Development of a Phase Change Thermal Control Device

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Theme

THE use of phase change material (PCM) as a thermal control technique has been proposed for many spacecraft applications, including planetary descent probes. Although many promising PCMs have been identified during previous studies, the data required to design a minimum weight PCM device is lacking. A development program was initiated to obtain practical design information, starting with PCMs and container concepts previously identified. This paper discusses the results of an experimental investigation, including the PCM selection, container design, test setup, data analytical correlation and problem areas.

Contents

In certain spacecraft applications, when the environment represents a heat source rather than a heat sink or when the heat sink of deep space is not readily accessible, the addition of thermal capacitance to the spacecraft heat sources is a practical solution to the temperature control problem. An efficient technique to add thermal capacitance is to use a material which exhibits a change of phase in the range of control temperatures. The spacecraft application for the results of the development program is a planetary descent probe. PCM is proposed as a basic component of the thermal control subsystems of Venusian[1] and Jovian descent probes[2] and would be used to absorb thermal energy inside the probes since the external environment is a high-temperature, high-pressure gas.

Phase change thermal control devices have recently flown on the Lunar Roving Vehicle and will fly on the upcoming Skylab Project.[3] The activity in this technology to date has concentrated in the search for high-performance PCMs and on an understanding of the phase change phenomena.[4] So far the greatest material evaluation effort has centered around solid-liquid phase change systems with particular emphasis on the *n*-paraffin compounds. The technology is deficient in design data that can be used to develop flight hardware.

The major tasks in this program were as follows: 1) PCM search; 2) cell design and fabrication; 3) PCM-cell material compatibility tests; 4) tests of a matrix of PCM-cell design combinations at various power levels; and 5) analytical simulation of the test results. The term cell design refers here to the external package plus the metalic filler (if any) required to conduct heat into the PCM. The relatively low PCM thermal conductivity was enhanced by placing metallic honeycomb inside the cells. Since both cell weight and volume impact the probe design, determining the optimum metal matrix for a given design condition is important.

The source of requirements and parameters for the testing of the PCM devices was the Pioneer Venus descent probe studies, but are general enough to include the Jovian probe applications as well. In fact, but for two reservations discussed below, the test program applies to the general field of phase change thermal control. The probe requirements affecting the PCM cell design were the interface, the heating rate, and the duration of the heat input. The probe requirements affecting the PCM itself were the allowable temperature range of the electronics, 4°–52°C, and the fact that the operational requirements consisted of only one half of a cycle, i.e., one solid-to-liquid transition. The allowable temperature range limits the possible PCMs to those with transition temperatures within that range, and the half-cycle requirement means that supercooling of the liquid PCM is not a problem. This latter condition and the fact that the descent probe will be in a gravity field similar to the Earth's make the test requirements simpler but less general. The heating rate was parameterized by testing each configuration at 10, 20, 30, and 40 w.

The selection of a good PCM involves trying to get the best combination of several properties, and for this study the key criteria used was a transition temperature of $28°C \pm 17°$. Because very little was known about most candidate PCMs, it was decided to select materials from different classes to protect against unknown problems. The five materials originally selected were: 1) *n*-docosane (60 cal/g); 2) lithium nitrate trihydrate (70.7 cal/g); 3) sodium hydrogen phosphate dodecahydrate (66.8 cal/g); 4) gallium(19.2 cal/g); and 5) Trans-Temp-97 (63 cal/g). The first material is a paraffin and was included partially for comparison to earlier studies. The next two materials are hydrated salts, the next material is a metal and the last material is a proprietary product manufactured by Royal Industries. Gallium was dropped from further consideration during a secondary screening.

Two different cell designs were evaluated during the development program. One cell was a stainless steel bellows, with a diameter of 127 mm and a depth of 75 mm. A 100 mm-diam heater was epoxied to the bottom aluminum plate to provide the heat load. The second cell was aluminum, was rectangular in shape and was designed to simulate a flight configuration. PCM expansion and contraction was permitted by means of a rubber diaphragm which formed the top of the cell. The control surface heat-transfer area was 76 × 151 mm while the cell depth was 52 mm. Two 51 × 51 mm heaters were epoxied to the bottom of the cell to supply the heat load. Thermocouples were mounted inside and outside both cells to monitor cell thermal response. The experimental equipment used consisted of a variac, voltmeter, ammeter, multichannel recorder, and the test cell. During the experimental runs, the test cell was insulated from external temperature fluctuations by approximately 50 mm of polyurethane insulation.

Three test configurations were used in each of the cells: no filler, 0.076 mm aluminum honeycomb and 0.254 mm aluminum honeycomb. Not all combinations were tested and only representative results are presented in this discussion. The data for each run consisted of input power and thermocouple response data vs run time.

Figure 1 shows the temperature distribution in the bellows cell with the lithium salt, with the melting temperature (T_f) and the

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Index categories: Spacecraft Temperature Control Systems; Thermal Modeling and Experimental Thermal Simulation.

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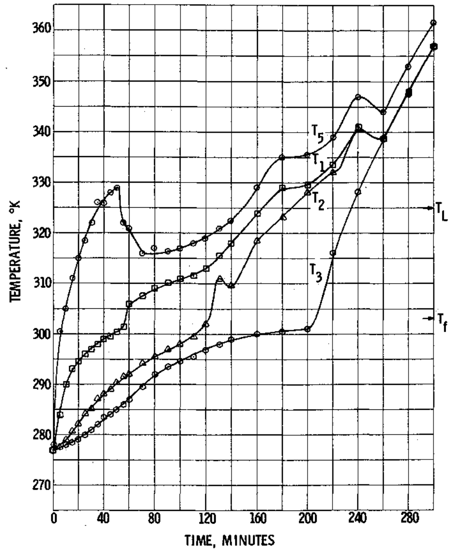

Fig. 1 Bellows cell/no filler, lithium nitrate trihydrate, 30.2 w.

design temperature limit (T_L) for the control thermocouple noted. The control thermocouple (T_5) was mounted on the inside of the heated surface while T_1, T_2, and T_3 are located in the PCM at progressively greater distances from the heated surface. The overshoot behavior of T_5 was present on several runs. The temperature would rise sharply at the beginning of a run and overshoot the steady-state value by several degrees. Figure 2 shows the response of the control thermocouple (T_2) for the rectangular cell, with heat load as a parameter. The effect of heat load is more pronounced if differences in initial temperatures are accounted for. Figure 3 is a comparison of control thermocouple response with filler configuration as a parameter. As expected, the temperatures decrease with the addition of filler. All runs were made by heating from the bottom, so natural convection was present in the liquid phase and helped to lessen temperature gradients.

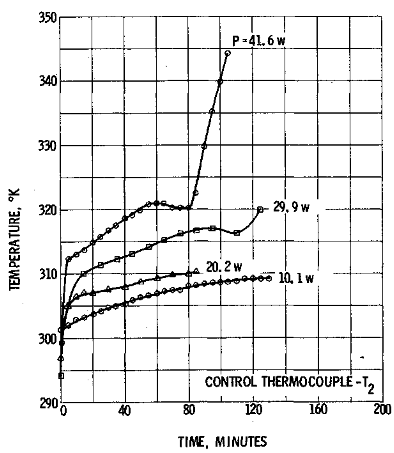

Fig. 2 Rectangular cell/0.254 mm HC, lithium nitrate trihydrate.

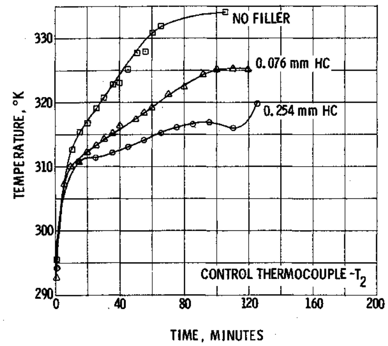

Fig. 3 Rectangular cell, lithium nitrate trihydrate, 30 w.

An attempt was made to correlate the experimental data using three separate analytical models: 1) a one-node forward difference scheme with no heat losses through the system boundaries; 2) a one-dimensional multinode forward difference scheme for the no-filler runs, and 3) a three-dimensional backward difference scheme for with-filler runs. The best correlation was achieved with the lithium salt and the one-dimensional model, which uses the hot plate temperature profile as one boundary condition.

A series of tests was conducted to evaluate long-term compatibility between PCMs and cell construction materials. The purpose of the test was to get relatively quick and simple answers to the question of whether serious compatibility or corrosion problems exist in using given metals and alloys with candidate PCMs. Several corrosion reactions were observed.

The series of tests with the sodium salt was terminated after 8 runs because of instability problems. The salt performed well during initial tests but the later tests appeared to suggest the absence of a significant phase change effect, probably due to the transformation to a lower hydrate form. During the Trans-Temp tests, water vapor condensate and solid crystals were observed at the thermocouple ports, and solid material collected on the bottom of the cell. Formation of an undesirable hydrate was suspected, and the remainder of this test series was suspended in lieu of a detailed laboratory investigation of melting points and temperature stability. The results of the investigation were inconclusive, but the degradation problems experienced with the material in this type of test program must be understood before continuing. It appears that air-tight test cells are required.

References

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