STRIPPING WITH A FOMBLIN SUPERSONIC JET AT 112.5 KEV/NUCLEON.*

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Abstract

The Fomblin oil vapor cell stripper, used for years in the Abel injection line at the SuperHILAC at LBL, has been replaced with a supersonic jet of Fomblin, leading to a system that uses less oil, is easier to maintain, and gives improved transmission in the stripping region.

Introduction

A project was initiated during the summer of 1987 to investigate possible replacement of the Fomblin vapor stripper in the Medium Energy Beam Transport line (MEBT) of the Abel injector. Ions produced in the source at low charge states and accelerated to 112.5 keV/nucleon in the Wideroe accelerator are then stripped to higher charge states for injection into the prestripper Alvarez tanks.

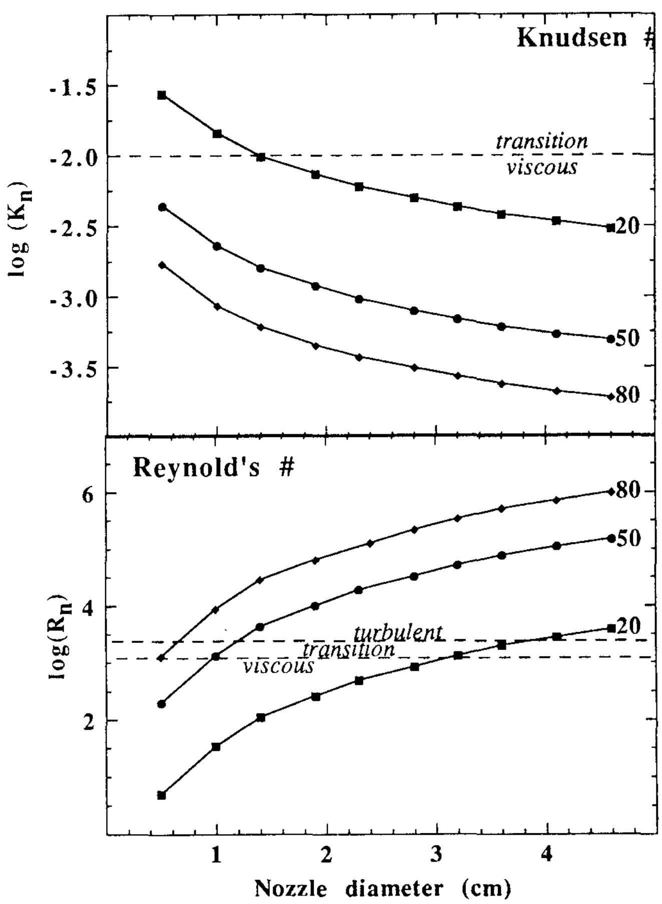

Figure 1. The calculated Knudsen number, K_n, and Reynold's number, R_n, as a function of nozzle diameter for three guesses for the diameter of the Fomblin molecule. The three regions of hydrodynamic flow are shown..

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The project goals were to i) improve the vacuum (transmission) in the stripping region of the injection line, ii) redesign the system to make it easier to maintain and use less oil, and iii) examine the physics of the stripping process for heavy ions in this energy regime in order to better predict equilibrium charge state distributions for beam tuning.

Background

Fomblin[1] diffusion pump oil has been used in the present vapor stripper system for several years. Fomblin 25/9 is a perfluoropolyether (PFPE) linear chain with an average molecular weight of 3400 amu. The vapor pressure has been measured up to 150°C. The molecule cracks into smaller pieces, including potentially noxious fluorine compounds, at a temperature of T ≥ 265°C. Because of the large size of the molecule, Fomblin shows some of the same density effects[2] in the stripping cross sections as a solid stripper, leading to equilibrium charge state distributions peaked at higher charges.[3]

In order to assess the feasibility of using a supersonic jet of Fomblin in this application, the assumption was made that for heavy ions below 100 MeV, charge state equilibrium is achieved at thicknesses of a few $\mu g/cm^2$.[2] Assuming effective thicknesses are needed of the order of 0.5-5.0 $\mu g/cm^2$, then in the stripping region, one needs 1-10 molecules/cm^2. For an ideal gas at 200°C, this corresponds to an effective length, P_L, of 4.3-43. mTorr-cm. This was our design criterion.

Calculations were done based on the standard equations for flow through an aperture.[4] Three regimes of flow can be identified: turbulent, viscous, and molecular. These regimes are characterized by two dimensionless parameters, the Knudsen number, K_n, the ratio of the mean free path of the molecule, λ, to the diameter of the nozzle, d, and the Reynold's number, R_n, the ratio of the driving forces to the dissipative force of viscosity, η, in transversing the nozzle, or:

$$K_n = \lambda/d \qquad \text{and} \qquad R_n = Urd/\eta,$$

where U is the stream velocity and r is the mass density. Ideally one would like to design a system in the viscous flow regime, where gas-wall collisions in the nozzle order the molecules in the forward direction, thus maximizing the pressure directly in front of the nozzle relative to the background pressure. The viscous regime is characterized by $K_n < 0.01$ and $R_n < 1200$.

The above equations assume an ideal gas of spherical molecules, rather than serpentine ones such as Fomblin. In addition, the vapor pressure must be extrapolated from lower temperature data.

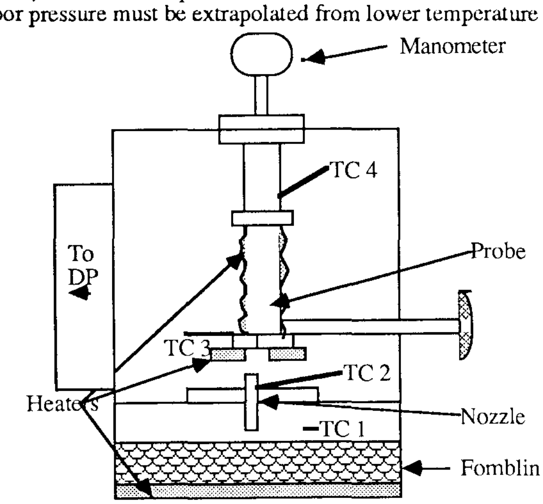

Figure 2. Setup used for Fomblin nozzle tests.

If, in spite of all these uncertainties, one assumes that the Fomblin molecule wraps itself into something relatively spherical with a diameter of ≈50± 30 Angstroms (estimated from the size of the elements in the chain), and extrapolates the vapor pressures, then one can calculate Kn and Rn.

The results are shown in Figures 1a) and 1b) as a function of nozzle diameter for three different guesses for the molecular diameter. One can see that there is only a narrow range of molecular diameter and vapor pressure for which the conditions for viscous flow are met. However, since one must assume broad distributions of molecular weights, molecular diameters, orientations, etc. of the molecules, leading to a broad distribution of mean free paths, it is likely that some molecules achieve ordered or partially ordered flow while passing through a nozzle. Thus, one cannot rule out the possibility of achieving viscous flow with a Fomblin nozzle, and experimental studies are in order.

Test Results

Measurements were performed on both the present vapor stripper and in a test chamber designed to test various nozzle configurations. The present Fomblin stripper consists of a "nozzle" similar to the throat of a diffusion pump, with a minimum dimension of 3.8 cm x 5 cm, situated 8.9 cm below the beam. Temperatures were measured by positioning thermocouple wires at various points in the oil, the nozzle, and other places in the system. The Fomblin in the present stripper is heated in an old diffusion pump with an internal coil heater. The temperature of the oil in this system was measured at several points in the oil at Variac settings typically used during normal operations. The heating of the oil with the internal heater was very definitely nonuniform, varying by as much as 90°C.

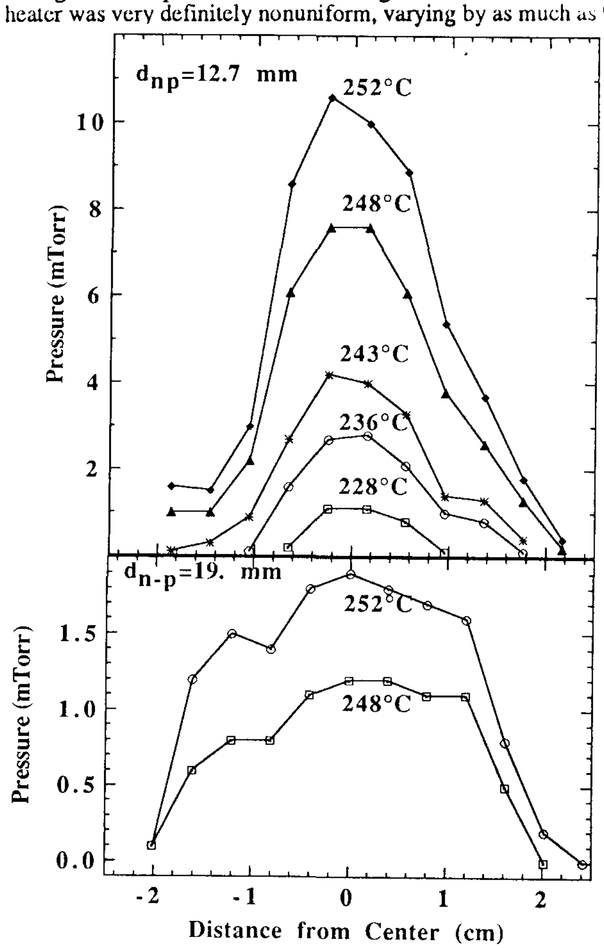

Figure 3. The pressure profile measured for a 4.76 mm (3/16") diameter nozzle at distances of a) 12.7 mm (1/2") and b) 19.0 mm (3/4") above the nozzle. For each distance, profiles are measured at several oil temperatures.

It had been observed that the Fomblin oil cracked over time, leaving a black, noxious compound; it remains to be determined, however, how much of this is due to interactions with the beam and how much to the local hot spots created by the nonuniform heating in the present system.

Pressure measurements were made with a 1-Torr absolute pressure capacitance manometer. This is one means of measuring pressure which is both sensitive in the 1-100 mTorr range and independent of the mass of the molecule being measured. The setup shown in Figure 2 was used to measure both the pressures obtained in the present system as well as the pressures obtained with a nozzle. The manometer was mounted on the top of the chamber in a stationary position. Attached to the nozzle was a probe consisting of a length of bellows material ending in a plate with a pinhole opening. The plate and the bellows were heated to approximately the same temperature as the nozzle. The probe could be moved across the nozzle by means of a shaft on a Wilson seal coming in from the side. The distance between the nozzle and the probe was varied by changing the length of the nozzle. This setup seemed to work well up to pressures of 75-100 mTorr, at which point the pinhole clogged.

The probe was tested to see if it was reading the actual pressure in the nozzle region by placing a second manometer in the test chamber external to the probe, and eliminating the cooling baffles and the pumping so that the whole test chamber was at one temperature and pressure. The two manometers read identically within their accuracy.

Charge states, q, were measured in the MEBT line using the present stripper setup with various nozzles, and analyzing the charge states using the M2 magnet. Other elements in the MEBT line were scaled to the current in M2 with no additional tuning.

P_L Measurements

When beam transverses the stripper, it generates light along the path. The intensity of this light seems to be qualitatively related to the density of the Fomblin. In observing the present stripper with beam, one sees a uniform path of light along the whole length of the stripper. This can be used as an estimate of the length of the stripping region, and with the assumption that the gradient of the pressure is zero along the path (except for end effects at the

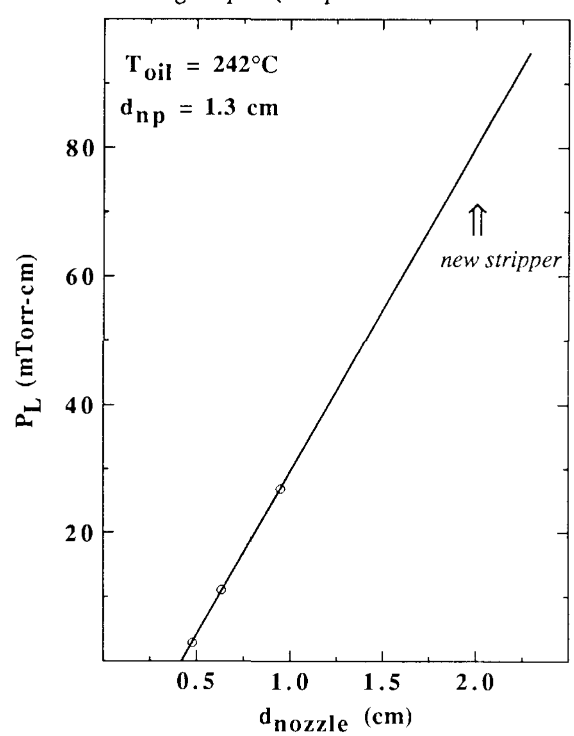

Figure 4. The integral of the pressure profiles as measured in Fig. 3. as a function of nozzle diameter for a fixed oil temperature of 242 °C and distance from the nozzle to the probe of 12.7 mm. The arrow denotes the length of the slit used in the final stripper design.

collimators), P_L can be calculated. Assuming a path length of 10 cm., the approximate length of the stripper region, and a measured pressure at beam height of 0.2 mTorr, a value of 2.0 mTorr-cm is obtained at the highest Fomblin temperatures (240-250 °C). This value of P_L is roughly half of the minimum criterion established by the calculations. Since equilibrium charge states have been observed in this system, it may well be that stripping is taking place over a much larger distance than 10 cm.

For the gas cell setup of Ref. 3, the system was small and the only cooling was at the ends of the cell. In this case, it was assumed that the whole cell was at the vapor pressure of the Fomblin, 1-10 mTorr for a temperature range of 170 - 190 deg C. This gives an effective length of 10-100 mTorr-cm., a factor of >5 higher than that of the present stripper.

In the chamber with the pressure probe, we could measure a profile of the jet at various heights above a nozzle and for various Fomblin temperatures. The profiles were sharply peaked above the nozzle. A sample of pressure profiles for a 4.76 mm diameter round nozzle is shown in Figure 3. Two things should be noted: 1) the pressure associated with the jet increases rapidly with increasing temperature of the Fomblin oil, and 2) the pressure drops off rapidly with height. Numerically integrating the profile gives a measure of P_L which can be compared to the calculated design criterion. In Figure 4, P_L is shown as a function of nozzle diameter (for the circular nozzles studied) at a distance 12.7 mm above the nozzle and a typical oil temperature. P_L increased linearly with the nozzle diameter. Extrapolating to the 1.9 cm slit (length along the beam) used in the final design, one estimates a value for P_L of approximately 70 mTorr-cm. for the nozzle being used in the redesigned vapor stripper. This is above the range of P_L calculated

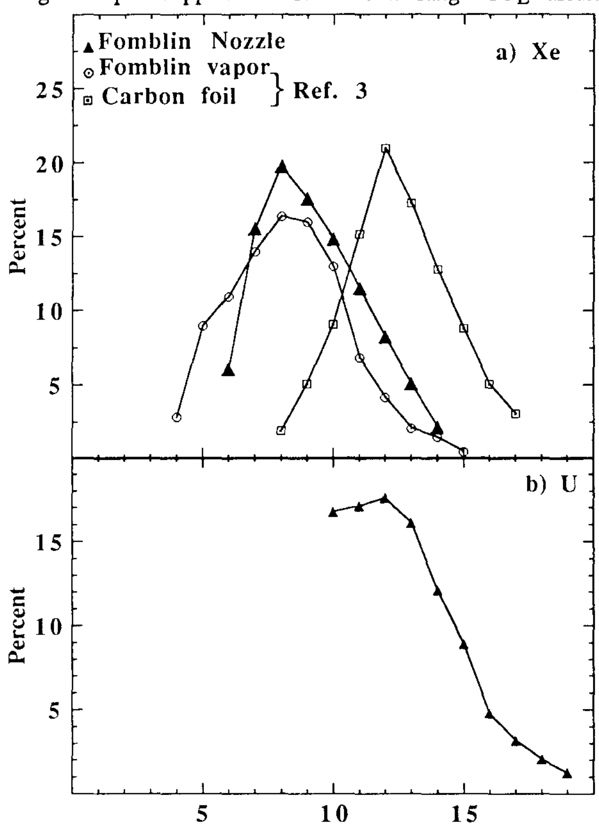

Figure 5. Measured charge state distributions using the final nozzle configuration, a 19.0 mm x 9.5 mm (3/4" x 3/8") slit 5 cm long. a) gives the charge state distribution measured for ^{131}Xe from the present work (▲), ^{136}Xe using Fomblin as a stripper (○) and ^{136}Xe using a solid carbon stripper (□) (from Ref.3) 5b) gives the measured charge state distribution for ^{238}U.

for best stripping, allowing for the possibility of errors in the calculation, or of running at a lower oil temperature or increasing the distance between the nozzle and the beam.

Charge State Distributions

Equilibrium charge state distributions were measured for several typical ions run out of the Abel injector ranging from Ar to U, for both the present stripper and with smaller supersonic nozzles fit over the present nozzle opening. Figures 5a) and 5b) show the measured charge state distribution for ^{131}Xe and ^{238}U for the final nozzle geometry chosen, a 9.0 mm x 9.5 mm slit 5 cm. long. Also shown in 5a) are results for ^{136}Xe from Ref. 3 using a gas cell of Fomblin as well as using a solid carbon foil. The average charge state, <q>, agrees within error to the results of Ref. 3. Raising the temperature (vapor pressure) of the oil has no effect on the average charge state obtained, verifying that we are indeed at equilibrium conditions.

Conclusions

Based on the measurements presented here, we have completely redesigned the Fomblin stripper in the Abel injection line, incorporating a supersonic nozzle into a much more compact system. The final schematic design is shown in Fig. 6. This design has been tested and is presently being installed. It has the features of being cleaner, more compact, uses less oil, and allows more even heating of the oil, giving less cracking.

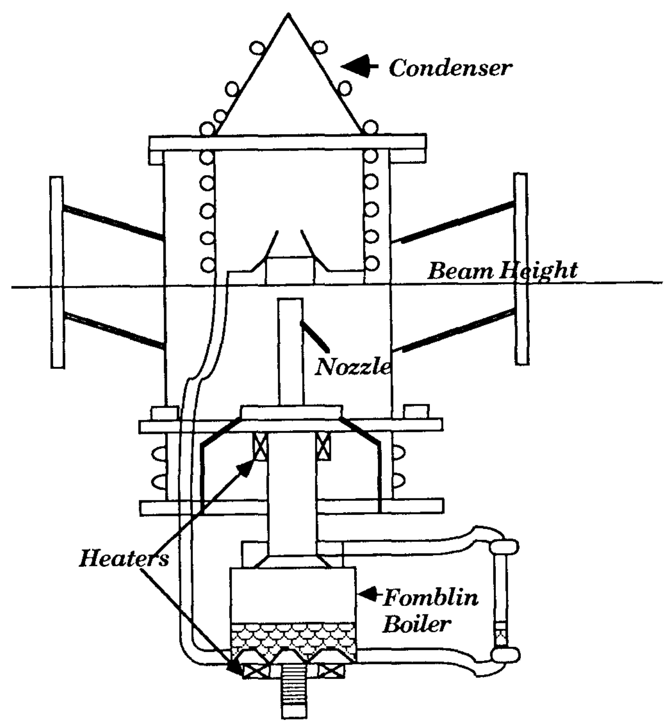

Figure 6. Schematic diagram of new stripper being installed in the MEBT line of the Abel injector at the SuperHILAC.

References

1) Montedison SpA, Italy
2) H.D. Betz, Rev. Mod. Phys. 44, 465(1972).
3) J.R. Alonso and B.T. Leeman, IEEE Transactions on Nuclear Science, 26, 3718(1979).
4) J.F. O'Hanlon, *A User's Guide to Vacuum Technology*, John Wiley and Sons, New York, (1980), pp. 20-22.