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Progress Report

An Experimental Study of the Cryoentrainment Pump

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In the previous progress report, it was noted that a change in the experimental method was responsible for an improvement of the response of the entrainment pump.

The initial method of operation was to pump liquid nitrogen into the condenser until a steady stream of liquid was exhausted through the vent line. The liquid nitrogen was allowed to vent in this manner for a period of approximately thirty minutes. At this time, the nitrogen supply was cut off with the condenser being supplied with liquid nitrogen periodically during the course of a given experimental run. Short bursts of the pumping medium were then admitted to the pump which had been previously filled to a given pressure level with helium.

The data shown in Figure 1 were obtained by such a technique. In this case the pumping fluid was $C_4 F_8$ (octocycloflourobutane) at an injection pressure of 25 psig.

It may be seen from the figure that a minimum value of the helium partial pressure occurs at approximately 1.3×10^{-6} torr with each injection of the $C_4 F_8$. The rapid release of the helium from the condenser is also evident with the helium partial pressure returning to a value near that prior to the injection within five minutes from the time of the $C_4 F_8$ injection.

At this point, the experimental procedure was changed so that the liquid nitrogen was allowed to flow constantly from the vent line during the course of an experimental run. This was done in the hope of insuring a more uniformly cooled condensing surface.

The data presented in Figure 2 were obtained employing this modified technique. The partial pressure-time profile for the helium is similar in the initial stages to the data in Figure 1. The obvious difference between the two methods is in the time period greater than one minute in the respect that the helium is more effectively prevented from re-entering the pump volume. As previously indicated, this was felt to be due to the more efficient cooling of the condensing surface with a subsequent higher retention capability for the $C_4 F_8$ and the helium. It may also be seen from this figure that additional bursts of the pumping fluid have the desirable effect of reducing the partial pressure with each burst.

The lowest helium partial pressure obtained with this technique was 4.73×10^{-7} torr or a reduction by a factor of approximately 2 over that obtained by the initial method using $C_4 F_8$ as the pumping medium. It should be noted that the data shown in Figure 2 were obtained using an injection pressure below 25 psig with no adverse effect on the operation of the pump.

Bearing in mind the fact that an improvement in the condenser cooling favorably influenced both the retention of the helium on the condenser with respect to time as well as the lowest value of the helium partial pressure, further modifications were made on the system. A 50 cfm Cenco mechanical pump was attached to the condenser liquid nitrogen vent line to further lower the condenser temperature.

The injection pressure was also lowered from the region of 25 psig to sub-atmospheric values in yet another attempt to prevent the pumping gas from leaking into the pump volume through the injection solenoid valves.

Figure 3 shows the effect of using CO_2 as the pumping gas at an injection pressure of 500 torr. The first injection is seen to reduce the helium pressure level by a factor of approximately four with the final pressure remaining relatively constant with time. The second injection provides a significant improvement in the pressure drop. This injection yields a a pressure reduction of a factor of 8. This is presumably due to the conditioning of the coils with an "ice" from the first injection. The rate of release of the helium from the "ice" is again seen to be quite slow as compared with the data of Figures 1 and 2.

The fact that the third injection of CO_2 shows only a small reduction in the helium partial pressure is felt to be due to the changing collision probability as a result of continually removing helium molecules from the pump volume.

The use of CO_2 as a pumping gas and an improved cooling technique for the condenser resulted in an overall pressure reduction factor of 40 with a much improved capability of helium retention on the coils. It is also estimated that 90 per cent of the injected CO_2 was condensed on the cooling coils. In order to estimate the percentage of the injected gas that was trapped on the coils, several bursts of gas were injected into the system with no liquid nitrogen in the condenser. This established a reference pressure level for no trapping of the injected gas. Then, during operation with the condenser filled with liquid nitrogen, the total pressure in the system after an injection as compared with the reference pressure level forms a basis for estimating the amount of the injected gas removed.

Future investigations of the efficiency of this condenser will be made by taking mass spectra of the system atmosphere as a function of time.

The response of the entrainment pump using C_4F_8 as the pumping fluid with an injection pressure of 380 torr. is shown in Figure 4. The initial pressure reduction is by a factor of 12 with the helium partial pressure remaining essentially constant at the final value of 2.2×10^{-7} torr for a period of one hour. Although the run was terminated at this point, the helium partial pressure showed no sign of increasing. It is estimated that, in this run, approximately 70 per cent of the injected C_4F_8 was trapped on the coils.

Figure 5 indicates the response of the entrainment pump using $C_4 F_8$ as the injected gas with injection pressures of 250 and 380 torr. The initial injection, at 250 torr, shows a reduction in the pressure by a factor of only 1.5. This is perhaps a result of only a small amount of momentum transfer to the helium molecules. It should be noted that although the pressure reduction for this injection pressure is not extremely high, the helium partial pressure exhibits a behavior similar to that in Figure 4 by tending to remain constant with time.

The second injection, at a pressure of 380 torr, yielded a pressure ratio of 14. A similar time response to that shown in Figure 3 was also found. Further injections had little effect on the minimum pressure attainable although the time response was essentially the same in that the helium was retained on the condenser for a long time period. In this case, it is estimated that approximately 90 per cent of the injected $C_4 F_8$ was removed by the condenser.

From the data shown in Figure 4, it would appear that the removal of the helium is quite sensitive to changes in injection pressure. For this reason the work in the immediate future will attempt to define the method--both the level of injection pressure and the duration of the injection cycle--to obtain the minimum pressure. This information will be determined for $C_4 F_8$, CO_2, H_2O, and A.

Since the removal of the injected gas varies from approximately 70 to 90 per cent of the total injected mass, short term pumping cycles will have the net effect of slowly raising the total pressure. Although the random motion of the injected gas particles would eventually carry them to the condenser where they would be removed from the system, it is usually desirable to have a capability of evacuating a vacuum system rapidly. For this reason, a secondary investigation has been undertaken to determine experimentally the effect of condenser design on the removal rate of the injected gas.

As a result of the work performed thus far, a paper tentatively entitled "An Experimental Study of the Cryoentrainment Pump" is in preparation to be submitted for presentation at the Rarefied Gas Dynamics Symposium to be held in the summer of 1970.

The present progress report,although the last to be filed under NASA Grant Number NGR 34-002-036 does not indicate termination of the experimental work. Future progress reports will be filed under NASA Grant Number NGR 34-002-106.

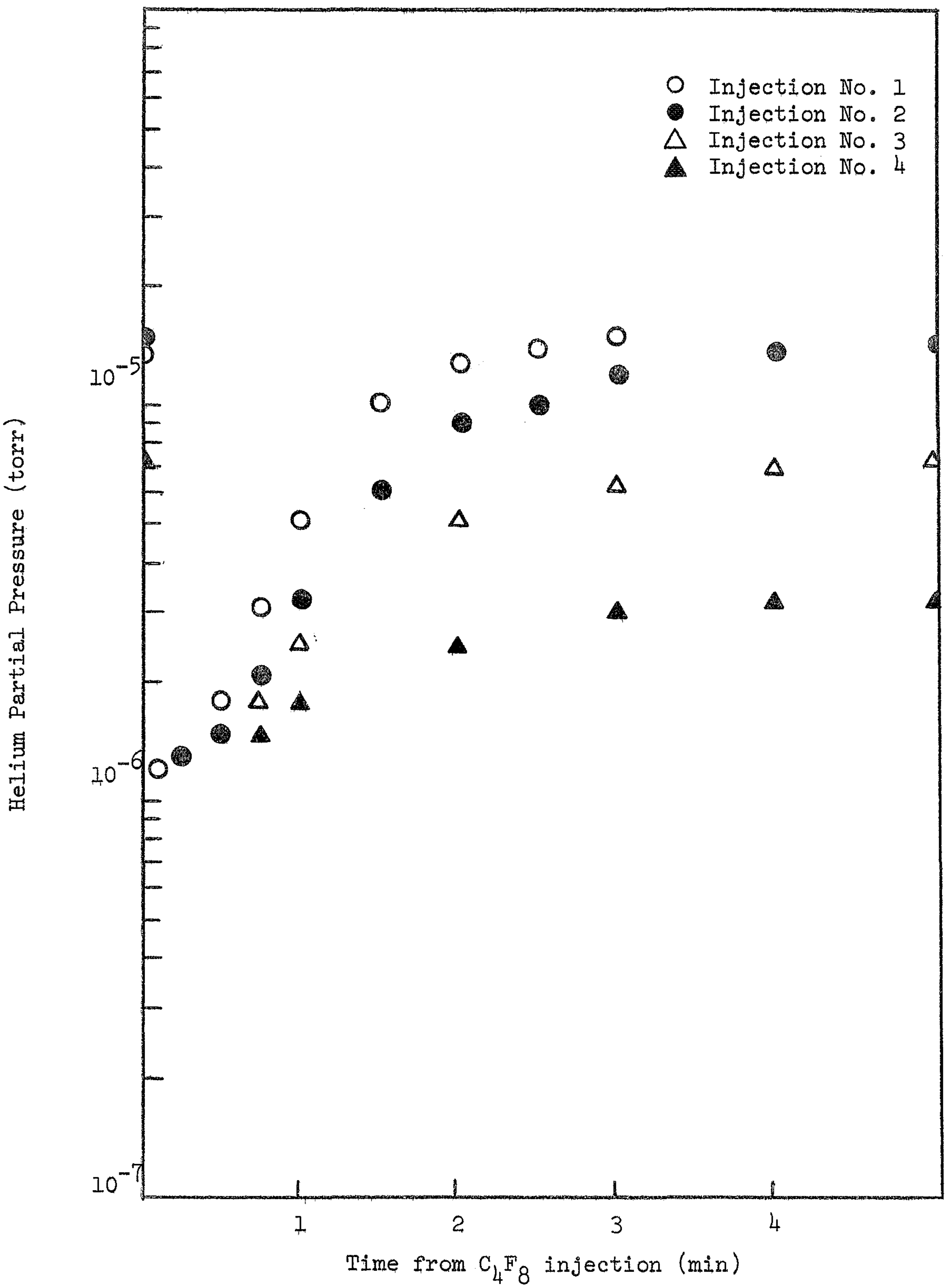

Figure 1. Helium pumping by C_4F_8 injection

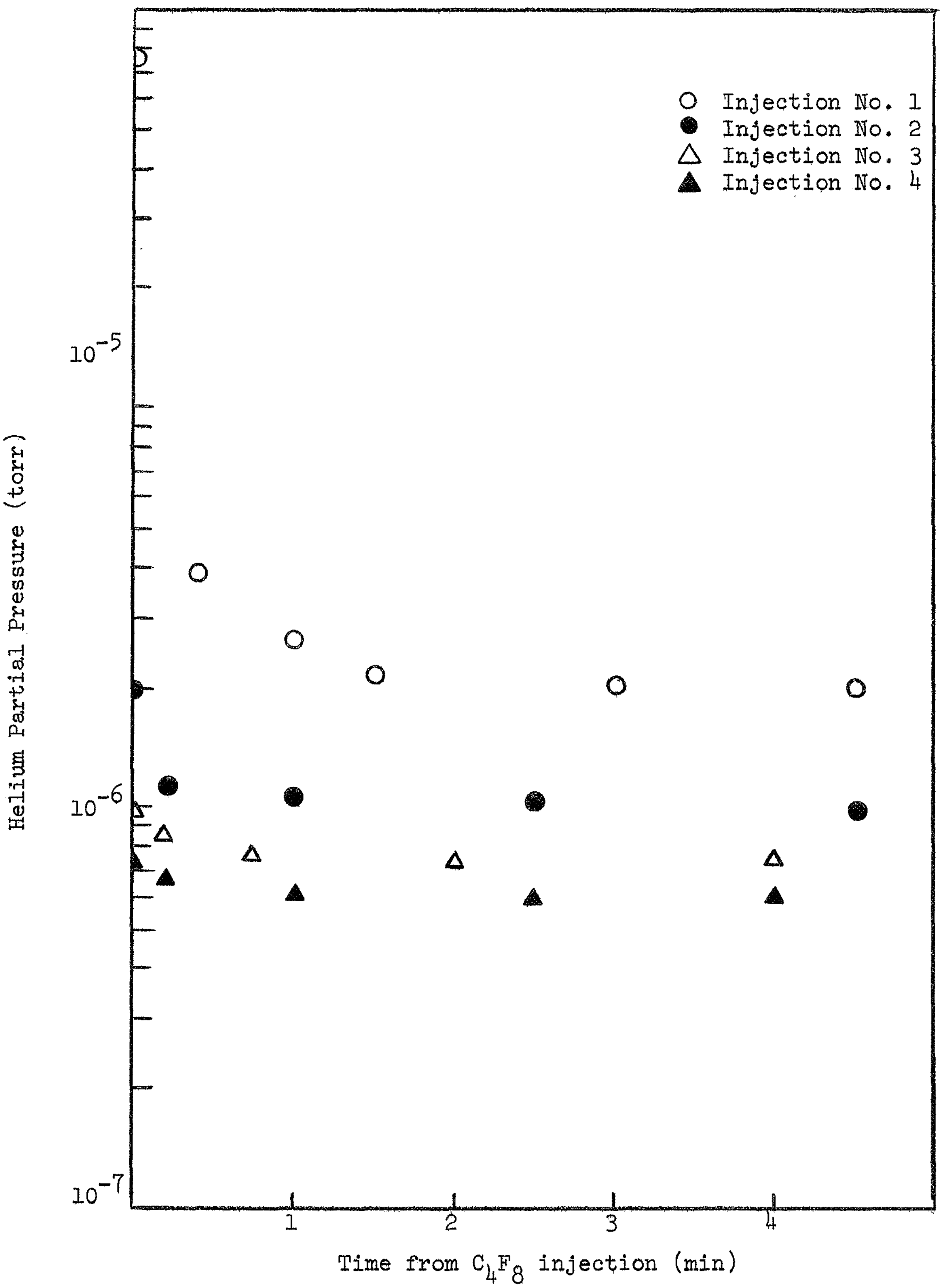

Figure 2. Helium pumping by C_4F_8 injection

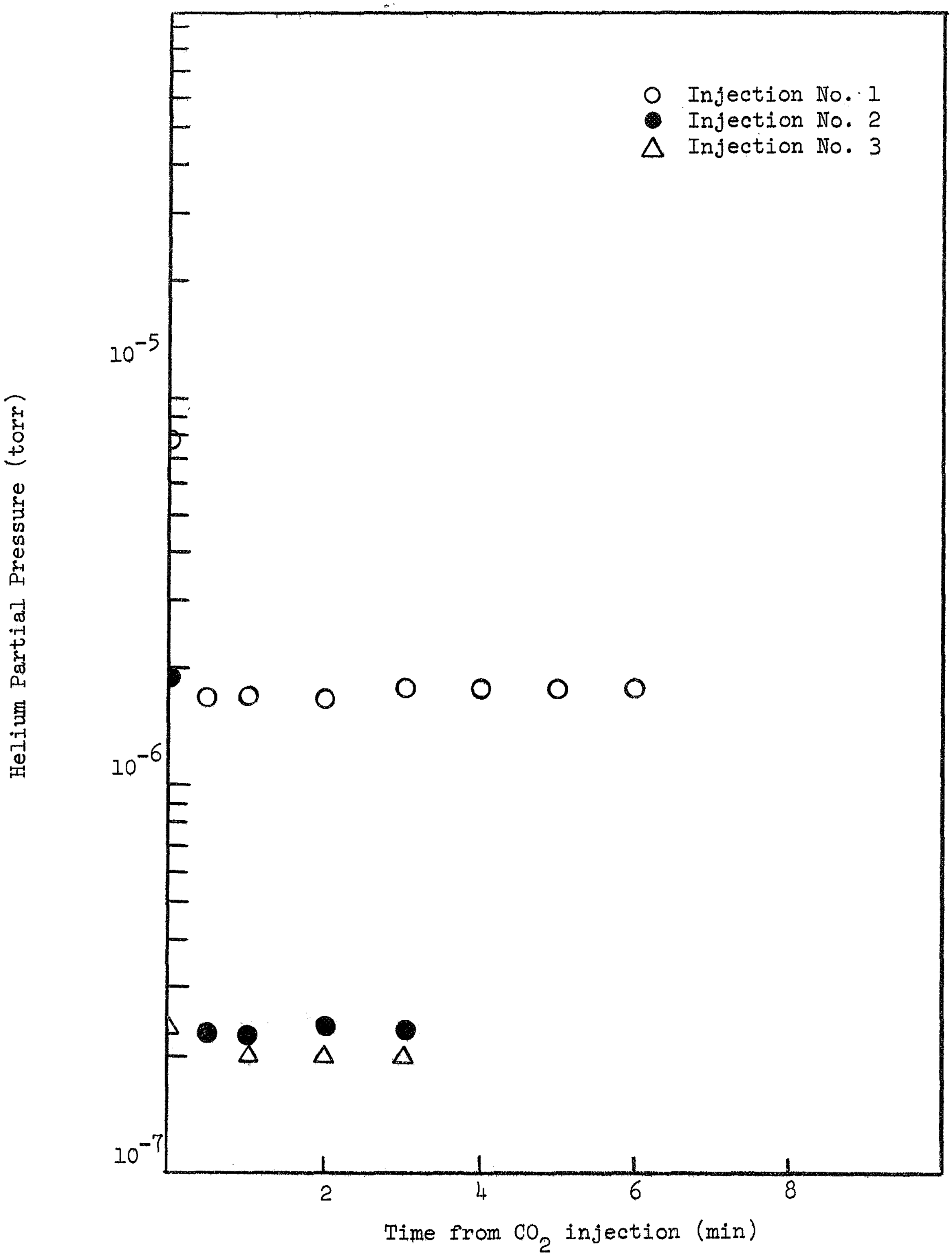

Figure 3. Helium pumping by CO_2 injection

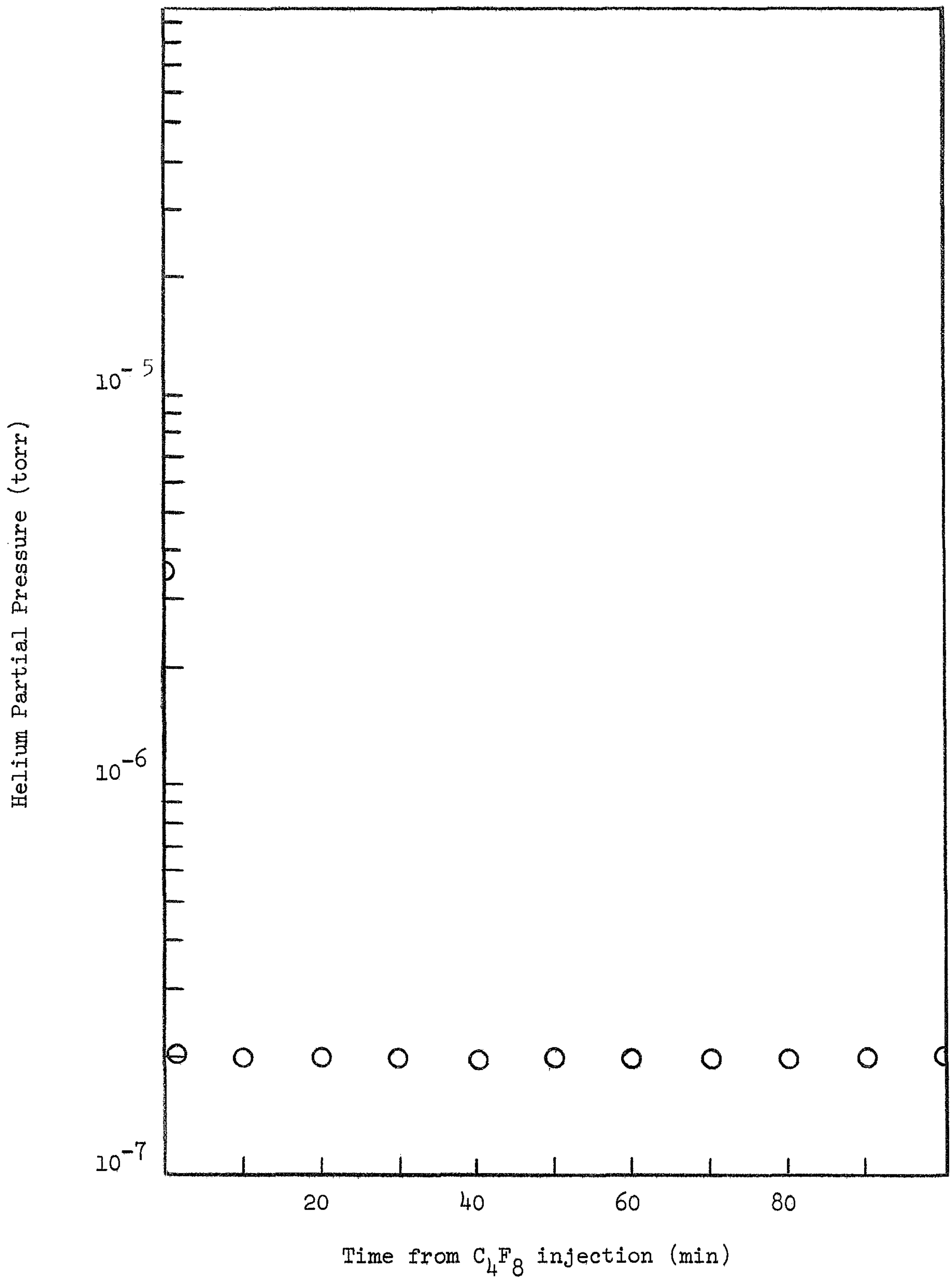

Figure 4. Helium pumping by C_4F_8 injection

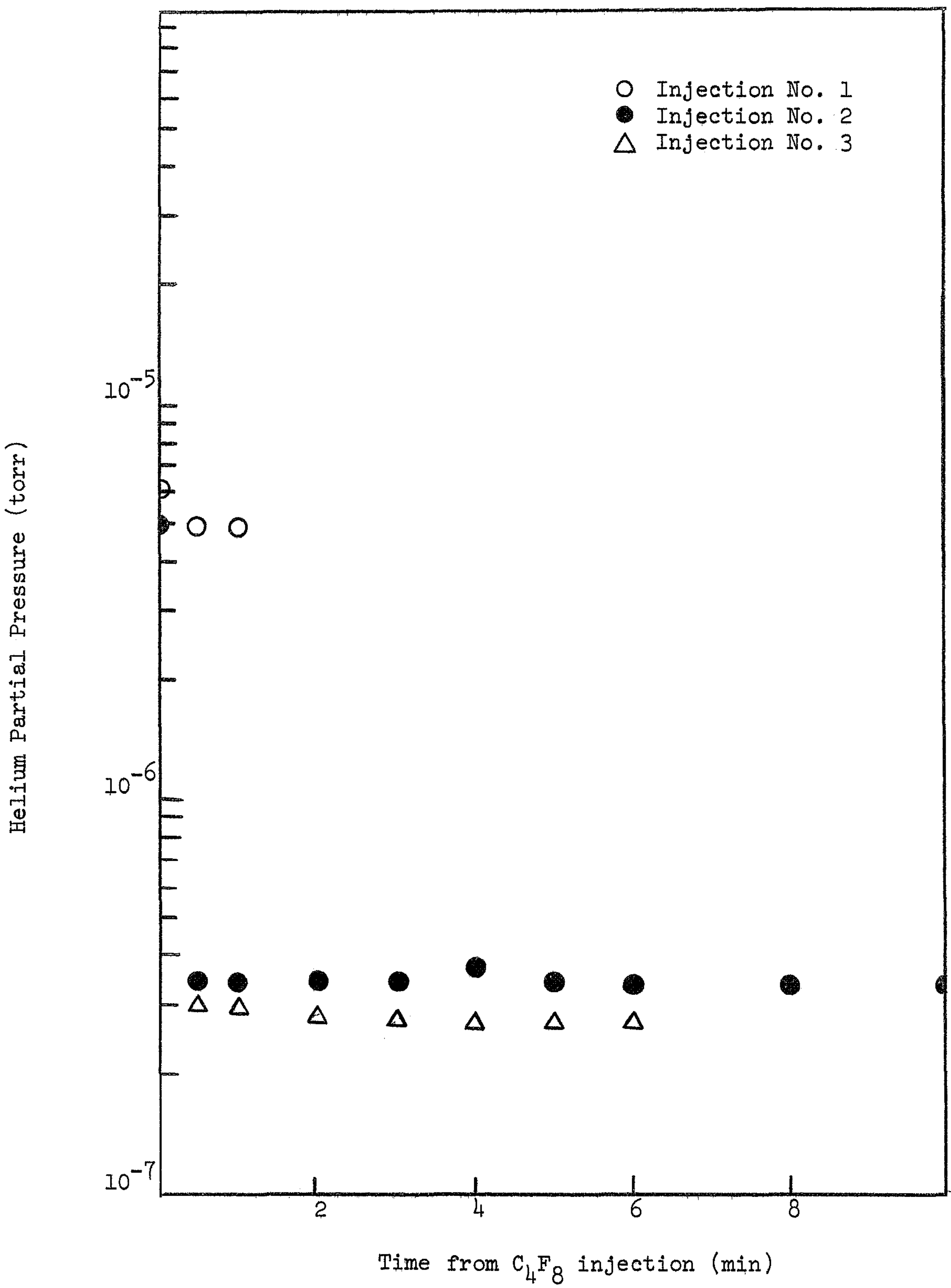

Figure 5. Helium pumping by C_4F_8 Injection