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Spacecraft Thermal Blanket Cleaning: Vacuum Baking or Gaseous Flow Purging

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The mass losses and the outgassing rates per unit area of three thermal blankets consisting of various combinations of Mylar and Kapton, with interposed Dacron nets, have been measured with an analytical balance using two methods. The blankets at 25°C were either outgassed in vacuum for 20 h, or were purged with a dry nitrogen flow of 8.5×10^{-2} m^3/h at 25°C for 20 h. The two methods have been compared for their effectiveness in cleaning the blankets for their use in space applications. The measurements were carried out using blanket strips and rolled-up blanket samples fitting the balance's cylindrical plenum. Also, temperature scanning tests were carried out to indicate the optimum temperatures for purging and for vacuum cleaning. The data indicate that the purging for 20 h with the N_2 flow can accomplish the same level of cleaning provided by the vacuum with the blankets at 25°C for 20 h. In both cases, the rate of outgassing after 20 h is reduced by three orders of magnitude, and the weight losses are in the range of 10E-4 g/cm^2. Equivalent mass loss time constants, regained mass in air as a function of time, and other parameters were obtained for these blankets.

Introduction

THERMAL blankets are used to protect surfaces of spacecraft and space instruments and to provide thermal control of the system they are covering. The blankets consist of layers of materials having highly reflective surfaces interposed by Dacron nets. The outer layers are, for protective reasons, thicker than the others and have surface coatings designed to reflect specific radiation wavelengths. These blankets are required to protect a satellite against electrons, protons, and ultraviolet radiation and to be stable in the presence of atomic oxygen, moisture, and radiation. Materials used for these blankets are Kapton and Mylar, which may be surface aluminized or gold coated. The primary function of thermal protection is accomplished by the evacuation of the space between the blanket layers. The evacuation eliminates thermal conductance of the gases between the layers. The elimination of gas conductance requires the pressures between the layers to be on the order of 10^{-5} to 10^{-6} Torr.

The evacuation to these low pressures requires the venting of the gases via perforations in the blanket and/or via the blanket edges. In edge venting, the initial gas evacuation occurs in the continuous, gaseous flow regime. This evacuation occurs quite rapidly, depending on the dimensions of the blanket and the size of the vent openings. After this initial evacuation, the flow changes first to the transitional flow regime and then to the molecular flow regime, when the molecules randomly move and find the exit vents. The escape of these residual molecules is very slow. It involves the release of molecules held on the material's surface, molecules produced by degradation of the material, and molecules diffused out of the material. The molecules that are released and removed from the blankets are mainly H_2O, N_2, CO_2, rare gases, and others originating from the environment, which are held on the surface by physical adsorption forces, or they are chemically adsorbed and require different levels of energy for their removal. The energies required for their removal vary from about 6 kJ/mole for H; 13–17 kJ/mole for Ar, O, N, and CO_2; and 40–60 kJ/mole for long-chain molecules. The water molecules, which may be the major constituent, are chemisorbed on the surface and require about 40 kJ/mole for removal. The surface molecules can be removed by pumping, by a scrubbing flow of purging gases, or by imparting thermal energy to the surface molecules. Concurrent with the removal of surface molecules, there may be releases by diffusion of decomposition products. The molecular removal, which can be described as an initial surface degassing followed by, or in conjunction with, an internal outgassing, decreases slowly with time. It involves simultaneous processes and can be represented, in general, by an inverse function of time to a power (0.5–2) reflecting the combination of those removal processes.

For the blankets to become effective thermal protectors in a reasonable time following launch, the blankets are cleaned by baking in vacuum chambers. The cleaning is quite expensive, since it involves considerable time and expense for the preparation of the vacuum chamber, the installation, the instrumentation, and the actual vacuum bake of the blanket. It may introduce scheduling conflicts for the use of a limited number of available vacuum chambers.

The cleaning of the blankets has other important benefits. It reduces the number of molecules originating from the blanket outgassing, which in space can deposit and contaminate adjacent contamination-critical surfaces such as cryogenic surfaces, mirrors, lenses, and other thermally controlled surfaces. It reduces the gaseous cloud of outgassed molecules that forms about a spacecraft in orbit and impairs optical observations. Also, cleaning the blanket before its application reduces the length of time required for the testing of the complete spacecraft in a vacuum chamber and eliminates possible contamination produced by the blanket outgassing.

In the context of this investigation, data on the outgassing behavior of blanket materials (Mylar, Kapton, Dacron net, Fibercloth) are reported in Refs. 1–4. Glassford[1] showed, among others, that by purging for 30 min at 100°C with N_2 or He the outgassing rate at 25°C of a plain, double-aluminized Mylar blanket would drop one to two orders of magnitude. The purging with gas at 25°C had a negligible effect on the outgassing rate.

The present investigation explores the effectiveness of using a purging flow of clean nitrogen gas through the blanket interfaces in a container at ambient pressure, in place of the vacuum-bake cleaning of the blanket. The purge is intended to

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provide a mechanical scrubbing of the surfaces and a gradient of concentration between the molecules on the surfaces and the purging gas, which provides partial pressure differences sufficient to remove the surface molecules and carry them away. Also, purging with the gas at elevated temperatures can provide sufficient activation energy and a rapid removal of those molecules that would be expected to outgas in flight. The purging method can be less costly, can be performed without interference with other tests requiring vacuum chambers, and can be carried out very near the launch time.

Tests

The tests for the comparison of the purge method and the vacuum bake method were both carried out at a temperature of 25°C in the same vessel. The tests consisted of measuring the blanket weight losses as a function of time. The blanket samples were exposed to the same environment of about 20°C, 50% relative humidity (RH) for an unknown—but long—period of time before the tests. The tests in each case were arbitrarily carried out for 20 h. However, the changes in mass were no longer measurable with the gravimetric instrumentation used for the tests after 20 h of testing. All weight loss tests were carried out in the vessel equipped with an analytical balance. The holding arrangement in the vessel is shown in Fig. 1.

The following tests on three different types of thermal blankets were carried out:

1) Measurement of the weight loss vs time of each of the three blankets held at 25°C as a function of time while in a vacuum of 10^{-6} Torr for a period of 20 h.

2) Measurement of the weight loss vs time of each of the three blankets while being purged with 8.3×10^{-2} m^3/h of dry nitrogen at 25°C for 20 h. The purge rate provided a volume change of about 24 changes/h.

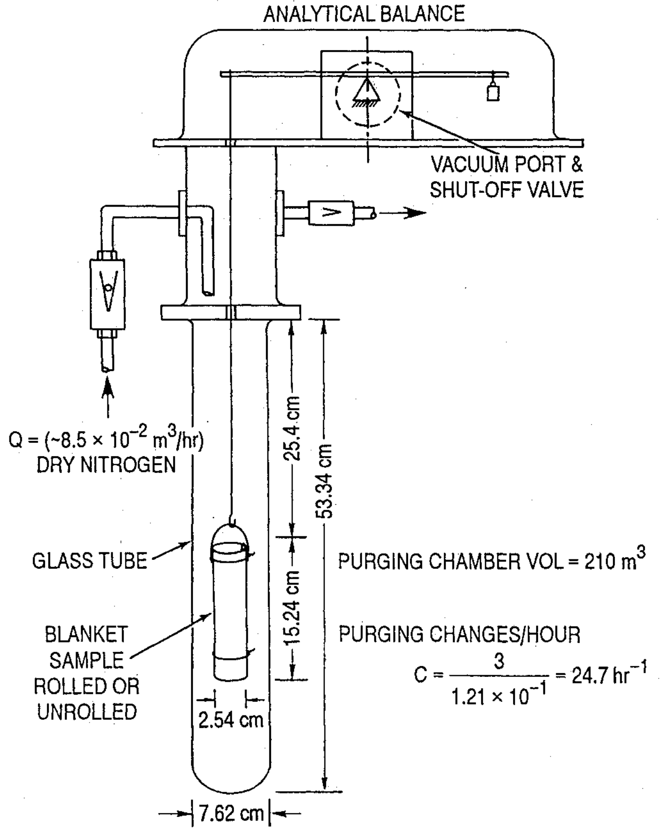

Fig. 1 Sketch of part of the analytical balance showing sample attachment, vessel, and purge setup.

3) Measurement of the weight loss of each sample as a function of time during an initial 6 h of purging followed by an additional 14 h under vacuum using the same pressures, temperatures, and flow rates indicated for tests 1 and 2. The changeover from purging to vacuum baking at 6 h was based on the flattening of the curve showing mass loss vs time. The same reasoning was followed in stopping the test at 20 h.

4) Measurement of the weight loss rates in vacuum while changing the blanket's temperature or changing the purging temperatures while the blankets were being purged. In these tests, designed to determine the most effective purging and blanket temperatures, the temperatures were chosen so as not to exceed safe blanket and spacecraft temperatures.

5) Measurement of the weight gain of a previously cleaned blanket sample as a function of time while exposed to air at 25°C and 50% RH.

6) Measurement of the total mass loss (TML), condensable volatile collected mass (CVCM), and water vapor regain (WVR) on a sample of assembled blanket and on the individual constituents of the blanket using the American Society of Testing and Materials ASTM-E-595 test[5] for outgassing of materials.

Thermal Blankets and Testing Apparatus

The thermal blankets tested for weight losses were designated by type numbers I, II, and III. The blankets were assembled from aluminized Mylar and aluminized Kapton with interposed Dacron netting. The three tested samples, 15.24 cm long and 15.24 cm wide, were rolled into cylindrical shapes approximately 2.54 cm in diameter and secured at both ends with chromel wires. The rolling of the blankets provided additional blanket surface areas within the confines of the 7.62-cm-diam cylindrical measuring instrument vessel. Tests were also carried out with unrolled samples for type II and type III blankets. The unrolled samples were 15.24 cm long by 3.81 cm wide. The samples under test were suspended on a stainless-steel rod attached to the balance. The blanket samples, sketched in Fig. 2, consisted of the following materials.

Blanket Type I

Of the two outermost materials, one consisted of 76.2-μm Mylar with an aluminized interior face. The other outermost material consisted of 25.4-μm Mylar that was aluminized, as was the other, on the surface facing the interior of the blanket. In between, both included 10 layers of 6.35-μm Mylar aluminized on both sides and 11 layers of Dacron netting sandwiched between each layer.

Blanket Type II

Both the top and bottom layers of material consisted of 76.2-μm Kapton with the exterior faces aluminized. They included 12 layers of 8.47-μm Kapton aluminized on both faces and 13 layers of Dacron netting.

Blanket Type III

One of the outer materials was 76.2-μm Mylar aluminized on both sides. The other outer layer was made of 76.2-μm Kapton, but with an aluminized interior-facing surface. They included 18 layers of 6.35-μm aluminized Mylar on both sides and 19 layers of Dacron netting.

The weight loss measurements in vacuum and at atmospheric conditions under N_2 purging were carried out using a recording vacuum balance. The balance had a capacity of 100 g and a sensitivity of 0.1 mg. The specimen weight loss was automatically recorded on the strip chart, which also recorded the temperature. The temperature of the specimen could be varied in increments of 5°C. The vacuum chamber in which the sample was inserted and heated was a quartz tube 50 cm long and 7.62 cm in diameter. The vessel shown in the sketch (Fig. 1) was evacuated with a 15.24-cm diffusion pump with an LN_2 trap backed by a roughing pump. A cylindrical

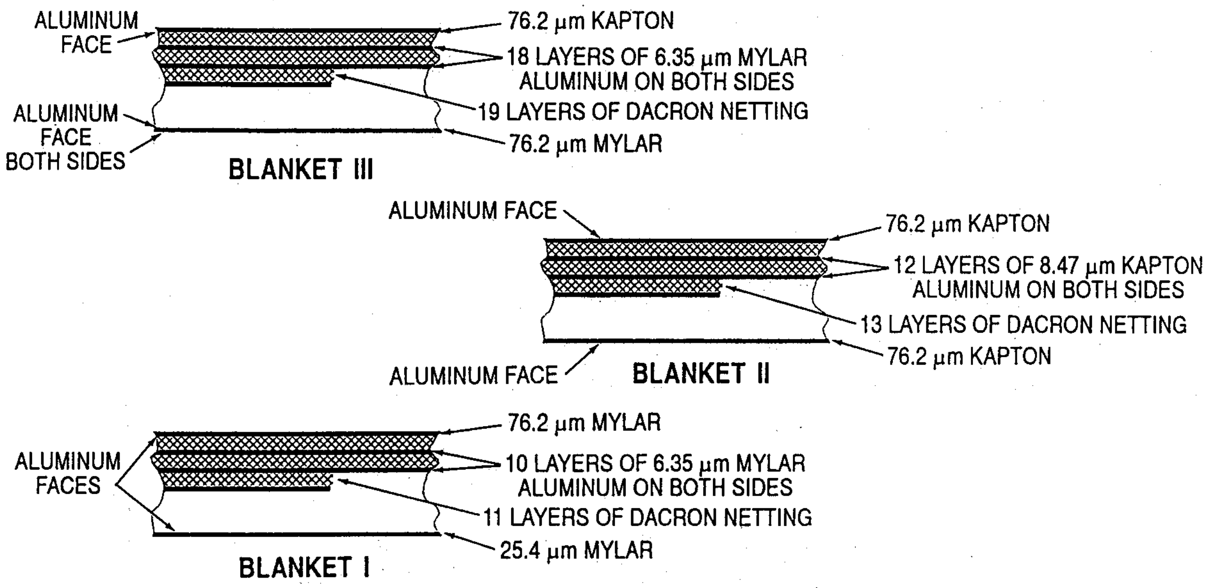

Fig. 2 Blanket compositions.

25.4-cm outside diameter, 25.4-cm-long electrical resistance heater provided radiative heating to the blanket, as desired. The initial operation consisted of weighing the samples before inserting them in the balance and using that weight as the initial starting point on the recorder.

Test Results

Figure 3 compares the weight loss for the three blankets while in vacuum and while under purging conditions. For both procedures, the test was run for 20 h at a temperature of 25°C. The open, single-face surface area of the rolled blankets was 232.25 cm^2. For the rolled blankets, the tests show that the weight losses after 20 h are, for all practical purposes, equal for both vacuum and purge. The total percentage weight loss for blanket I is about 0.17, whereas for blanket II (consisting of external and internal layers of Kapton) the percentage is about 0.56. The weight loss percentage of blanket III (consisting of a large number of layers and with one face made of Kapton) was about 0.3.

The results indicated in Table 1 were derived from the test data shown in Fig. 3. Blanket III weight losses per unit area were 1.62×10^{-4} g/cm^2 when exposed to vacuum at 25°C for 20 h, and 1.54×10^{-4} g/cm^2 when purged with 25°C dry nitrogen for 20 h. The mass losses per unit area of blanket II were 2.69×10^{-4} g/cm^2 for both vacuum and purging tests. For blanket I, the mass loss for the vacuum test was 5.5×10^{-5} g/cm^2, and for purging the loss was 5.9×10^{-5} g/cm^2. As shown in Fig. 3, the weight losses plot as exponential functions of time that reflect first-order reaction rates. Based on those plots, an approximate evaluation of the length of time for the weight losses to reach about 64%, i.e., $(1-1/e)$, of the asymptotic final weight loss indicates that for the vacuum tests the time was 2.4 h for blanket III, 3.8 h for blanket II, and 1.6 h for blanket I. The corresponding times for the purging tests were 3, 6.3, and 2 h, respectively.

The tests on purging and vacuum cleaning of unrolled blanket strips reproducing more closely the blankets' applications again showed limited differences between purging and vacuum cleaning. The mass losses per unit area for the blanket III strip were 2.06×10^{-4} g/cm^2 for both vacuum and purge tests. The time constants were 2.4 h for vacuum and 1.6 h for purging. The shorter time to accomplish the 64% weight loss under purging compared with vacuum baking is also experienced with blanket II. The purging time constant was 3.4 h and the vacuum baking time constant was 4.5 h. The mass losses per unit area for this blanket were 2.06×10^{-4} g/cm^2 for vacuum baking and 2.58×10^{-4} g/cm^2 for purging.

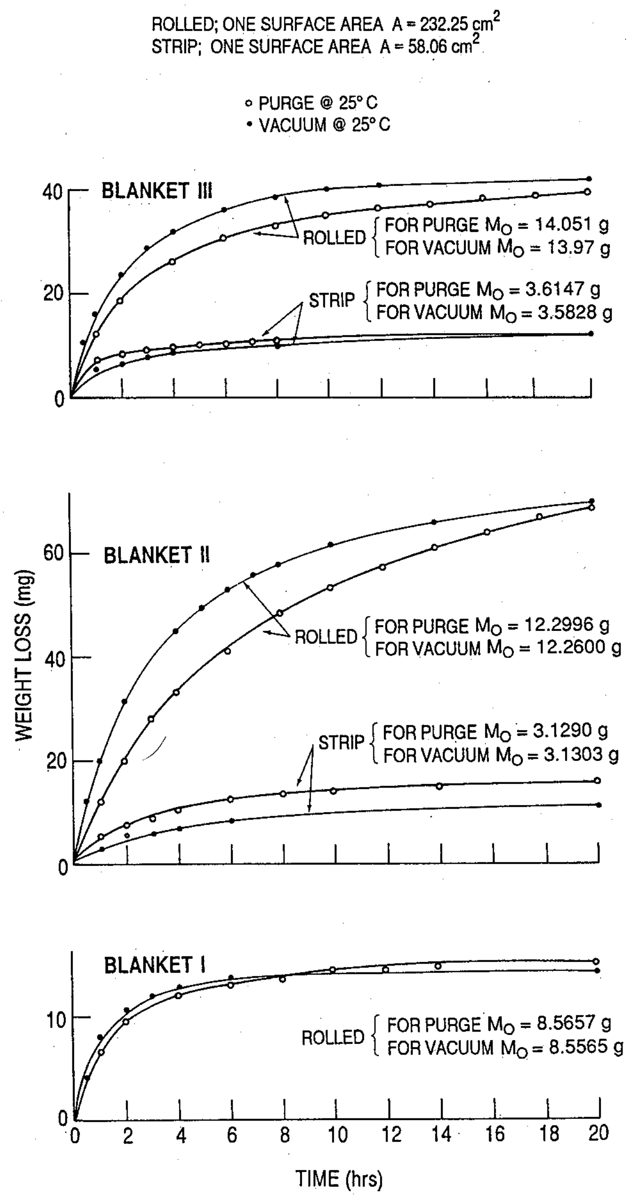

Fig. 3 Weight losses of blanket samples of under purge and/or vacuum.

Table 1 Weight losses and time constants of thermal blankets

	Weight loss, g/cm^2			
	Rolled blanket[a]		Unrolled (strip) blanket[b]	
Blanket	Vacuum[c]	Purging[d]	Vacuum[c]	Purging[d]
III	1.62×10^{-4}	1.54×10^{-4}	2.06×10^{-4}	2.08×10^{-4}
II	2.69×10^{-4}	2.69×10^{-4}	2.06×10^{-4}	2.58×10^{-4}
I	5.5×10^{-5}	5.95×10^{-5}	——	——
	Time constant, h			
III	2.4	3	2.4	1.6
II	3.8	6.3	4.5	3.4
I	1.6	2.0	——	——

[a]Blanket 15.24 cm × 15.24 cm rolled into a 2.54-cm-diam cylinder. [b]Blanket 15.24 cm × 3.81 cm unrolled strip. [c]Vacuum degassing for 20 h at 10^{-5} Torr; blankets at 25°C. [d]Purge cleaning with N_2 at 25°C for 20 h.

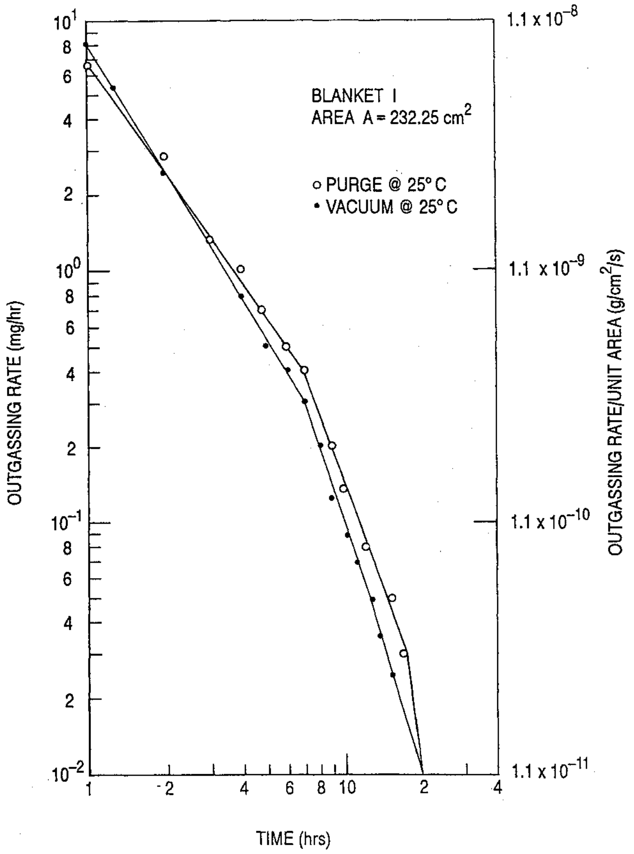

Fig. 4 Outgassing rates for blanket I obtained with purging and vacuum bake.

The following figures show the outgassing rates of the three blankets as obtained from the weight losses shown in Fig. 3.

Figure 4 shows the outgassing rates for blanket I in mg/h or in g/s cm^2 when the surface area is included in the evaluation. The vacuum outgassing rate is greater than that produced by the purging for about 2-3 h of the initial cleaning period, after which the purging rate is higher. Both curves indicate a rapid change in slope about 7 h into the test, indicating depletion of the outgassing.

Figure 5 shows the outgassing rates for blanket II. The crossover where the purge provides a higher rate than the vacuum bake occurs at about 6 h, and the depletion of outgassing and the corresponding slope change occurs at about 14–15 h.

Figure 6, showing outgassing rates for blanket III, indicates a crossover at about 6–7 h and the depletion between 10 and 12 h.

The outgassing rates for the strips are shown in Figs. 7 and 8. The purging mass loss rates are slightly higher than those from vacuum baking, which reflect the test measurements.

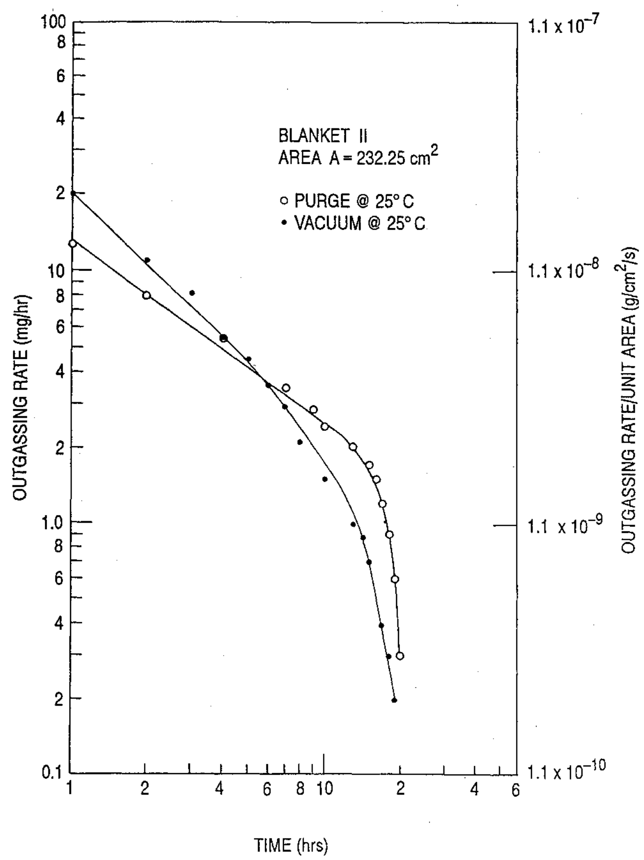

Fig. 5 Outgassing rates for blanket II obtained with purging and with vacuum bake.

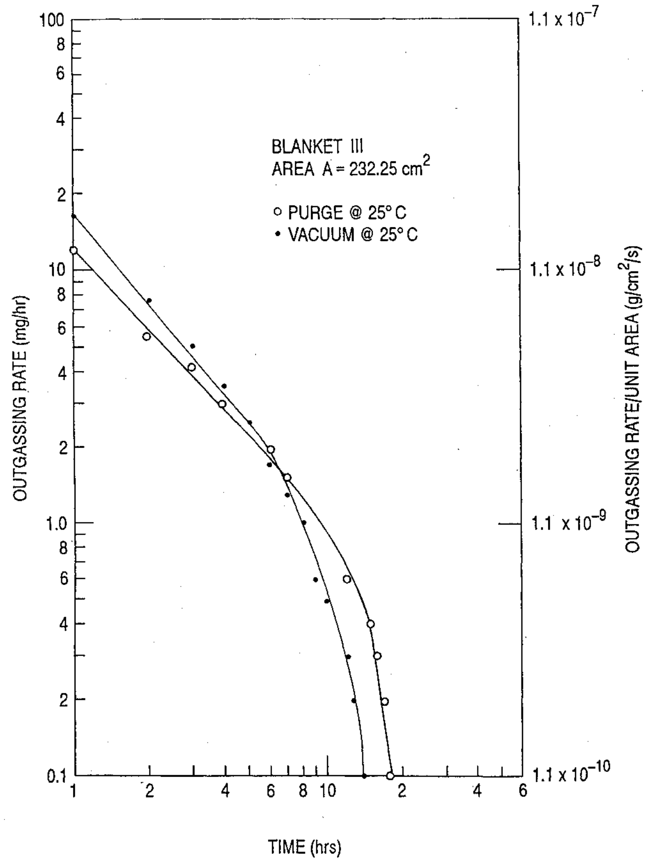

Fig. 6 Outgassing rates for blanket III obtained with purging and vacuum bake.

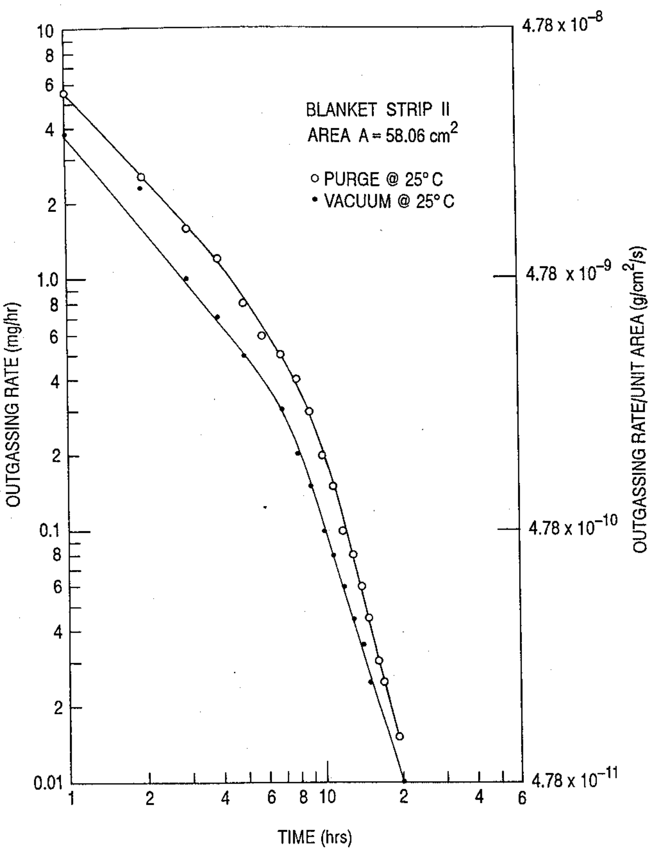

Fig. 7 Outgassing rates for the unrolled strip of blanket II obtained with purging and with vacuum bake.

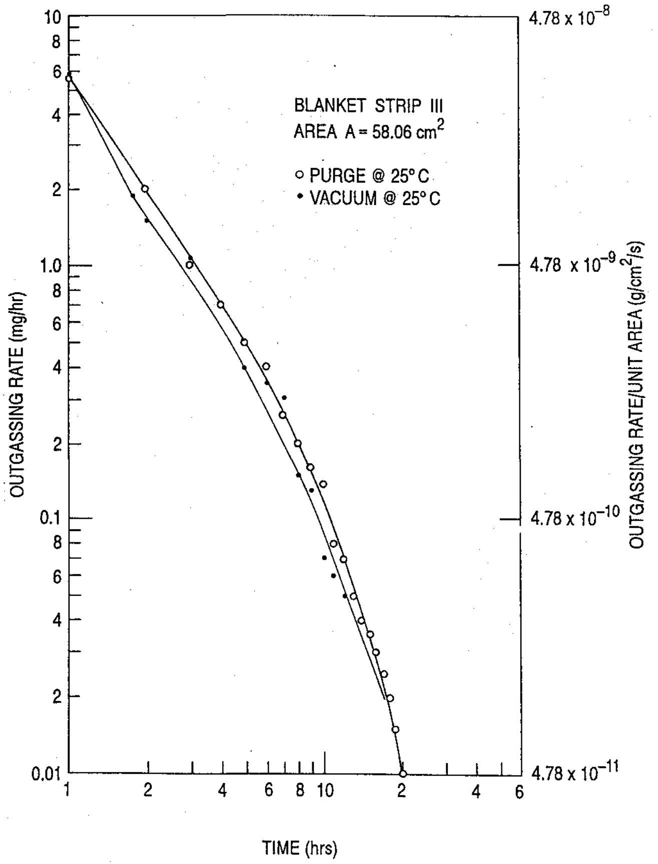

Fig. 8 Outgassing rates for the unrolled strip of blanket III obtained with purging and vacuum bake.

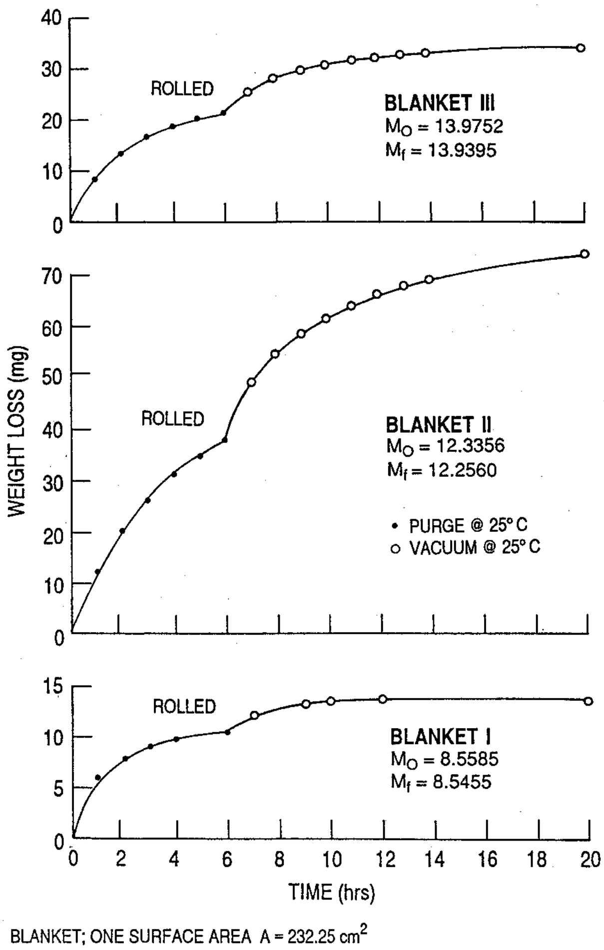

Fig. 9 Weight losses of blanket samples: purge followed by vacuum.

Rapid depletion occurs at about 8–9 h in both vacuum and purge tests. Further tests were carried out to validate the previous results.

The weight-loss-vs-time data and the corresponding outgassing rate data (Figs. 9 and 10) show the results of using an initial 6 h of purging followed by vacuum for a total of 20 h. Within experimental limits, the resulting mass losses are the same as those obtained by independently employing either vacuum or purging for 20 h.

As an attempt to identify the outgassing sources from the blankets and to note the temperatures either during vacuum or during the purging when maximum rates of cleaning can occur, tests were carried out on each blanket type to measure the rate as a function of temperature. In these tests, the temperature was increased at a rate of 1°C/min, and the corresponding change in mass loss was measured. Both temperature and mass loss were recorded simultaneously.

Figure 11 shows the loss rates as a function of temperature recorded during the vacuum cleaning. It shows that blanket I (with all Mylar layers) has a maximum outgassing rate at about 45–50°C followed by another maximum at about 180°C. Blanket II (with Kapton layers) has a maximum at about 110°C, with both lower rates on each side of 110°C. Blanket III (all Mylar with an outer Kapton layer) shows a maximum at about 50°C. Superposed on the same plot, the rate vs temperature produced by the netting alone is shown. The plot shows a maximum for the Dacron net at about 30°C and an apparent increase starting at about 180°C. The increased rates after 180°C may indicate material degradation.

Figure 12 shows the outgassing rates vs temperature, while changing the purging gas temperature. The plots reproduce, as can be seen, the indications provided during the temperature scan for the vacuum cleaning. From these, it appears that

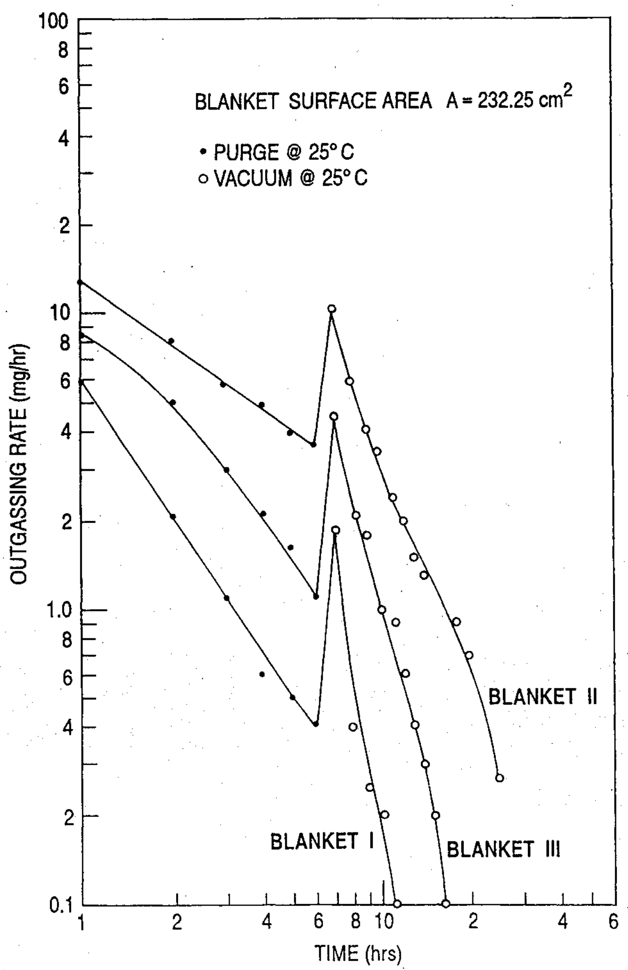

Fig. 10 Outgassing rates for blankets in vacuum after an initial purge.

Kapton (blanket II) releases a large quantity of material, probably water, at 100–110°C. The other two blankets (using mostly Mylar) reach a maximum outgassing rate at about 40–50°C, and the outgassing material at those temperatures originates from the netting. Tests on the temperature scans of Mylar and Kapton by themselves were not carried out because the balance was no longer available for use.

Figure 13 shows the percentage of weight regained as a function of time by blanket III as a system and by the Kapton and Mylar material components. These were exposed to room conditions of 20°C, and 51% RH after they had been baked at 125°C for 24 h in a vacuum of 10^{-6} Torr. The percent of TML and the CVCM on a 25°C collector indicated by that test, which conforms to the ASTM-E-595 test for space applications acceptability of materials, are indicated in this figure. Those results show that the outgassing is mostly water, as is also indicated by Ref. 1 (<98% water vapor).

Discussion

Purging can accomplish the cleaning of blankets to a level equivalent to that of a vacuum when both the purging and the vacuum cleaning are carried out for about 20 h at 25°C. Tests of both procedures show that the rates of outgassing are approximately the same using either method of cleaning. Both methods reduce the outgassing rates by about three orders of magnitude after 20 h.

The weight loss per unit area of blanket II (made up of outer and inner layers of Kapton) was an average of 2.5×10^{-4} g/cm^2 for the 20-h, 25°C tests. Blanket III, with one outer layer of Kapton and all of the others of Mylar, produced an average loss of 1.82×10^{-4} g/cm^2. The smallest weight loss of 5.7×10^{-5} g/cm^2 was produced by blanket I, which was made entirely of Mylar. These values are averages obtained by combining the measurements of vacuum and purging tests. The differences in weight loss between vacuum and purging tests were ±7% for the rolled blankets.

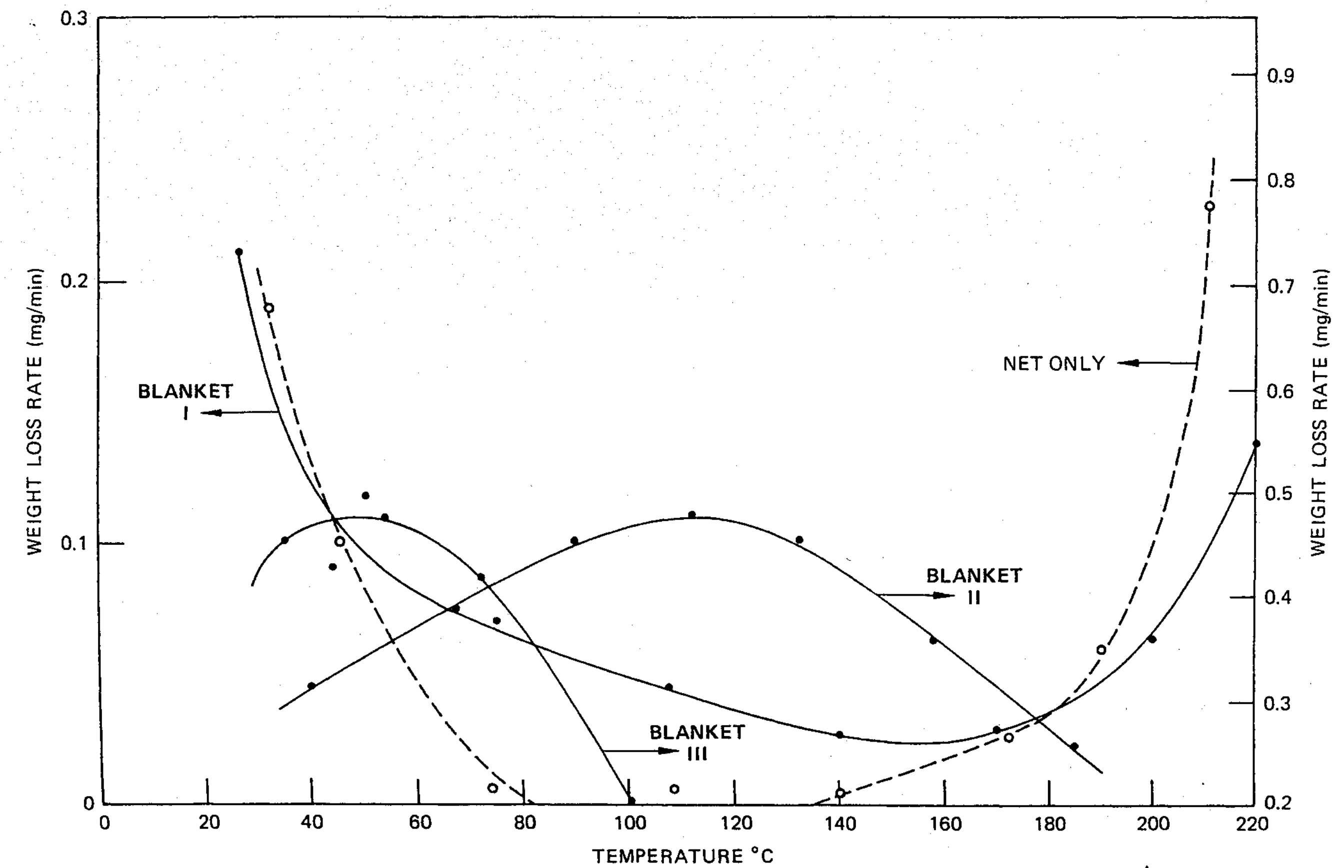

Fig. 11 Weight loss rates vs blanket temperatures.

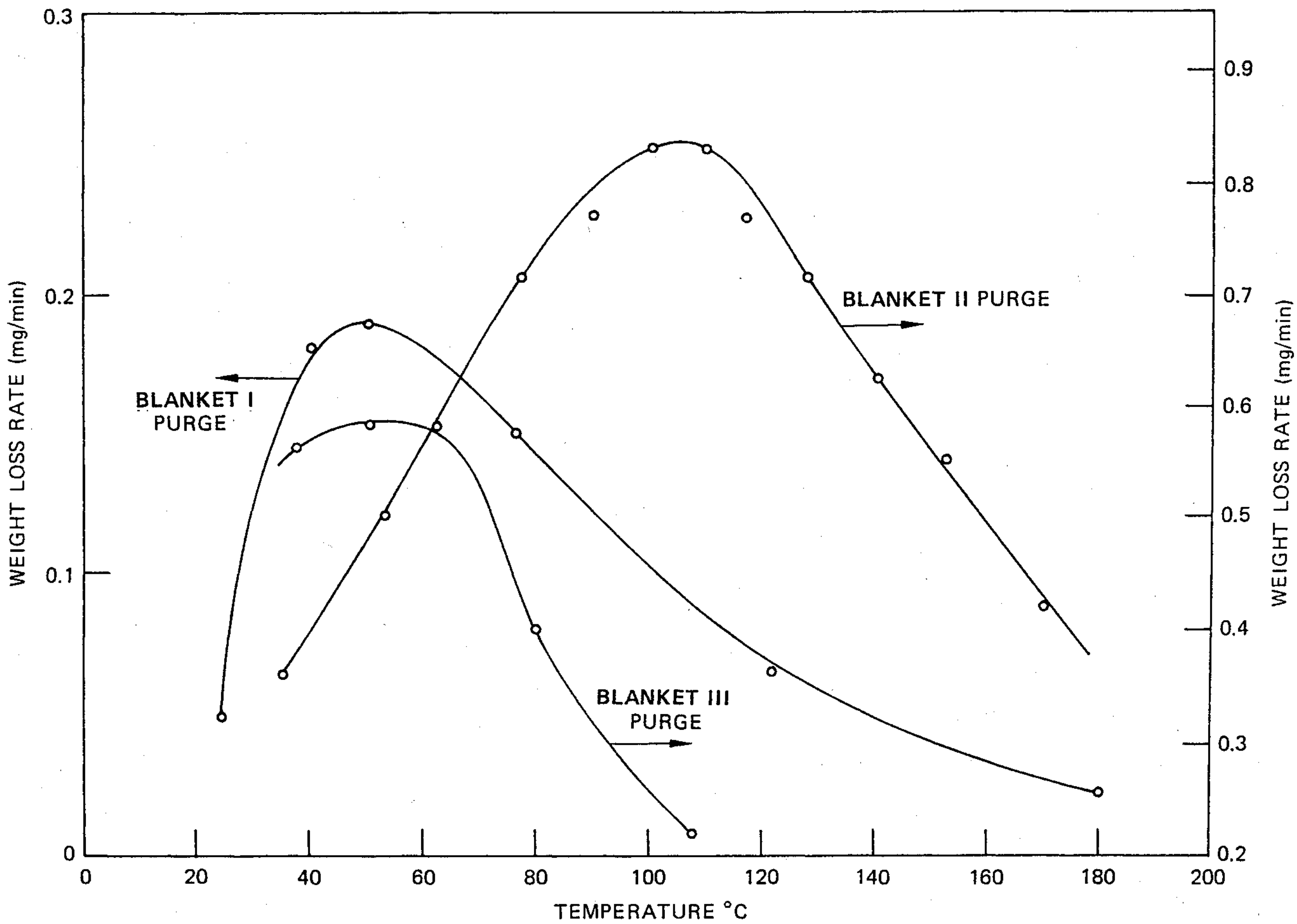

Fig. 12 Weight loss rates vs purging temperatures.

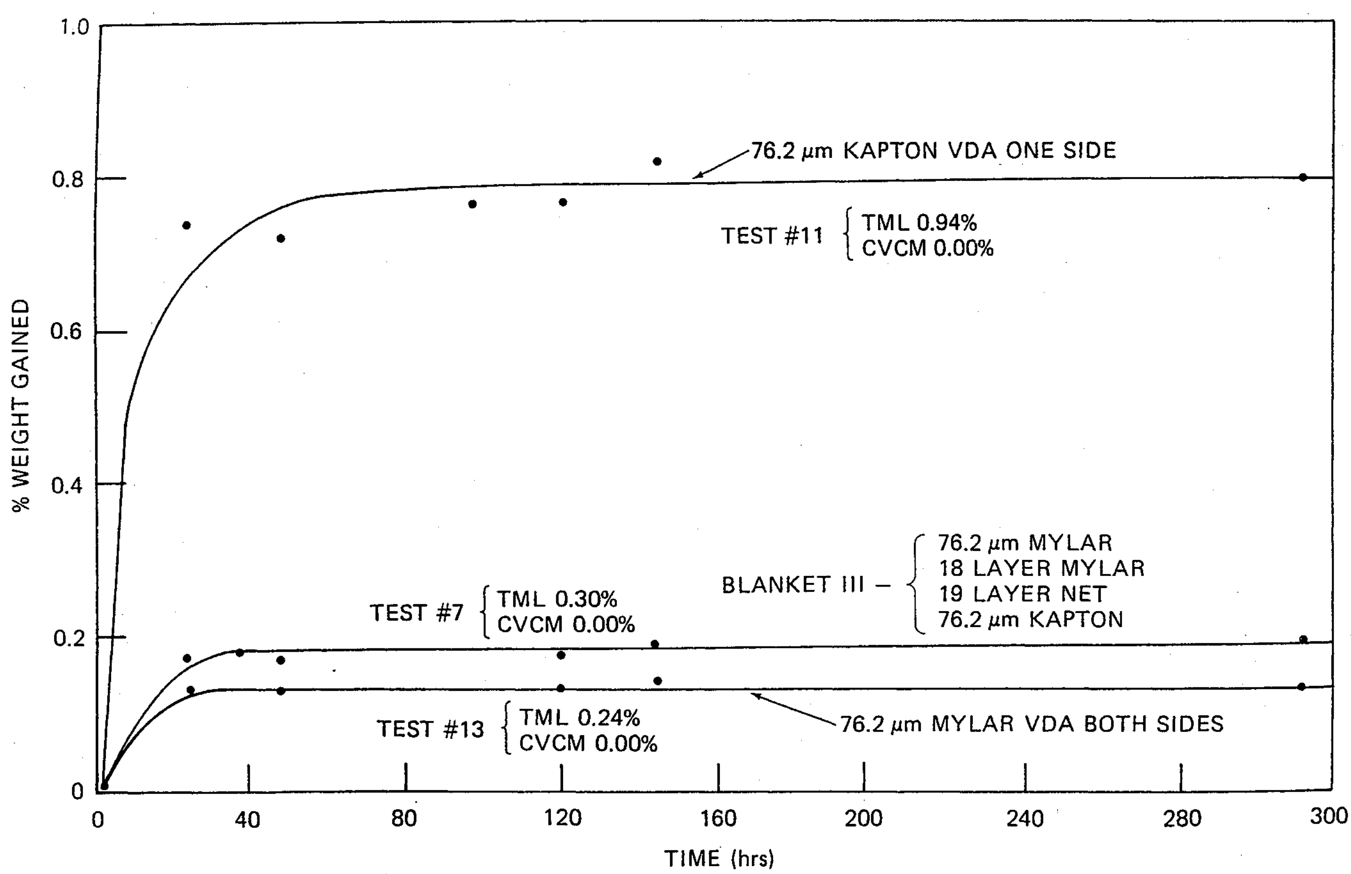

Fig. 13 Percentage of weight regained vs time for assembled blanket III, a Mylar component, and a Kapton component.

The time constants for the rolled blankets varied from about 1.6 h for blanket I to 3.8 h for blanket II in vacuum and, for the purging, from 2 h for blanket I to about 6 h for blanket II. These longer times for purging than for vacuum must reflect the difficulty of the purge gas entering the rolled blankets and dislodging molecules within the blanket layers.

For the unrolled blankets, the weight losses from purging were slightly larger than those from vacuum: about 1% for blanket III and close to 25% for blanket II. The larger percentage may reflect the nature of the many Kapton surfaces making up that blanket. The time constants of these strips, reflecting the freer exposure of the surfaces to the purge gas, were shorter for purging than for vacuum; 1.6 vs 2.4 h for blanket III, and 3.4 vs 4.5 h for blanket II.

The vacuum cleaning for the rolled blankets provides a larger rate of cleaning during the first 2–3 h than the purge cleaning provides. After that initial period, the purging provides slightly higher cleaning rates. As a result, the two methods are equivalent. On the other hand, for the strip of unrolled blanket, the purge cleaning appears to provide a larger rate of cleaning than does the vacuum cleaning. For blanket III, the initial rate of cleaning for the purge was larger than that for the vacuum. The results for blanket II indicate a slightly better cleaning from purging than from vacuum throughout the test.

The rate of outgassing during the initial 8–9 h represents a removal of molecules from the surface. This process is followed by a rapid depletion of the degassing source. That lower outgassing may represent a diffusion process of molecules out of the material.

The maximum rate of outgassing is shown to occur at about 40–50°C for blankets I and III, which are made mostly of Mylar and netting. This reflects the maximum outgassing of the net at about 40°C. The maximum rate of outgassing for blanket II occurs near 100°C, showing that the most probable outgassing source is water.

The outgassing of types I and III Mylar blankets can be more effectively and more rapidly outgassed in vacuum or under purging at a temperature of 40–50°C. These temperatures may be tolerable to the blankets and other nearby systems. The blankets can be degassed by purging with dry nitrogen at temperatures that are acceptable for vacuum bake. The purging should be carried out for at least 10–15 h. After this time, the degassing drops rapidly. For that length of time, both purging and vacuum accomplish a blanket degassing rate reduction of more than two orders of magnitude.

Stopping the purge and allowing the blanket to be exposed to a normal environment of 25°C, 50% RH results in the reacquisition of moisture on the blanket. Measurements show that, after about 2 days, the blankets would reacquire almost all of the mass released in 24 h at 125°C.

Blanket venting at the edges assists the degassing. A flow of 8.5×10^{-2} m^3/h appears sufficient for purging.

Purging with a gas at temperatures higher than 25°C expedites and is more efficient in the degassing of thermal blankets.

Conclusions

Thermal blankets are an important component of every spacecraft. They are used to protect surfaces, systems, and instruments from electrons, protons, and uv radiation and to provide thermal control of the surfaces and instruments they cover. Effective thermal protection and prevention of blanket outgassing in orbit has been accomplished by baking the blankets before launch. The procedure is to bake them in vacuum chambers. This is an expensive, time-consuming activity. Using the alternative method of employing a purge gas (nitrogen) to pump through the blanket interfaces at ambient pressure, time and resources can be saved, and the cleaning process can be conducted very near launch time.

Mass losses and outgassing rates for our three blanket samples have been measured in both test conditions: vacuum bake and gaseous flow purge. There were minimal differences in cleanliness level and outgassing between the two methods.

It is concluded that purging at normal pressure and temperature for up to 20 h is equivalent to vacuum degassing at the same temperature and time for most blanket applications. Purging can be much more economical, eliminating vacuum chamber preparation, blanket installation, chamber instrumentation, and vacuum chamber scheduling.

Acknowledgment

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