A TSTA compound cryopump[a)]

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The Tritium System Test Assembly (TSTA), at the Los Alamos Scientific Laboratory, is intended to demonstrate realistic fuel supply and cleanup scenarios for future fusion reactors. The vacuum pumps must be capable of handling large quantities of reactor exhaust gases consisting largely of mixtures of hydrogen and helium isotopes. Cryocondensing pumps will not pump helium at 4.2 K; while cryosorption pumps using molecular sieves or charcoal have good helium pumping speed, the adsorbent clogs with condensed hydrogen while pumping mixtures of both. A solution to this problem is a compound design whereby the first stage condenses the hydrogen species and the second, or sorption, stage pumps the helium. The TSTA pump designed at Lawrence Livermore National Laboratory uses argon gas to cryotrap the helium in the helium–hydrogen mixture. The argon is sprayed directly onto the 4.2 K surface at a rate proportional to the helium flow rate, permitting continuous pumping of the helium–hydrogen mixtures in a single-stage pump. However, the possibility of differential desorption as a first stage in the TSTA gas separation cycle required the inclusion of a first-state hydrogen isotope condenser. The design, performance, and operating characteristics are discussed.

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I. INTRODUCTION

The current generation of magnetic fusion experiments and future fusion reactors will require pumping systems capable of very large through-puts of gas mixtures consisting largely of deuterium, tritium, and helium at pressures ranging from 10^{-4} down to 10^{-8} Torr (1.3×10^{-2}–1.3×10^{-6}Pa). The deuterium through-put of the Mirror Fusion Test Facility[1] at Livermore can be as high as 2200 Torr l/s and require a pumping speed of tens of millions of l/s. Deuterium-tritium (D-T) burners, such as the proposed Experimental Test Facility Tokamak,[2] will have gas loads of the same order with the additional burden of pumping the reaction product, helium. However, the pulsed nature of Tokamaks and the possibility of pumping the diverters at relatively high pressure (3–5×10^{-3} Torr) reduces the total pumping speed requirements to several hundred thousand l/s. The 750 MW_t produced by ETF will generate a helium gas load of 9 Torr l/s. It is clear that large cryogenic pumping systems capable of continuously pumping large quantities (~1 mol/s) of hydrogen isotopes and helium mixtures will be required for steady-state fusion reactors.

An initial step in developing and qualifying all the principal hardware for fuel processing in D-T burning reactors will be the Tritium System Test Assembly (TSTA)[3] under construction at the Los Alamos Scientific Laboratory (LASL). The TSTA high-vacuum pumps were required to meet the following specifications:

(i) Pump mixtures of D-T, helium, and plasma impurities.

(ii) Produce base pressures of 10^{-8} Torr or less.

(iii) Be unaffected by pulsed gas loads that produce brief pressure excursions of 10^{-3} Torr.

(iv) Be restricted to a 40 cm diam flange opening, and provide the following pumping speeds and capacities:

Deuterium—16,000 l/s − 2 mol

Helium—1500–5000 l/s − 0.2 mol

80% D + 20% He (no diminution in the pumping speed of either gas).

(v) Allow for differential desorption of the helium separate from the D-T, and be demountable and easily maintained.

Three pumps were authorized for construction and test on the TSTA. The first was designed by LASL and used molecular sieve as the helium adsorbent; the second was designed by Brookhaven National Laboratory (BNL) and used charcoal adsorbent; the third (the subject of this paper) was designed at the Lawrence Livermore National Laboratory and used condensed argon as the helium adsorbent.

II. DESIGN

The decision to use condensed argon for the adsorbent in the LLNL design was made for two reasons: (i) we had done considerable developmental work with continuous-flow argon cryotrapping, including the Helium Neutral Beam Direct Conversion Cryopump,[4] and (ii) we were concerned with the helium-pumping difficulties experienced by Walthers[3] and Watson[4] when using molecular sieves, i.e., cryocondensed hydrogen blockage of the sieve and the diffusion-rate limitation.

A compound design is not necessary for pumping hydrogen isotopes and helium mixtures with the argon adsorber as it is for the molecular sieve or charcoal, the pores of which are subject to blocking by the cryocondensed hydrogen. However, to meet the differential desorption requirement, it was necessary to have two pumping stages in series, which resulted in a compound design. The first stage would pump the D-T gas; the second stage, the helium.

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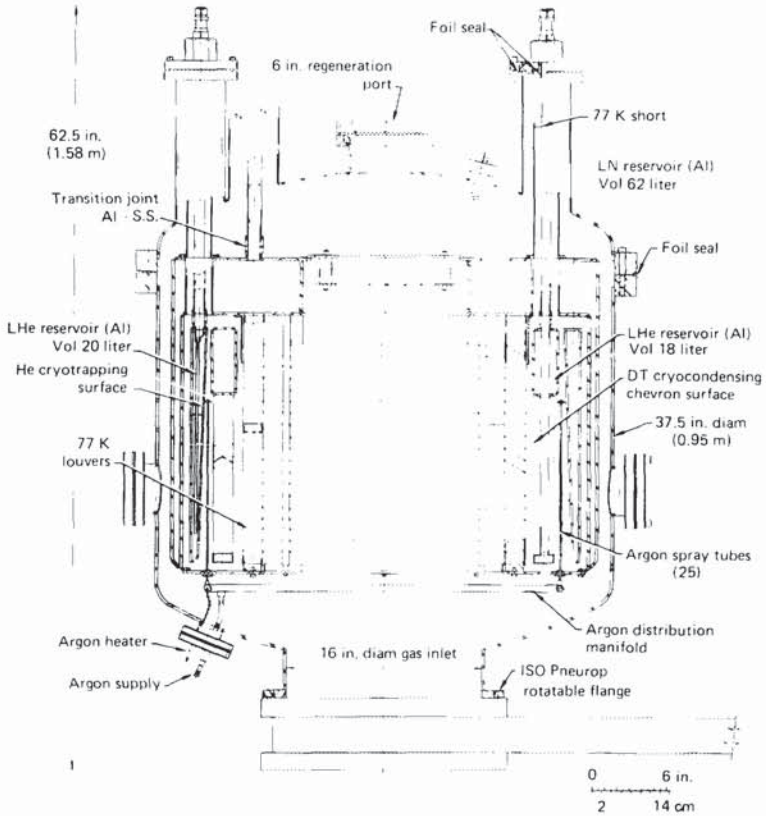

FIG. 1. General arrangement of the TSTA compound cryopump.

The general arrangement of the LLNL TSTA pump is shown in Fig. 1. The outer, stainless steel vacuum vessel is cylindrical and has a volume of 490 l. The pump must be installed vertically with a 40 cm inlet on the bottom. All vacuum flanges are metal sealed. There are three cryogen reservoirs in the interior, one for liquid nitrogen and two for liquid helium.

The LN_2 reservoir assembly, shown partially in Fig. 2, has a volume of 60 l and provides the thermal-radiation shielding for the LHe reservoirs. The gas inlet side has conduction-cooled louvers, arranged in an octagonal pattern. The annular opening through which the LHe reservoirs are inserted is closed with a bolted-on plate. The gas desorption baffle is mounted on top of the LN_2 reservoir and, through holes (tubes), allows the six LHe fill-and-support tubes to penetrate the reservoir.

The inner LHe-cooled reservoir (Fig. 3) has a volume of 18 l and is connected by two diametrically opposed tubes to a lower rectangular tube. Arranged vertically and welded to the top reservoir and the bottom tube ring is the 120° chevron assembly that forms the first-stage D-T condensing panel.

The outer LHe reservoir (Fig. 4) has a volume of 20 l; its inner surface provides the second-stage helium cryotrap. In the annulus between the two LHe reservoirs, 25 spray tubes are positioned with their 350 0.004 in.-diam exit holes, preferentially oriented to coat the inside surface of the outside LHe reservoir with argon.

Figure 5 shows the argon distribution manifold assembly, which is a 1 in. diam copper tube formed into a ring, onto which 25 $^3/_{16}$-in.-diam copper tubes are fastened with flare fittings. The tubes penetrate the LN_2 cooled radiation-shield closure plate; the manifold is mechanically supported and thermally tied to the same plate. Temperature control of the argon gas is accomplished with a nichrome-heater wire within the manifold. A stainless steel tube with a metal-sealing fitting brazed into the copper manifold is the argon inlet. A ring of thin, stainless steel sheet is fastened to the tops of the spray tubes to stabilize them mechanically and to reduce argon gas scatter.

The cryogenic subassembly is shown in Fig. 6. All three reservoirs are fabricated from 5052 aluminum while the louver and chevron subassemblies are dip-brazed 6061 aluminum. Each of the three reservoirs is suspended by three 1-in.-diam, 0.02 in. wall, stainless fill and vent tubes, connected by aluminum to stainless transitions. Both LHe reservoirs fill from the bottom to expedite cooldown time. All six of the LHe-fill vent tubes are thermally shorted by 12-in.-long copper cylinder halves to the top of the LN_2 reservoir. The thermal shorts minimize conductive heat leak to the LHe reservoirs from the room temperature vacuum seals and serve

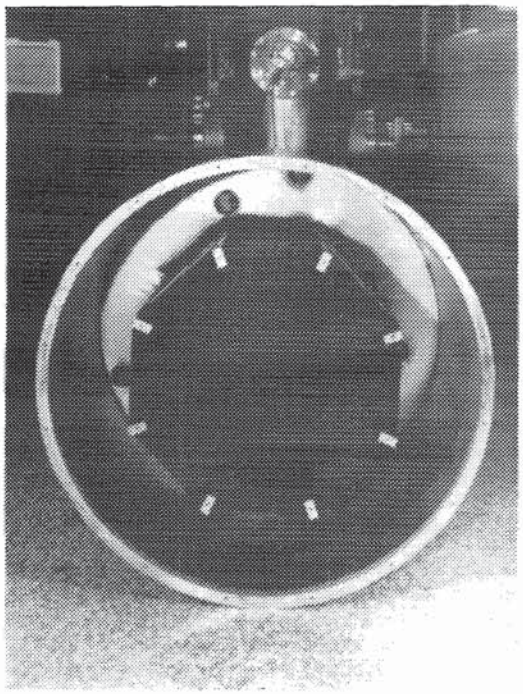

FIG. 2. Liquid nitrogen reservoir assembly.

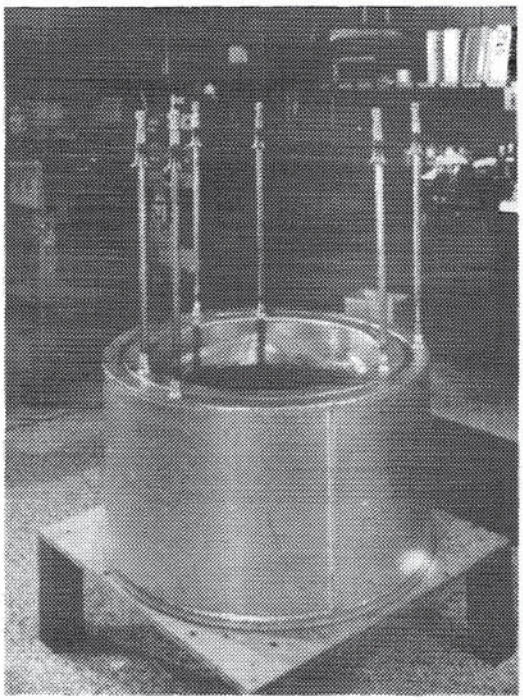

FIG. 4. Outer liquid helium reservoir.

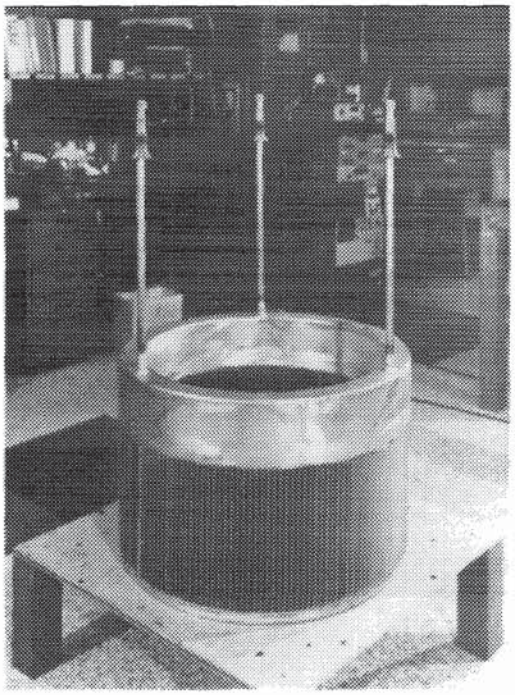

FIG. 3. Inner liquid helium reservoir and D–T condensing chevron assembly.

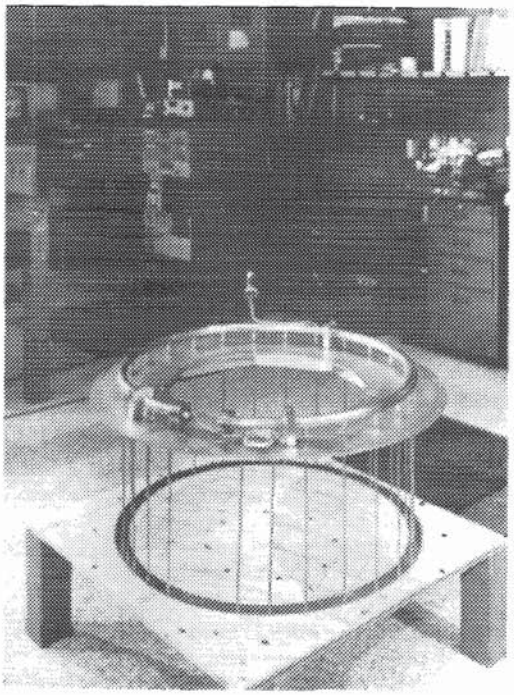

FIG. 5. Argon distribution manifold assembly.

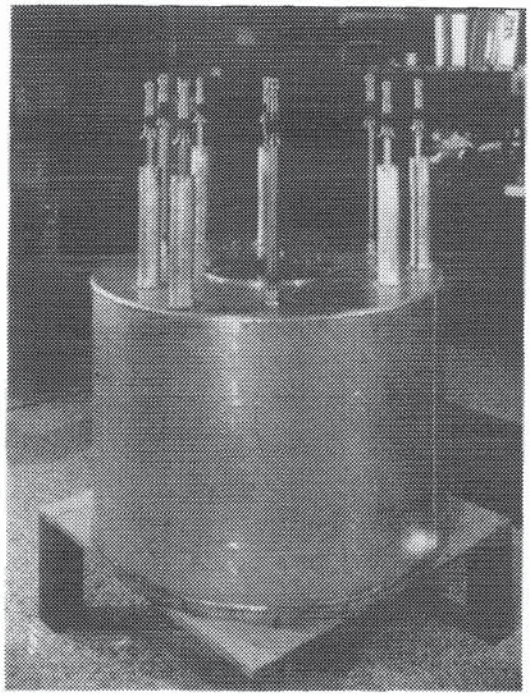

FIG. 6. Cryogenic subassembly.

to stabilize the structure mechanically. Each of the three cryogen reservoirs are fitted with three temperature sensing diodes (top, bottom, and middle) to monitor operating temperature. One diode, to monitor argon temperature, is located midway on an argon spray tube.

The pump was sized to meet the pumping requirements in the following way:

(i) The length of the fixed-entrance opening (40 cm diam), including the valve, was selected to maximize the conductance to the louver array and allow for fastenings and clearance for the cryogenic surfaces.

(ii) For a theoretical louver transmissivity of 0.35 and a deuterium sticking probability of 1.0 (on the 4.2 K chevron surface), the cylindrical louver area was sized (with a length-to-diameter ratio of ~1) to yield a conductance which, in series with the entrance conductance, would meet the deuterium pumping speed requirement.

(iii) For a measured transmissivity of 0.23 to the 120° chevron array and a measured sticking probability of 0.1 for helium on the 4.2 K argon frost, the helium pumping speed was determined to exceed the requirements.[4]

For these assumptions and procedures, the following pumping speeds were computed with an entrance length of 30 cm and a louver panel area of 6000 cm^2:

Deuterium:	Pump entrance speed	S_P = 17 000 l/s
	Louver panel speed	S_L = 65 000 l/s
Helium:	Pump entrance speed	S_P = 8300 l/s
	Louver panel speed	S_L = 13 000 l/s

These values were then checked with a Monte Carlo code, using the same sticking probabilities. Referred to the entrance area of 40 cm in diameter, the capture coefficients were 20% for helium and 40% for deuterium, which corroborate the hand calculation.

III. TEST ASSEMBLY AND INSTRUMENTATION

Figure 7 shows the pump assembled on the test stand in operating condition. The vacuum instrumentation includes three nude ionization gages, one mass spectrometer, and a capacitance manometer. Two of the ionization gages monitor the pressure in the test vessel; the third is placed at the top of the pump vessel. The mass spectrometer monitors the test vessel, while the capacitance manometer measures the pressure in the argon manifold. Gas flow is measured by three calibrated flow meters with ranges of 0–50, 0–1000, and 0–5000 atm cm^3/min^{-1}. The cryogenic instrumentation includes the previously mentioned temperature sensors and three cryogen liquid-level indicators.

IV. OPERATING PROCEDURES

There are only two features that distinguish the TSTA pump from a conventional cryopump: (i) two separate liquid-helium reservoirs, and (ii) the continuous argon-gas-bleed feature. The double helium reservoirs require a modified cooldown procedure, and the argon system requires proper sequential and flow-rate procedures.

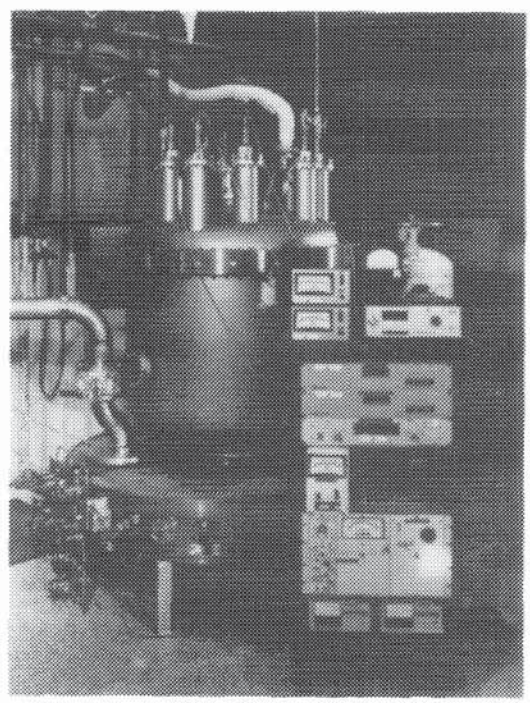

FIG. 7. Pump and test stand assembly.

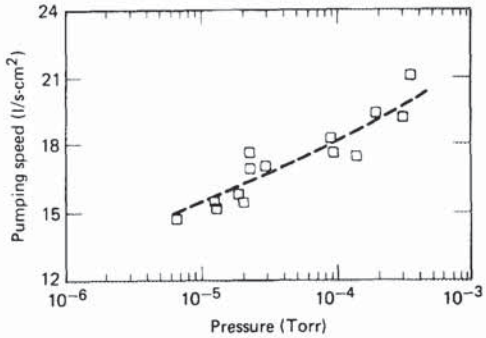

FIG. 8. TSTA compound cryopump performance, showing least-squares fit to log (data) of pump specific speed vs tank pressure for deuterium.

To minimize cooldown time, the two LHe reservoirs must be cooled simultaneously after the LN_2 reservoir is filled. If only one supply Dewar and transfer line is available (our case), the two reservoirs must be cross-connected during cooldown to force the cold helium gas through both. When about 100 K is reached in the downstream reservoir, they can then be filled separately in the usual way. From room temperature to all reservoirs full takes about three hours by this means.

When helium gas is to be pumped, the argon gas flow must be initiated first at a rate of 20 to 30 times (atoms/atom) the anticipated flow rate of the helium. Before argon flow is initiated, the manifold temperature should equilibriate at about 120 ±10 K to prevent argon liquifaction and minimize the heat load to the LHe-cooled panel. This requires about 30 W to the manifold heater.

V. PERFORMANCE

Pumping speeds were calculated from measurements of pressure in the test tank and the pump vessel and of the gas feed rate into the test tank. The test-tank pressure gave overall pump speed, and the pump-vessel pressure gave louver-panel pumping speed. The indicated gage pressures were corrected by a factor of 2.5 for deuterium and 7 for helium. The mass spectrometer was set to monitor the argon peak in the test vessel during helium speed runs.

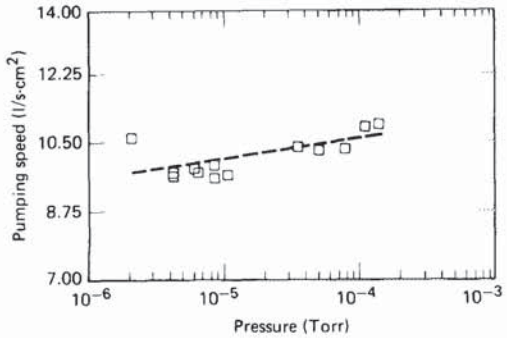

FIG. 9. TSTA cryopump performance, showing least-squares fit to log (data) of louver specific speed vs pump pressure for deuterium.

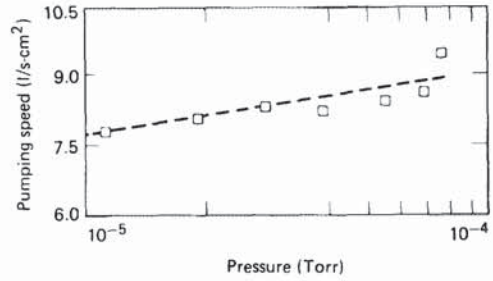

FIG. 10. TSTA cryopump performance, showing least-squares fit to log (data) of pump specific speed vs tank pressure for helium.

A. Deuterium

The measured pumping speeds for deuterium were:

$\bar{S}_P$ (Pump entrance speed) = 22 600 l/s or 17.5 l s^{-1} cm^2,

$\bar{S}_L$ (Louver panel speed) = 65 300 l/s or 10.2 l s^{-1} cm^2.

The flow ranged from a tenth to ten Torr l/s. Figures 8 and 9 show the specific speed vs pressure in terms of the 1.26×10^3 cm^2 pump entrance area and the 6.4×10^3 cm^2 projected louver area, respectively. From the averaged data for specific pumping speeds, the capture coefficient for deuterium is 33% for the louver array and 56% for the pump.

B. Helium

Throughout the helium speed measurements, the argon to helium flow ratio was maintained from 28 to 30–1. Prior to each increase or decrease in helium flow rate, the argon flow would be established at the proper anticipated rate. Pressure equilibrium after a helium flow rate change is established in a matter of several seconds. The measured pumping speeds for helium were:

$\bar{S}_P$ (Pump entrance speed) = 11 200 l/s or 8.77 l/s cm^2,

$\bar{S}_L$ (Louver panel speed) = 18 500 l/s or 2.89 l/s cm^2.

The flow ranged from a tenth to one Torr l/s. The specific pumping speed vs pressure for the pump entrance area and the louver area is shown in Figs. 10 and 11. The resulting capture coefficients are 9.3% for the louver array and 28% for the pump. For the capture coefficient for the louver array of

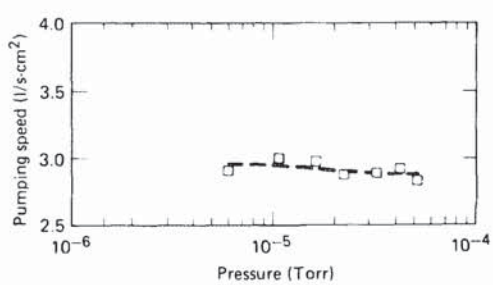

FIG. 11. TSTA cryopump performance, showing least-squares fit to log (data) of louver specific speed vs pump pressure for helium.

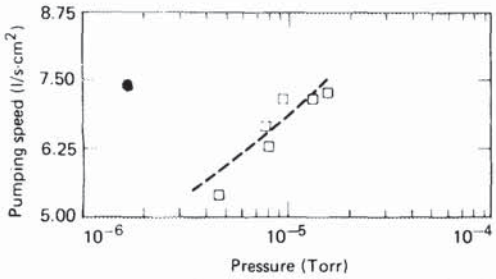

FIG. 12. TSTA cryopump performance, showing least-squares fit to log (data) of louver specific speed vs pump pressure for mixture of deuterium and helium.

9.3% and the calculated transmissivity of the louver-chevron series, the helium sticking probability on the 4.2 K argon surface is 18%. The argon flow rate ranged as high as 30 Torr l/s with no indication on the mass spectrometer above the initial background.

C. 80% Deuterium, 20% Helium Mixture

The gases were pressure mixed in a bottle, the flow rate and ionization gage pressure corrections were prorated accordingly, and the argon flow rate was adjusted to correspond to the partial helium flow. In the speed measurements, no attempt was made to estimate gas mixture concentration in the pump body in terms of the previous, independently measured speeds; for the 80–20 D–He mixture, speeds for the assumed corrections of the indicated pressures and flows were:

$\bar{S}_P$ (Pump entrance speed) = 15 550 l/s or 12.4 l/s cm^2,

$\bar{S}_L$ (Louver panel speed) = 42 500 l/s or 6.7 l/s cm^2.

Figure 12 shows the specific speed (for the louver area) vs pump pressure for the mixture.

VI. CONCLUSIONS

The preliminary test on the LLNL designed TSTA pump indicated that it adequately meets the pumping speed requirements for deuterium, helium, and mixtures of both. The base pressure could not be checked, because we had no isolation valve to separate the pump from the many O-ringed test tanks, even though the base and recovery pressure in the pump was $1\text{–}2 \times 10^{-8}$ Torr with a corresponding pressure in the test tank of $1\text{–}2 \times 10^{-7}$ Torr. Furthermore, comprehensive testing will be carried out at LASL to qualify the pump for TSTA use.

[a]Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

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