increasing the number of flashes to three was not beneficial because the gas load at which the system saturated did not increase. Thus, the optimal number of flashes was two.

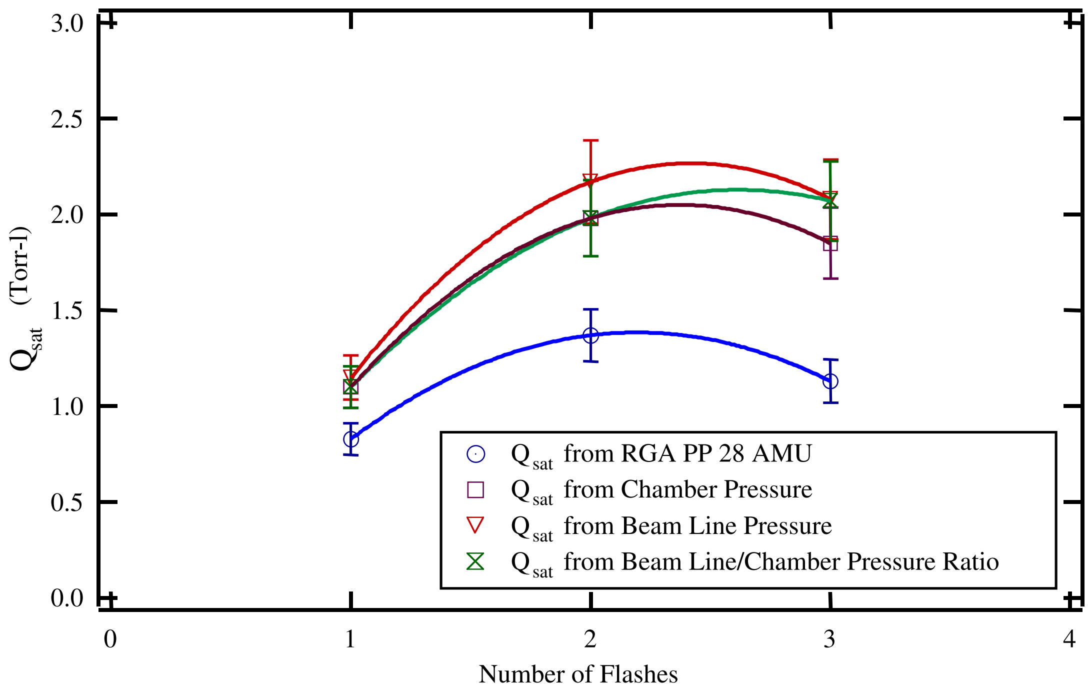

Figure 2. CO Saturation Gas Load Values vs. Number of Flashes

N_2 Saturation

The purpose of a saturation with nitrogen was to determine the sensitivity of the RGA. In order to obtain this, it was necessary to find the ratio of the intensity due to 14 AMU to the intensity due to 28 AMU. Since both CO and N_2 have a mass of 28 AMU, the mass of atomic nitrogen (14 AMU) was used to find the ratio of nitrogen composition. After the system saturated, it was valid to assume that the primary gas load was due to nitrogen. Thus, the 14/28 ratio after saturation was used to determine the RGA sensitivity to be 0.105, as shown in Figure 3.

CO-2: CO Saturation after N_2 Saturation

The goal of this saturation was to investigate the pumping characteristics of a nitrogen-saturated chamber. It was necessary to determine whether saturated titanium would pump CO, or if the nitrogen would prohibit it. Figure 4 shows the intensity trends for various atomic masses as the system saturated.

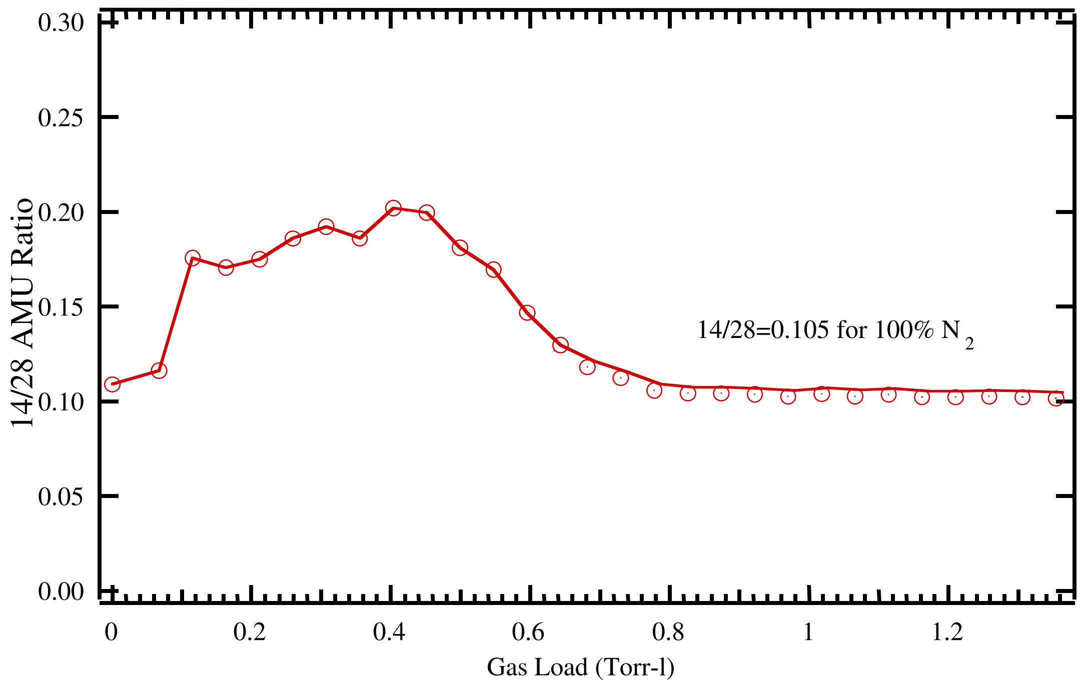

Figure 3. Determination of RGA Sensitivity

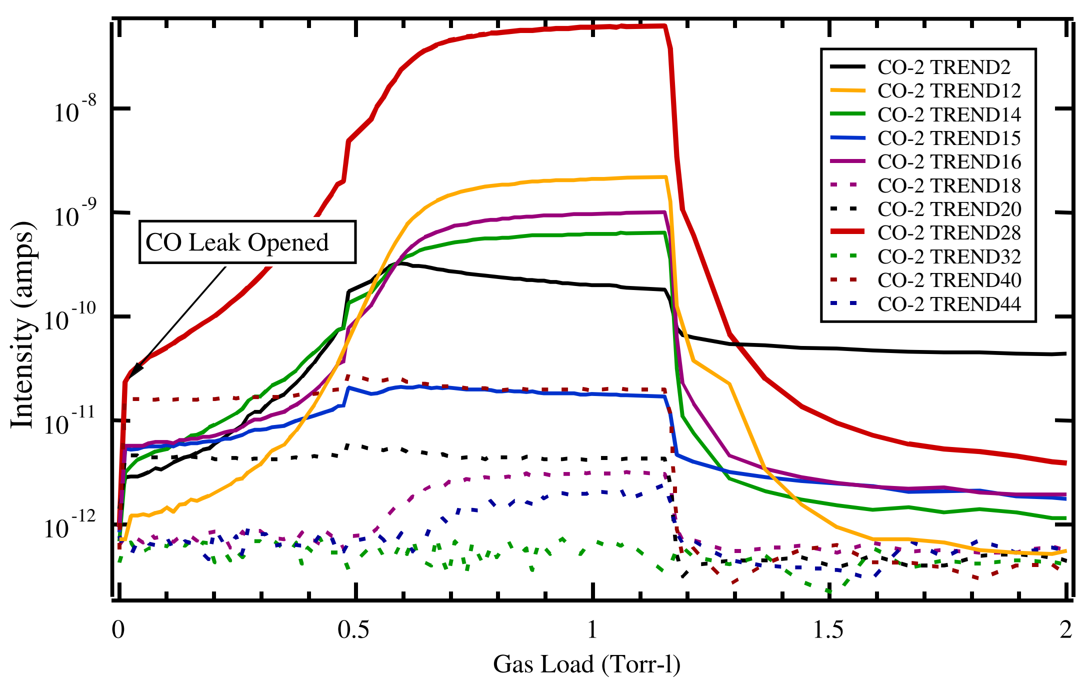

Figure 4. CO-2 Intensity Trends vs. Gas Load

The trend of 28 AMU had the greatest increase, but this was not entirely due to CO composition. As previously stated, both N_2 and CO have molecular masses of 28 AMU. Thus, it was necessary to correct the 28 AMU trend for nitrogen contributions. Several spectra on which to perform this correction were selected from throughout the saturation. It was insufficient to simply correct for the 14/28 ratio because 14 AMU also included a significant contribution from methane. Therefore, any methane content had to be accounted for. Methane had characteristic mass peaks at 14, 15, and 16 AMU. 15 AMU was primarily due to methane, so it was used to normalize the other two peaks. After this normalization and subtraction of an expected ratio of methane[1], the corrected ratios of 14/28 and 16/28 were obtained. This ratio of 14/28 accounted for any nitrogen contributions to the gas load. This ratio was then used to calculate the partial pressure due to CO using equation 4.

$$PP_{CO} = \frac{I_{28}}{0.96GS} \left(1 - \frac{(14/28)}{0.105}\right) \tag{4}$$

I_{28} is the uncorrected trend intensity of 28 AMU, and GS is a calculated factor accounting for the gain and sensitivity of the RGA.

Figure 5 compares the uncorrected partial pressure of CO to the values calculated using equation 4. The initial difference between the raw and corrected partial pressures was due to the contribution from nitrogen in the 28 AMU intensity trend. This difference resulted in an initial outgassing of nitrogen during the saturation. Thus, it is shown that a nitrogen-saturated chamber will pump CO. It was hypothesized that incoming CO molecules displace the N_2 molecules attached to the titanium. The N_2 molecules were then released, accounting for the initial partial pressure difference shown in Figure 5. This difference became less significant as the saturation proceeded because fewer N_2 molecules were there to be displaced by incoming CO.

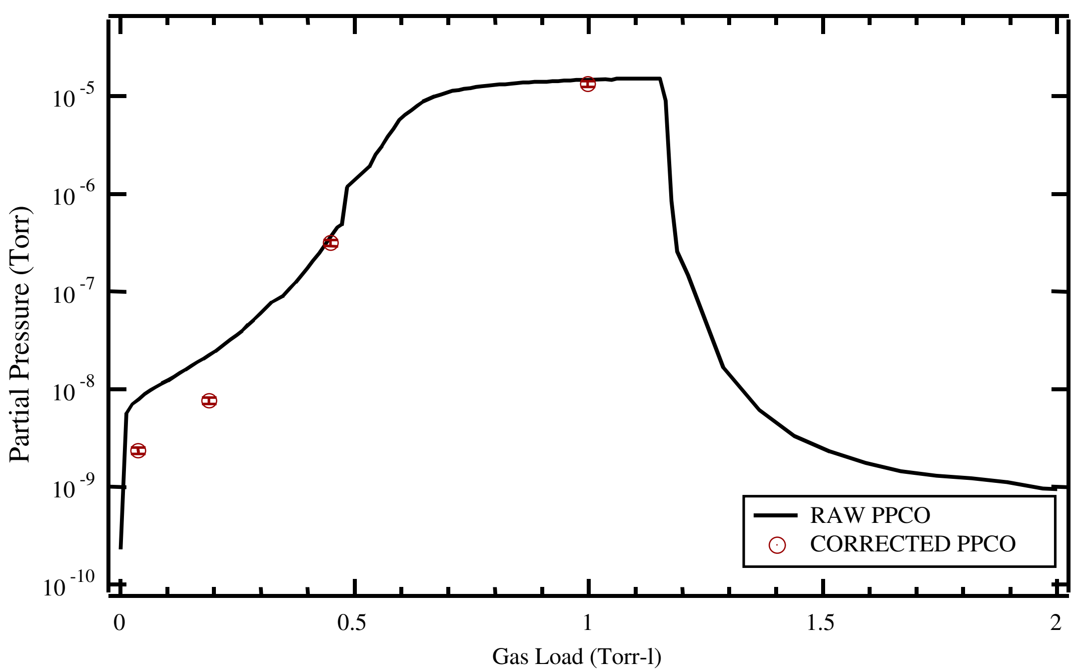

Figure 5. CO-2 Partial Pressure vs. Gas Load

CO-4: CO Saturation After Two Flashes

One of the goals of this saturation was to act as a comparison to CO-2 without the preceding nitrogen saturation. It was also used as a comparison to the single and triple flash saturations.

As in CO-2, the 14/28 ratio was used to correct the partial pressure of CO for any N_2 or CH_4 contributions. Figure 6 shows the corrected 14/28 ratio. The raw data ratio lacks any corrections for methane or nitrogen contributions. The recalculated data ratio accounts for methane content. The initial difference between the raw data and these recalculated points was then due to the methane contribution, which became less significant as the amount of CO in the chamber increased. It was apparent from the relatively constant 14/28 ratio that the N_2 in the system was not a dynamic factor in 28 AMU.

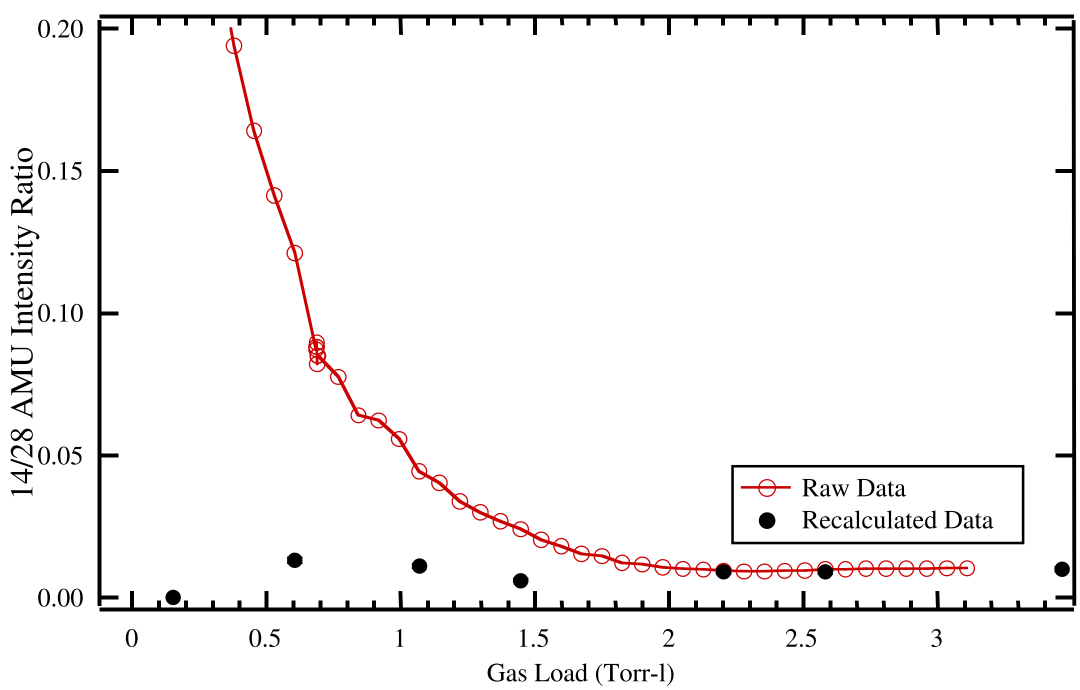

Figure 6. CO-4 14/28 AMU Intensity Ratio vs. Gas Load

Figure 7 shows the corrected partial pressure of CO compared to the raw partial pressure. It was apparent from the similarity between the raw and corrected partial pressure values in Figure 7 that nitrogen was not a significant component. Thus, we knew that nitrogen was not outgassed at the beginning of the saturation as it was in CO-2.

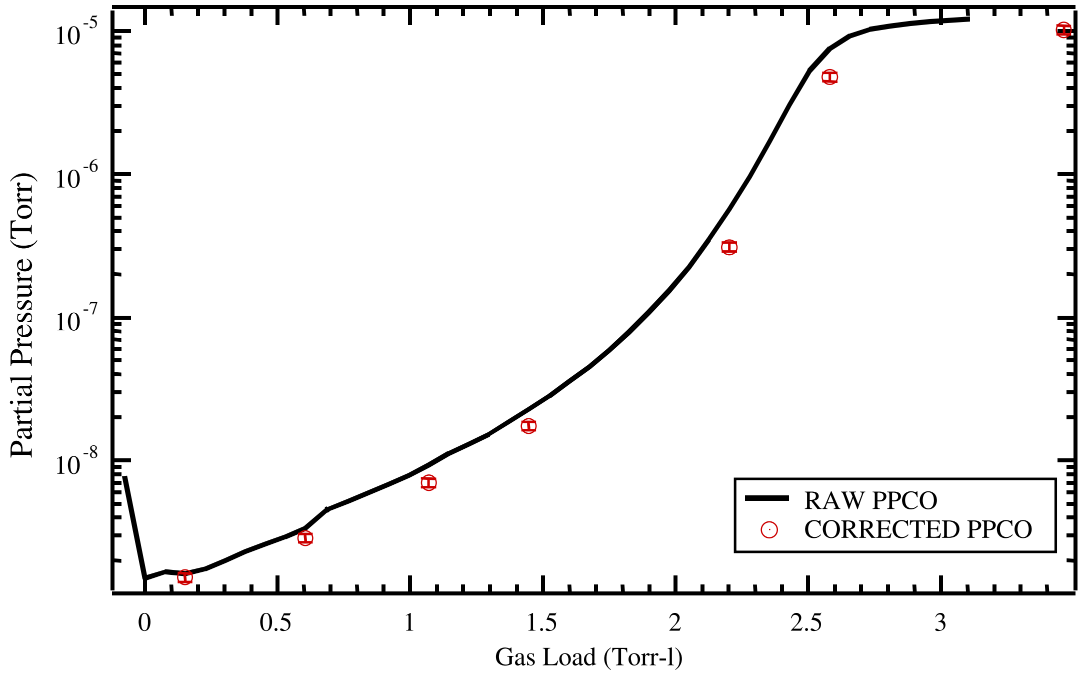

Figure 7. CO-4 Partial Pressure vs. Gas Load

Conclusions

The TiSP3 will be effective in maintaining the vacuum needed in the beam pipe because of the high pumping speeds obtainable. It has been shown that the pumping capacity was doubled by increasing the number of flashes from one to two, but no significant improvement was made by flashing three times. Finally, we have shown that a nitrogen-saturated chamber will pump CO. It has been hypothesized that nitrogen molecules are released and then replaced by CO.

Acknowledgements

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Footnotes and References

1. From *Transpector Gas Analysis System Manual*, Leybold Inficon, Inc., 1995, East Syracuse, NY