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MOLECULAR AND RADIATION TRANSMISSIVITIES OF CHEVRON TYPE BAFFLES FOR CRYOPUMPING

by

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Abstract

The function of a cold baffle in a cryopump is to protect its condensing surface from room temperature radiation, not only in order to decrease the cooling power consumption, but also to achieve H_2 saturation pressures lower than 10^{-9} torr. The introduction of the baffle, however, decreases the pumping speed, and therefore its design has to be optimised with respect to both molecular and radiation transparencies. We have studied the transmission probabilities for molecules and photons, assuming diffuse and specular reflection respectively, as a function of the geometry and surface reflectivity of chevron type baffles, using the Monte Carlo method. The calculated figures are in good agreement with our experimental results. Using a black paint which provides a reflectivity of ~ 0.10 we have achieved, for example, a molecular transmissivity of about 0.24 together with a radiation transmissivity of $\sim 7 \times 10^{-4}$.

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1. Introduction

Cold baffles are almost universally used to protect the cold surface of a cryopump from room temperature radiation; their presence is usually justified by an important saving of cooling power and therefore of running cost. The design and the operating temperature of such baffles depend on the temperature of the cryosurface; when the latter is lower than about 20 K the baffles are usually cooled to about 80 K, often by means of liquid N_2 at atmospheric pressure. In this particular case the intensity of the radiation emitted by the cooled baffle is 200 times lower than that of corresponding 300 K radiation, and therefore it is worth trying to obtain a radiation transmissivity lower than 10^{-2}.

Furthermore, the H_2 saturation pressure at 2.3 K was recently found[1)2)3)] to depend strongly on the intensity and spectral distribution of the thermal radiation reaching the cryosurface; for a silver-plated cryosurface, which is the best amongst the surfaces we have tested so far, the effect of the radiation produced by a baffle at 77 K is about 1000 times lower than the effect of the corresponding 300 K radiation. In the case of cryopumping by condensation at pressures below 10^{-12} torr (as in our particular application) radiation transmissivities lower than 10^{-3} would therefore be desirable. In practice a radiation transmissivity lower than any desired value can very easily be obtained by simply increasing the number of the baffles of the available type which protect the cryosurface; however, the increased optical efficiency will be accompanied by a decrease of pumping speed. The choice we made[2)] before obtaining the results reported here exemplifies this situation. Our best baffle (of chevron type out of anodised aluminium) was characterised by a 300 K radiation transmissivity of 4×10^{-3}, and a corresponding H_2 saturation vapour pressure of about 6×10^{-12} torr, which was too high for the particular application. We were therefore obliged to protect the cryosurface with two such baffles with the result that the optical efficiency was then excessively good while reducing the pumping speed by a further factor of two (5 instead of 10 litres sec^{-1} per cm^2 of cryosurface for H_2). From this example the two goals of our following investigation clearly appear : on the one hand, materials presenting very high emissivities at 300 K were sought in order to reduce the radiation transmissivity of our baffle possibly by an order of magnitude without decreasing the pumping speed; on the other hand to find the optimum geometrical compromise between molecular and radiation transmissivities for any particular application. This latter goal implies the possibility of varying in a continuous manner the two transmissivities in order to avoid the situation described in the example given above.

Our investigation has been carried out experimentally and theoretically; the chosen baffle, shown in Figure 1 with its characterising parameters, was of the chevron type. This choice is due to the encouraging results already achieved and to the attractive possibility of obtaining the required continuity by simply varying the overlap of two adjacent chevrons (p in Figure 1).

2. The experimental procedures

Both the molecular and the radiation transmissivities have been obtained experimentally in an indirect manner by means of the model E cryopump already described[3].

a) molecular transmissivity

The physical quantity actually measurable on our experimental apparatus is the pumping speed S of the cryopump on which the baffle to be studied is mounted (bolted to the bottom flange of the liquid N_2 container). The measured pumping speed is then assumed to be correlated to the conductance C of the baffle and to the pumping S_c of the cryosurface by the equation*

$$\frac{I}{S} = \frac{I}{C} + \frac{I}{S_c} \qquad (1)$$

* the gas used is H_2 in order to avoid pumping effects on the cold baffle.

Subsequently, S_c is obtained by measuring the pumping speed of the cryopump in absence of baffle, taking into account that this value is slightly lower than that contained in equation (1) because in this latter case the temperature of the H_2 molecules is 300 K, whilst it is 80 K in presence of the baffle. The measured value is therefore multiplied by the ratio of the sticking probabilities at 80 and 300 K (~ 1.2) before being inserted in equation (1). The transmissivity is then by definition the ratio of the value of C obtained from equation (1) and of the calculated conductance of a surface of the same area.

(b) radiation transmissivity

In order to obtain experimentally this quantity we have profited by the observation[1)2)3)] that the saturation H_2 pressure (at 2.3 K) induced by 300 K radiation is proportional to the intensity of the radiation reaching the cryosurface. When a baffle protects the cryosurface the H_2 saturation pressure is a function of the amount of 300 K radiation filtering through the baffle and of the radiation emitted by the cold baffle. The latter contribution can be obtained by measuring the H_2 saturation pressure in a situation where the effect of the room temperature radiation is negligible and, by subtraction, the effect of the 300 K radiation can be estimated. For a given baffle the radiation transmissivity is then the ratio of this corrected H_2 pressure to the pressure measured in absence of a baffle. Since the equilibrium pressure of H_2 condensed at 2.3 K on a silver plated surface fully exposed to room temperature walls is about 10^{-9} torr and we can measure on our experimental apparatus H_2 saturation pressures as low as 10^{-13} torr, the method described permits us to estimate radiation transmissivities as low as 10^{-4}. If necessary, a sensitivity higher by an order of magnitude could be obtained by replacing the silver on the cryosurface by a material yielding higher H_2 pressures under the same radiation load (for instance Be, MgF_2).

3. Theoretical estimations

The transmissivities of baffles of various geometries have been calculated by means of the Monte Carlo program already described[4)5)]. The basic assumptions are that the molecules and the photons are reflected diffusely and specularly respectively and that the sheets which constitute the chevrons have zero thickness. In order to obtain a complete picture of the characteristics of this type of baffle all its parameters have been varied in a quasi-continuous manner and the transmissivities for molecules (T_m) and photons (T_p) calculated for each set of parameters. We have then selected the most meaningful plots and presented them here. The parameters of a chevron baffle are (see Figure 1) : the ratio d/h where d is the radius and h the height of the baffle; the chevron's angle α; the overlap p of the orthogonal projections of two adjacent chevrons in the plane of the baffle (we have normalised p to the distance between two adjacent, non-overlapping chevrons of the angle under consideration, and therefore p can vary between zero and one); and finally for photons only, the reflectivity R of the chevron's surfaces. Figure 2 shows the variations of T_m (upper plot) and T_p (lower plot) when varying d/h. In order to avoid confusion we have only plotted the results corresponding to angles of 120^o and 90^o and three different reflectivities. The justification for the choice of the angles will appear from Figure 4; the reflectivities cover in reasonable intervals the range of our practical interest. All these curves have been obtained by putting p=0, which, as far as we know, is the only case already studied[6)] only for molecules. The agreement between our results and that quoted in the reference 6 is very good. The dotted line in Figure 2 shows the d/h value corresponding to the size of the baffles we have used for the present investigation (d = 13.6 cm, h = 4 cm).

The dependence of T_m and T_p on p is shown in Figure 3 (upper and lower part respectively). Note that the curvatures relative to molecules and photons is downwards in the first and upwards in the second case, respectively, thus making the low p region particularly attractive. Very little can be gained optically when increasing p above 0.2, whilst T_m decreases very rapidly. Note also that the required T_p value (lower than 10^{-3})

could be obtained for reasonably low p if reflectivities below 0.15 are available. Since this appears to be the case (we have now at our disposal a special black paint with R = 0.1) and since p = 0 introduces the danger of anomalously high radiation transmission due to small deformations of the copper sheets constituting the chevrons, we have chosen for our application p = 0.1.

The only parameters left are therefore α and R, the latter being for photons only. Figure 4 shows the dependence of T_m (upper plot) and T_p (lower plot) on these parameters. The relatively narrow maximum presented by T_m around $\alpha = 120^o$ justifies the choice of the values made in Figure 2. On the contrary, T_p, for a given R, is practically independent of α. Ultimately, we should be able to obtain $T_m = 0.24$ and $T_p = 7 \times 10^{-4}$ for the set of parameters characterising our chevron (d = 13.6, h = 4, p = 0.1, $\alpha = 120^o$, R = 0.1).

4. Comparison with the experimental results

We have measured T_m only for the set of parameters considered in Figure 4 and for $\alpha = 90^o$ and 120^o. The experimental values (squares in Figure 4) agree with the theoretical estimations within our measuring accuracy. In terms of pumping speed (for H_2) we have obtained 8.8 ± 0.5 litres sec^{-1} per cm^2 of cryosurface for $\alpha = 120^oC$. This value is slightly lower than the figures already published[2)3)] because of the small dimensions of the cryopump used (figure 2 shows that we are below the T_m plateau with the present d/h choice) and because of the higher overlap.

In order to compare the calculated T_p values with the experimental results the reflectivities of the materials used must be known. We are not equipped for this kind of measurement but we were given invaluable assistance at CNES (Toulouse), where the reflectivities were measured for us. We first selected a few materials compatible with UHV and characterised by a high emissivity value in the infrared range (according to the literature) and then prepared samples which were subsequently sent to Toulouse. The average emissivity at room temperature was obtained by fixing the samples to a holder immersed, under high vacuum, in a cavity at 77 K and then measuring the electric power which must be dissipated in the holder in order to keep its temperature constant (293 K in our case). The quoted accuracy of these measurements is ± 0.02. A chevron baffle was then prepared for each of the four best materials, i.e. glass (on copper), Al_2O_3 (on aluminium), teflon (on copper) and a black paint specially developed under CNES contract (on copper). The comparison of the T_p values obtained experimentally (squares) and calculated (dots) is given in Figure 5 where T_p is plotted as a function of R for the indicated set of parameters and for a variable number N of baffles (for the meaning of fractional N see Figure 1). The sources of error arise from the T_p and R measurements (vertical and horizontal error bars on the experimental points in Figure 5) and from the mechanical realisation of the baffle, the latter resulting in some uncertainty in the knowledge of p. This uncertainty is represented in Figure 5 by the double curve ($p = 0.1$ and $p = 0.05$) corresponding to a value of $N = 1$. As the figure shows, the black paint provides the expected T_p ($7 \pm 2 \times 10^{-4}$) and therefore represents a good solution to our particular problem. Furthermore, this paint is also the best from the vacuum point of view; it is bakeable at 450°C (teflon only at 200°C; anodised aluminium becomes soft above 200°C and the sheets tend to bend) and does not introduce any noticeable degassing during or after bakeout (the glass coating we have tested contains occlusions of air which is liberated during the cooling to 77 K; anodised aluminium is a practically infinite source of water vapour during the bakeout because the baking temperature is too low to ensure a quick water desorption).

5. Conclusions

Both the goals of our investigation have been reached: we have now at our disposal a chevron baffle characterised by a T_m of about 0.24 and T_p of about 7×10^{-4}. Further, if lower T_p values are required, we are able to choose the best T_m-T_p compromise by manipulating p and N. Assume, for example, that the baffle is cooled to 50 K instead of 77 K in order to reduce both the liquid He consumption and the H_2 saturation pressure of our pumps. The intensity of the radiation emitted by the baffle and its effects on both these quantities would be thus reduced by approximately a factor of six according to the Stefan-Boltzmann law. A similar reduction of T_p could therefore be desirable to maintain proportionally constant the effects of the 300 K radiation. The required T_p would then become $1 - 2 \times 10^{-4}$. From Figure 5 it appears that $T_p = 10^{-4}$ can be achieved by means of one and half baffles of chevron type presenting the characteristics indicated thereon along with an R = 0.1. The measured T_m is then 0.12 ± 0.01. Alternatively (see Figure 3) $T_p = 2 \times 10^{-4}$ together with $T_m = 0.2$ could be provided by a baffle presenting $\alpha = 120^o$, p = 0.2 and R = 0.1.

6. Acknowledgements

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7. References

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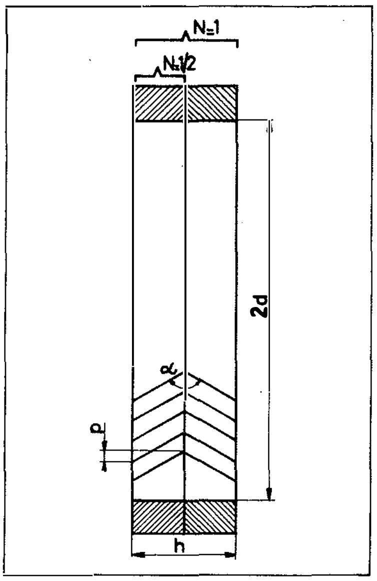


Fig.1 The chevron baffle and its parameters

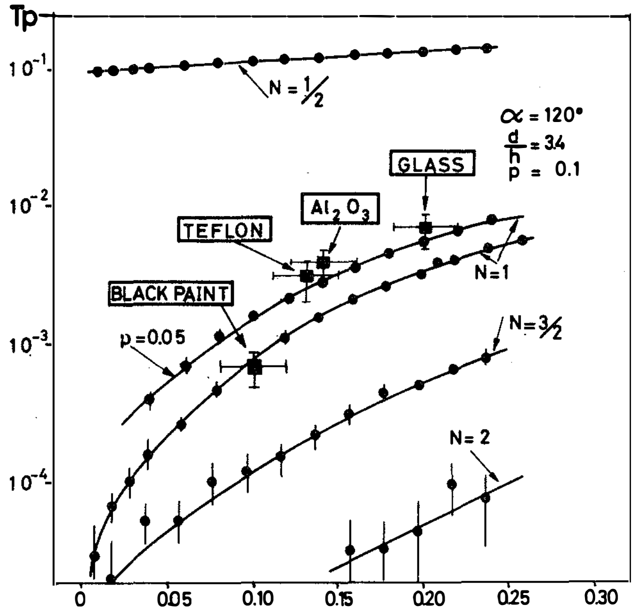
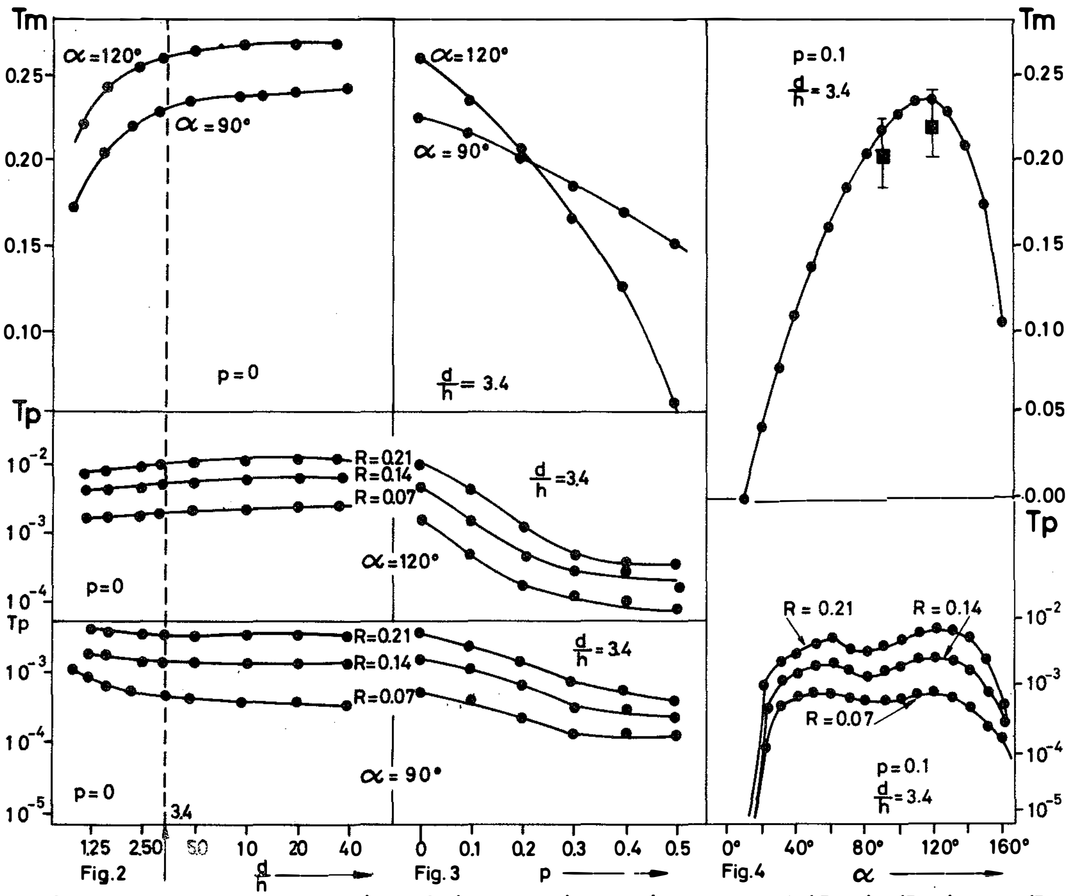


Fig.5 Tp as a function of R for the chosen set of parameters. The squares represent the experimental values. The double curve (p=0.05 and p=0.1) for N=1 indicate the uncertainty due to the mechanical realisation.



The variation of Tm (upper plots) and Tp (lower plots) as a function of d/h (Fig.2), p (Fig 3), and α (Fig 4). The dots represent the calculated values, the squares the experimental results.