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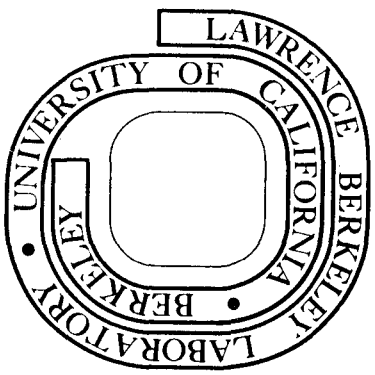

DISCLAIMER

Thermal Accommodation Coefficients of Inert Gases on Stainless Steel and UO_2

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One of the most uncertain aspects of the determination of the temperature distribution in oxide fuel pins is the conductance of the fuel-cladding gap. The gap conductance is generally taken to be the sum of heat transfer by conduction via contact points between the two rough solids and by conduction through the gas in the remainder of the gap. The latter term is given by:

$$h_{gas} = \frac{k_g}{\delta + g_c + g_f} \qquad (1)$$

where k_g is the thermal conductivity of the gas and δ is the thickness of the gas film (in the case of a closed gap, δ is proportional to the sum of the mean roughness heights of the fuel and cladding). The quantities g_c and g_f are "temperature jump distances" which account for the discontinuity in temperature between the gas immediately adjacent to the solid and the solid proper. Formulas for g were first worked out by Knudsen in 1911, and the derivation as reproduced by Kennard (1) yields:

$$g = 2 \left(\frac{2 - \alpha}{\alpha}\right)\left(\frac{\gamma}{1 + \gamma}\right) Pr\lambda \qquad (2)$$

where γ is the ratio of the specific heats, Pr is the Prandtl number and λ is the mean free path of the gas at the temperature and pressure in the gap. The parameter α is the thermal accommodation coefficient, which reflects the completeness of energy exchange between the gas and the solid. If a stream of gas molecules at temperature T_i impinge on a solid at temperature T_s and the gas is reflected with temperature T_r, the thermal accommodation coefficient is:

$$\alpha = \frac{T_r - T_i}{T_s - T_i} \qquad (3)$$

The code GAPCON (2) avoids the problem of having to specify α by setting g proportional to λ, with the constant empirically determined. The WARD gap conductance model (3) calculates g by use of a formula similar to Eq (2), in which α is set equal to 0.035. Thermal accommodation coefficients this low are usually found only with light atoms on clean metal surfaces (4,5). Godesar et al (6) present a plot of the thermal accommodation coefficient as a function of atomic weight of the gas for the combination UO_2-Fe. The method by which this curve was obtained was not explained, nor was the meaning of a single accommodation coefficient for a pair of solids. In any case, the values of α_{He} and α_{Xe} from the plot of reference 6 are $\sim$ 0.2 and $\sim$ 0.8, respectively.

In view of the absence of data on this parameter, we have measured α of helium and xenon on stainless steel and UO_2. The method, which is described in detail in reference 7, utilizes the vacuum apparatus shown in Figure 1. A molecular beam of the gas is produced by effusion through an orifice in the end of the tube on the left hand side of the drawing, mechanically chopped, collimated by a hole in the vacuum chamber wall, and strikes the hot solid. A small portion of the reflected beam is detected by a mass spectrometer located in the third vacuum chamber.

The periodic signal generated by the beam of reflected molecules passing through the mass spectrometer is processed by a lock-in amplifier. This instrument determines the difference in phase between the mass spectrometer signal and a signal obtained from beam chopper. This phase lag represents the time required for the molecules to travel over the distance separating the chopper and the target and from the target to the mass spectrometer. The transit time for the second leg of the flight path depends upon the average molecular speed, and hence on the temperature T_r, of the reflected gas. Measurement of the phase lag permits direct determination of the thermal accommodation coefficient of the incident gas molecules on the solid target. Experiments were conducted with solid temperatures between 500 and 1200°K. The incident beam was not heated, so that T_i was always 300°K. No attempt was made to clean or polish either the UO_2 wafers or the stainless steel samples.

The thermal accommodation coefficient calculated by inserting the specified values of T_i and T_s and the measured value of T_r

into Eq (3) do not represent the "global" values which are obtained by the classical hot wire methods. Rather, our system measures the value of α for a particular combination of molecular incidence and reflection angles, which are determined by the cant of the target in Figure 1 but whose sum is always 90°. Global thermal accommodation coefficients can be obtained from the point values by integration over all incidence and reflection angles. Local thermal accommodation coefficients are not particularly strong functions of the angles of incidence and reflection (8), so we expect that the measurements made with our apparatus are qualitatively applicable to the global energy exchange obtained with an isotropic gas in contact with the solid. To check the effect of angle on the accommodation coefficients, the stainless steel target was tested in two different angular configurations.

The results presented in Figure 2 show that thermal accommodation of xenon is considerably larger than that of helium. At incidence and reflection angles of 45°, α at 1000°K is 0.6 for xenon and 0.2 for helium. The results for stainless steel are not significantly different from those for UO_2. For all combinations of gases and solids, the accommodation coefficient decreases with increasing solid temperature. Changing the impingement and reflection angles by 15° causes a decrease of α_{Xe} on stainless steel from 0.6 to 0.5, but has no effect on α_{He}.

The thermal accommodation coefficients determined in the present study are about an order of magnitude larger than the values used in the WARD gap conductance model (3).

The experimental values of α_{He} are comparable to that utilized in reference 6 which, however, does not account for the significant temperature dependence shown in Figure 2. At all temperatures α_{Xe} from the correlation of Godesar et al (6) is significantly higher than the observed values.

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FIGURE CAPTIONS

1. Apparatus for determining thermal accommodation coefficients by the lock-in detection of modulated molecular beams scattered from the solid.

2. Point thermal accommodation coefficients of helium and xenon on stainless steel and UO_2 for two sets of incidence and reflection angles.

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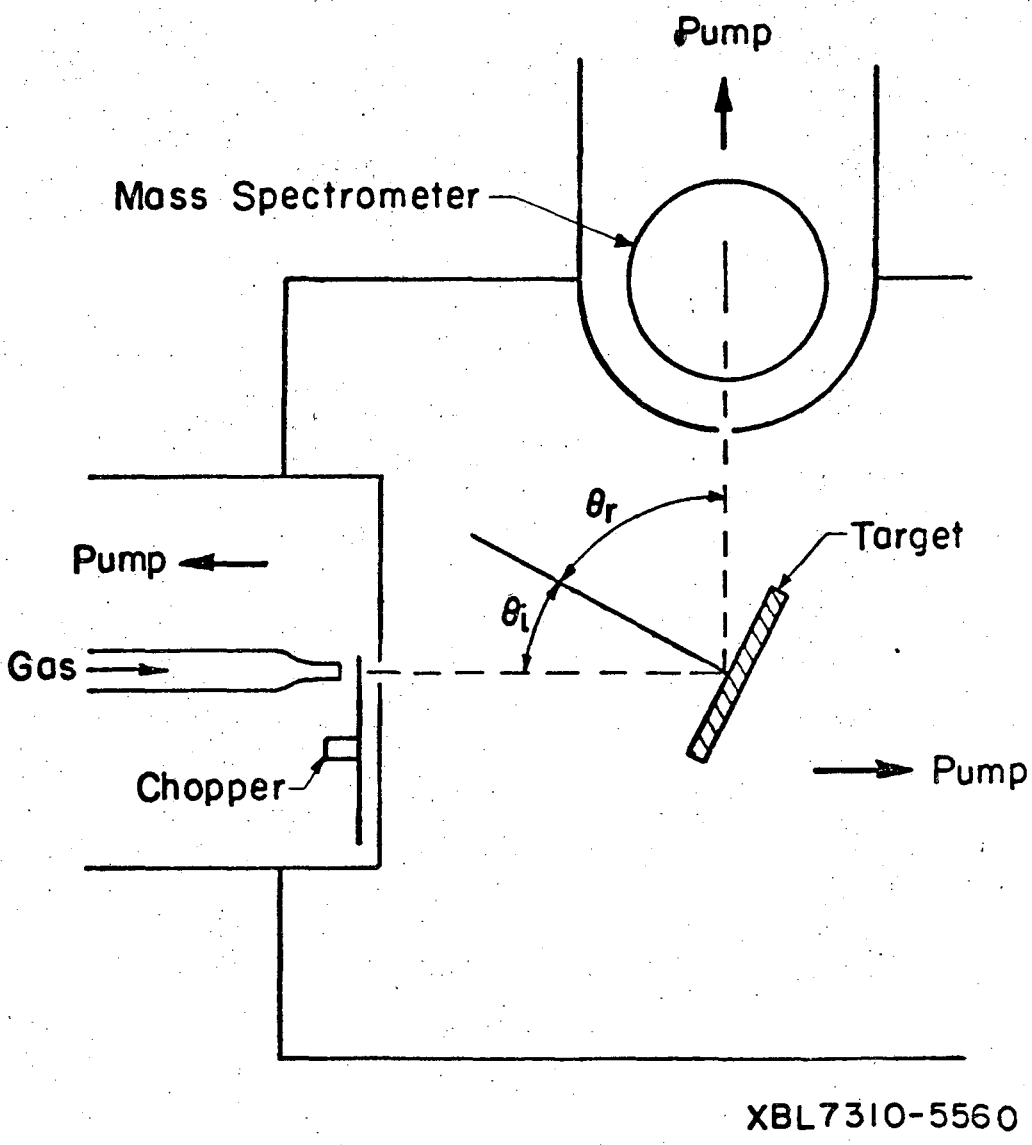
Pump
Mass Spectrometer
Pump
Gas
Chopper
θ_r
θ_i
Target
Pump
XBL7310-5560

Fig. 1.

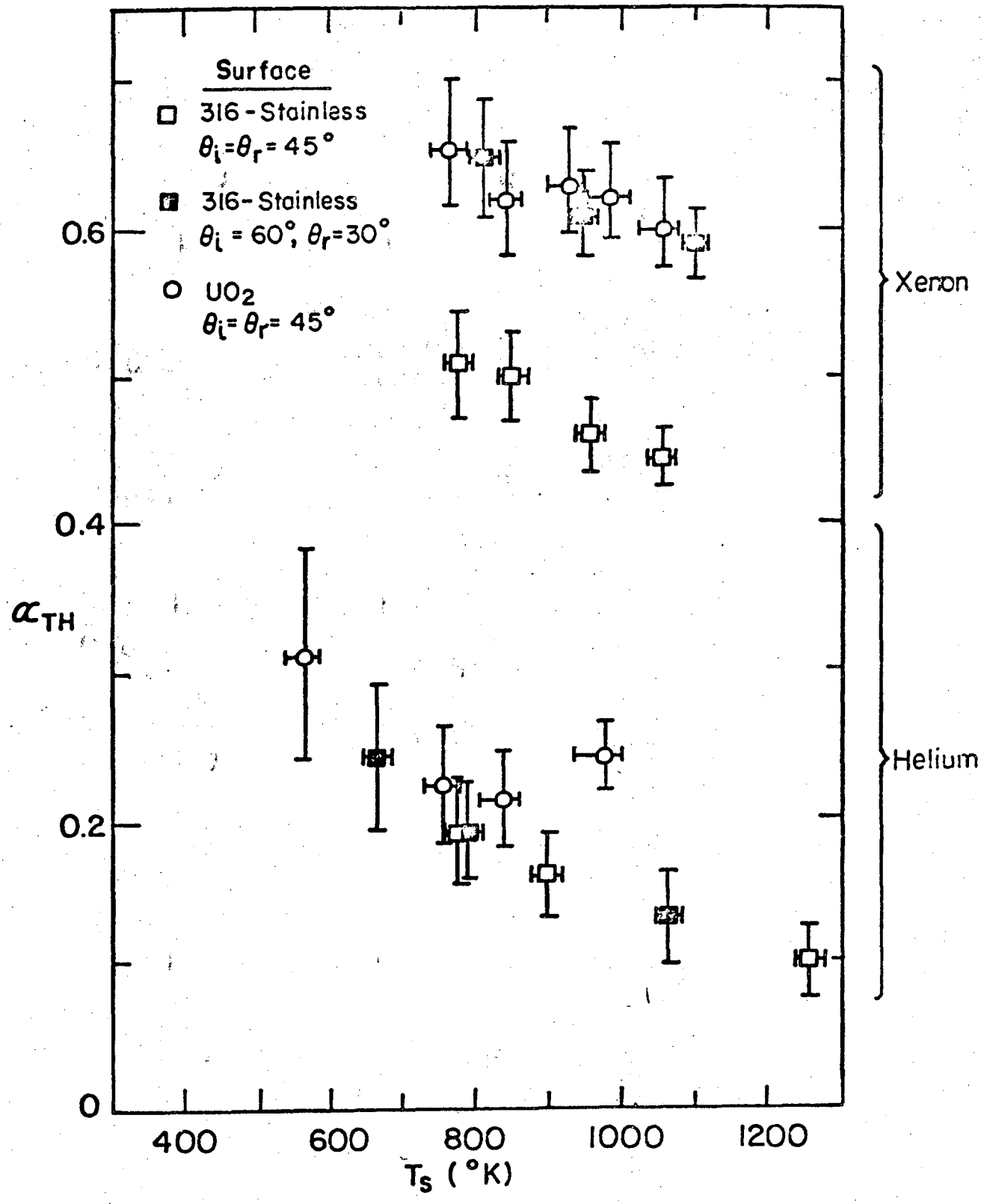
Surface
316 - Stainless
$\theta_i = \theta_r = 45°$
316 - Stainless
$\theta_i = 60°, \theta_r = 30°$
UO_2
$\theta_i = \theta_r = 45°$
Xenon
Helium
α_{TH}
0
0.2
0.4
0.6
400
600
800
1000
1200
T_S (°K)
XBL 7310 - 5559

Fig. 2.

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