$$\frac{V_f}{V_p} = 1 - \frac{\left(\frac{S}{w}\right)\left(\frac{\sin(\varepsilon\pi/n)}{\cos(\bar{\theta}/2)}\right) - \left.\frac{f}{l}\right)^2}{\pi\left(1 + \frac{\sin(\varepsilon\pi/n)}{\cos(\bar{\theta}/2)}\right)^2 - \left(\frac{\sin(\varepsilon\pi/n)}{\cos(\bar{\theta}/2)} - \frac{f}{l}\right)^2\left(\frac{A_{p_i}}{w^2}\right)} \tag{5}$$

$$\frac{R_m}{w} = \left[\cos\frac{\varepsilon\pi}{n} + \frac{f}{l\sin(\bar{\theta}/2)} - \sin\frac{\varepsilon\pi}{n}\cot\frac{\bar{\theta}}{2}\right] \Big/ \left[\frac{\sin(\varepsilon\pi/n)}{\cos(\bar{\theta}/2)} - \frac{f}{l}\right] \tag{6}$$

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Definition of Specific Impulse

S. W. Greenwood*

The University of Maryland, College Park, Md.

SPECIFIC impulse is a widely-used parameter in space vehicle performance computations. Although the concept is extremely simple it appears to have acquired a mystique that often baffles even those who frequently employ it.

An impulse imparted by an applied force T operating between times 0 and t is defined as

$$I \equiv \int_{s=0}^{s=t} T\,ds \tag{1}$$

If the force T is constant over the time interval, the impulse becomes

$$I = Tt \tag{2}$$

It is evidently a favorable performance characteristic to have a high value of I imparted to a vehicle by a motor. A price must be paid, however, and it is necessary to specify some expended quantity that results in the generation of I, so that I may be related to it in specific terms.

The motor thrust may be written

$$T = \dot{m}\bar{u}_e \tag{3}$$

where $\dot{m}$ is the propellant mass flow rate and $\bar{u}_e$ is the effective exhaust velocity. The equality in Eq. (3) necessitates the use of a Consistent System of Units in computations from this form of statement of Newton's Second Law of Motion.

If the mass flow rate is constant over the time interval t, the mass flow rate can be written

$$\dot{m} = (m/t) \tag{4}$$

where m is the mass of propellant expended.

We define specific impulse SI as the ratio of the impulse imparted to the vehicle to the mass of expended propellant.

$$\mathrm{SI} \equiv (Tt/m) \tag{5}$$

Combining Eqs. (3–5) we have

$$\mathrm{SI} = \bar{u}_e \tag{6}$$

We see that, provided we have used a consistent system of units, the specific impulse is simply the effective exhaust velocity. In trajectory analysis and computation the latter is the more convenient variable, the concept of specific impulse then becoming superfluous. This becomes immediately apparent when we note that the units for SI in the SI System of Units (The International System) are:

$$(\text{Newton}\cdot\text{sec/kg}) \equiv (\text{meter/sec})$$

In conclusion it must be emphasized that any gravitational force exerted on the expended propellant (i.e., the weight of the expended propellant) has no relationship to the generation of I. It is therefore a nonsense to make I specific in regard to the expenditure of propellant weight, at one standard Earth gravity or any other condition. Let us therefore consign the so-called "weight" definition of SI to the oblivion it has always deserved, and recognize that the "mass" definition of SI is simply the familiar parameter, the effective exhaust velocity.

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* Instructor, Dept. of Aerospace Engineering. Associate Fellow AIAA.

Desorptive Transfer: A Mechanism of Contaminant Transfer in Spacecraft

H. K. Alan Kan*

The Aerospace Corporation, El Segundo, Calif.

Introduction

CONTAMINATION in spacecraft has received much attention recently, particularly as it relates to contamination on critical optical surfaces. On such surfaces, contamination usually leads to increased absorption and scattering of light, which results in a degradation of the optical devices. For those surfaces that are exposed to the sun, such as solar cell covers and thermal control coatings, there is the additional effect of UV-irradiation of the contaminants, which may result in further optical changes. It can be readily appreciated that a film with a thickness of only a few hundred angstroms can affect the optical properties of a surface significantly.

The control of contamination requires an analysis of potential sources and transfer mechanisms. Likely sources include materials with appreciable vapor-pressure and the exhaust from engines. The mechanism of contaminant transfer commonly considered is an assumed line-of-sight transfer between source and collector. In this assumption, it is implicit that if an optical surface views only surfaces made of materials with negligible outgassing, then that optical surface will not be contaminated. It is the purpose of this Note to point out that desorption processes can lead to an apparent non-line-of-sight transfer. Thus, the optical surface mentioned above may very well receive contaminants generated elsewhere, with the surfaces that it views acting as transfer surfaces.

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Index categories: Spacecraft Temperature Control Systems; Thermal Surface Properties, Spacecraft Sterilization.

* Head, Radiation Sensitive Materials, Chemistry and Physics Laboratory.

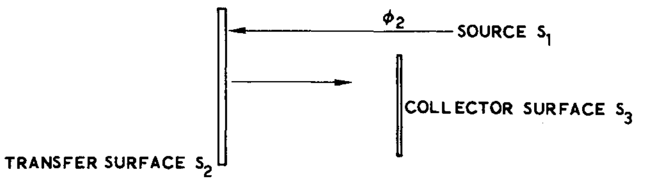

Fig. 1 Desorptive transfer of contaminants.

In the desorptive transfer mechanism, molecules are transferred by being first adsorbed on a surface and subsequently desorbed to a collector surface so that an apparently non-line-of-sight transfer results. The physical mechanism of such a transfer is intuitively obvious, but the magnitudes of the important parameters are not evident. The importance of such a desorptive transfer apparently has not been sufficiently recognized in contamination problems to be considered explicitly. The parameters that govern the efficiency of such a transfer and the kinetics of contaminant build-up are analyzed below in a model calculation. The temperature range will be from room temperature to $-100°C$, the latter being the nominal lower limit achievable by passive thermal control solar reflector surfaces.

A Model for the Transfer of Contaminants by Desorption

A model of contaminant transfer by desorption is shown in Fig. 1. The collector surface of interest S_3 does not directly see any of the contaminants emanating from source S_1, but it does view a surface S_2 that intercepts a contaminant flux ϕ_2. The intermediate surface S_2 is nonvolatile; it does not emit any material of its own. However, S_2 may serve as a transfer surface of contaminants to S_3. The purpose of the model is to find the conditions under which contaminants transferred by way of S_2 to S_3 can be significant. It will be assumed that contaminants cover the surfaces uniformly. This simplifying assumption will make the physical interpretation apparent and will not affect the important conclusions.

The concentrations of contaminant particles $n_2(t)$ on S_2 and $n_3(t)$ on S_3 are given by

$$\frac{dn_2}{dt} = \phi_2 - \frac{n_2}{\tau_2} + g_{23}\left(\frac{n_3}{\tau_3}\right) \tag{1}$$

$$dn_3/dt = g_{32}(n_2/\tau_2) - n_3/\tau_3 \tag{2}$$

Equation (1) assumes the deposition rate on S_2 to be determined by the incident flux ϕ_2, the surface desorption rate, and a certain number of particles emitted from S_3 in proportion to a view factor g_{23}. In Eq. (2) the only source of particles for the collector surface is by desorption from the transfer surface S_2. The factor g_{32} is the geometric view factor obtained by a suitable integration over S_2. The assumption of uniform coverage allows the interpretation of the view factors as simple geometric factors. The quantities τ_2 and τ_3 are the mean residence times of particles on S_2 and S_3, respectively. It will be assumed that the source flux ϕ_2 is far greater than the flux re-emitted from the collector surface, i.e., $\phi_2 \gg g_{23}(n_3/\tau_3)$. Equation (1) then yields

$$n_2(t) = \phi_2 \tau_2 [1 - \exp(-t/\tau_2)] \tag{3}$$

The solution of Eq. (2) with the initial condition of $n_3(0) = (0)$ is

$$n_3(t) = g_{32}\phi_2\tau_3 \left\{ 1 - \exp\left(-\frac{t}{\tau_3}\right) - \frac{\tau_2}{\tau_3 - \tau_2}\left[\exp\left(-\frac{t}{\tau_3}\right) - \exp\left(-\frac{t}{\tau_2}\right)\right]\right\} \tag{4}$$

Equations (3) and (4) give the contamination concentrations. Equation (4) shows that as $t \to \infty$, $n_3 \to g_{32}\phi_2\tau_3$. This means surface S_3 will eventually contain an equilibrium concentration as though the primary flux is directly incident on it, modified only by the view factor. Thus, the effect of an intermediate surface is not to change the equilibrium contaminant concentration on the collector surface, but rather to change the kinetics of buildup. Of course, kinetics are important, because the time constant can be long and the equilibrium concentration may never be reached in practice.

The residence time τ of adsorbed molecules on a surface at a temperature T is determined by a thermal activation process and is generally found to follow the equation[1]

$$\tau = \tau_0 \exp(Q/RT) \tag{5}$$

where τ_0 is typically 10^{-13} to 10^{-14} sec, R is the gas constant, and Q is usually referred to as the adsorption energy.[1] In the present context, Q may be more descriptively called the thermal activation energy for desorption; it may exceed the heat of adsorption by the activation energy for adsorption.

Discussion

The kinetics of contaminant buildup is determined largely by the residence time. The values of Q have not been compiled for common contaminants, but are expected to be in the range of 10 to 25 kcal/mol. The value τ_0 is typically the period of a molecular vibration and will be assumed to be 10^{-13} sec. Figure 2 shows a plot of the residence time τ in months vs temperature in K for $Q = 15$ to 25 kcal/mol. Several observations may be made from the values in Fig. 2. If all the surfaces are at room temperature, then the concentration of contaminants on all the surfaces of the spacecraft will reach the equilibrium values in only a few days, since τ is less than 2 days. Thus, for a mission of a few years, the level of contaminants will essentially remain constant after the first few days. On the other hand, if the collector surface is at 173 K, then only contaminants with $Q < 15$ kcal/mol will be in dynamic equilibrium with the flux from the transfer surfaces, while those with $Q > 15$ kcal/mol will continue to be collected throughout a mission duration of a few years. Thus, the species of contaminant may change in time.

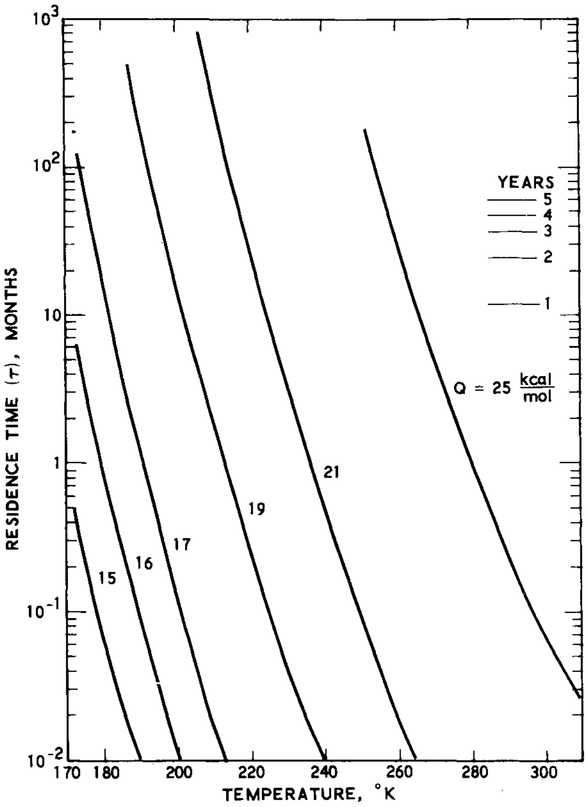

Fig. 2 Residence times of contaminant molecules on a surface vs surface temperatures.

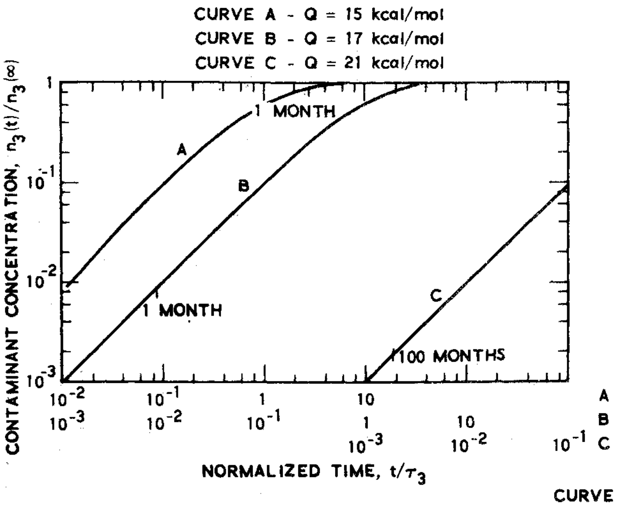

Fig. 3 Buildup on a surface at 173 K of contaminants with different absorption energies (efficient transfer surface is assumed).

The parameters that would make a given surface an efficient transfer surface can also be deduced from Fig. 2. An efficient transfer surface may be defined as one that transfers the contaminants to a collector surface S_3 rapidly so that the buildup of contaminants is determined by τ_3 only. This condition implies $\tau_2/\tau_3 \ll 1$. It can readily be shown that, under this condition, Eq. (4) reduces to the simple exponential form of Eq. (3). Suppose Q is independent of surface and $\tau_2/\tau_3 \leq 10^{-2}$ is used as a condition to define S_2 to be an efficient surface; it can be seen in Fig. 2 that all surfaces at $T_2 > 200$ K will act as efficient transfer surfaces for a collector at 173 K. Thus, surfaces that are normally thought of as cold can act as efficient transfer surfaces. In application, the residence time τ_2 on an efficient transfer surface should be much smaller than both τ_3 and the mission duration. Such considerations can be used in designs to control contaminants on critical surfaces.

As an example of the type of kinetics that may be obtained, Fig. 3 shows the build up of contaminants on a surface at 173 K when an efficient transfer surface is viewed. With the assumption of $\tau_2 \ll \tau_3$, the buildup $n_3(t)$ reduces to the functional form of Eq. (3), so the curves in Fig. 3 are really the same curve displaced along the horizontal axis. It is seen that, in curve A, the buildup of contaminants essentially reaches an equilibrium in 1 month; in curve B, it is linear for the first 3 years, and in curve C, the buildup essentially continues indefinitely. Thus, a wide range of kinetics is possible within the normal range of spacecraft temperatures and expected values of Q. Figure 3 clearly shows the importance of knowing Q.

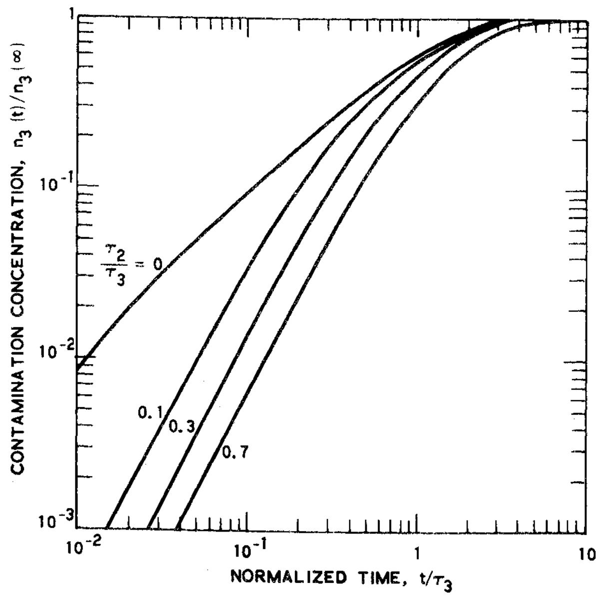

Fig. 4 Kinetics of contaminant buildup on a collector surface with transfer surfaces viewed with different residence times.

As a transfer surface temperature decreases, the residence time τ_2 will increase, which results in a less efficient transfer. Figure 4 is a plot of Eq. (4) that shows the buildup of contaminants as transfer becomes less efficient (increasing τ_2/τ_3). The top curve $\tau_2/\tau_3 = 0$ applies to an efficient transfer surface. As τ_2 increases, the buildup is noticeably slower, but mostly only in the region of $t < \tau_3$. The kinetics of buildup at different τ_2/τ_3 may be distinguishable only if accurate data can be obtained, since qualitatively they appear similar in Fig. 4.

In conclusion, the above results show that the desorptive transfer mechanism should be explicitly considered in any modeling of contaminant transfer. Moreover, the need for measuring adsorption energies for common contaminants is clearly indicated.

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Announcement: 1974 Author and Subject Indexes

The indexes of the four AIAA archive journals (*AIAA Journal, Journal of Spacecraft and Rockets, Journal of Aircraft*, and *Journal of Hydronautics*) will be combined and mailed separately early in 1975. In addition, papers appearing in volumes of the *Progress in Astronautics and Aeronautics* book series published in 1974, as well as technical papers published in the 1974 issues of *Astronautics & Aeronautics*, also will be included. All subscribers to the four *Journals* are entitled to one copy of the index for each subscription which they had in 1974. All others may obtain it for $10 per copy from the Circulation Department, AIAA, Room 730, 1290 Avenue of the Americas, New York, New York 10019. **Remittance must accompany the order.**

Ruth F. Bryans
Director, Scientific Publications