

Figure 1. A Slat Heater Box surrounds an object under test and is heated to a controlled temperature.

of the slat heater box and the cold chamber wall.

Given (1) the temperature of the chamber wall, (2) the fractions of the field of view occupied by the chamber wall and the slat heater box, and (3) the emissivities of the slats, chamber wall, and the surface of object under test, the slat temperature required to maintain a desired sink temperature can be calculated by solving the equations of gray-body radiation for the steady-state adiabatic case (equal absorption and emission by the object under test).

Slat heater boxes offer an important advantage over the infrared lamps that

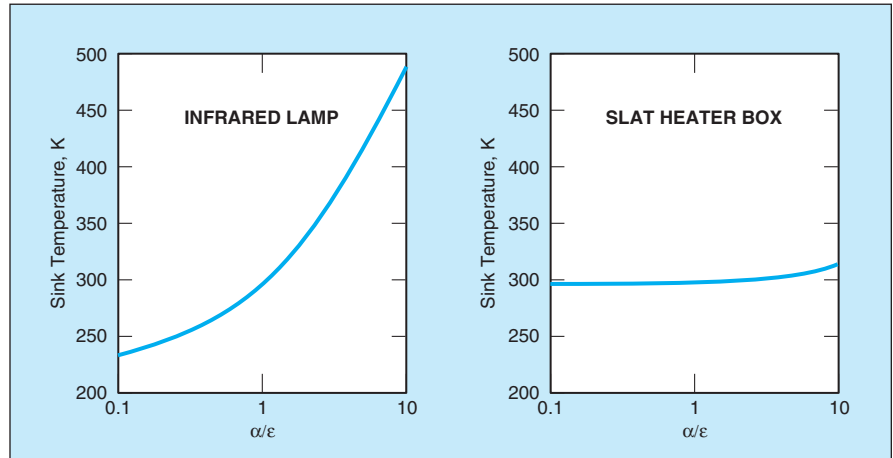


Figure 2. The Sink Temperature of a test object as a function of α/ϵ was calculated for a representative case of heating with a quartz infrared lamp at 10-percent power and a representative case of a slat heater box occupying a third of the field of view, with an emissivity of 0.865 and slat temperature of 410 K.

have been previously used to obtain desired sink temperatures: In comparison with an infrared lamp, a slat heater box provides a greater degree of sink temperature uniformity for a test-object surface that includes multiple areas with differing optical properties. This advantage can be seen by solving gray-body radiation equations for some representative cases of test objects for which the emissivity or absorptivity at wavelengths $<4 \mu\text{m}$ (denoted α) differs from the emissivity or absorptivity at wavelengths $>4 \mu\text{m}$ (denoted ϵ). [The term α is often denoted solar absorptivity because most of the power of solar radiation lies in the wavelength

range below $4 \mu\text{m}$, while the term ϵ is often denoted infrared or thermal emissivity because most of the power of room-temperature objects lies in the wavelength range $>4 \mu\text{m}$.] Figure 2 presents the results of one such calculation that illustrates the superiority of a slat heater box over an infrared lamp, in that the sink temperature is much less sensitive to α/ϵ in the case of the slat heater box.

This work was done by Eugene Ungar of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-23023

System for Testing Thermal Insulation of Pipes

Thermal and flow conditions are carefully controlled to minimize errors.

John F. Kennedy Space Center, Florida

An apparatus and method have been developed for measuring the rates of leakage of heat into pipes carrying liquids, the purpose of the measurements being to quantify the thermal performance of the insulation system. The apparatus is designed primarily for testing pipes used to carry cryogenic liquids, but can also be used for measuring the thermal performance of other insulated pipes or piping systems.

The basic measurement principle is straightforward: The outer surface of the pipe insulation is maintained at a fixed warmer temperature. The interior of the pipe is maintained in a narrow fixed lower-temperature range by means of a regular liquid (e.g., water) that is

pumped through the pipe at a known flow rate or a cryogenic liquid (e.g., nitrogen) that is saturated at atmospheric pressure and replenished until steady-state conditions are achieved.

In the case of water or another liquid pumped through, the inlet and outlet temperatures are measured and heat-leak power is calculated as the mass flow rate of the liquid multiplied by the specific heat of the liquid multiplied by the inlet-to-outlet temperature rise of the liquid. In the case of liquid nitrogen or another low-temperature boiling liquid, the heat-leak power is calculated as the rate of boil-off multiplied by the latent heat of vaporization of the liquid. Then the thermal-insulation perfor-

mance of the pipe system can be calculated as a function of the measured heat-leak power, the inner and outer boundary temperatures, and the dimensions of the pipe.

The apparatus can test as many as three pipes simultaneously. The pipes can have inner diameters up to $\approx 15 \text{ cm}$ and outer diameters up to $\approx 20 \text{ cm}$. The lengths of the pipes may vary; typical lengths are of the order of 18 m.

Two thermal guard boxes — one for each end of the pipe(s) under test — are used to make the inlet and outlet fluid connections to the pipe(s) (see figure). The connections include bellows that accommodate thermal expansion and contraction of the pipes. The guard boxes

and pipe(s) are positioned so that the pipe(s) slope upward from the upstream to the downstream end at an angle of at least 2°. The upward slope allows vapor bubbles to accumulate at the downstream end.

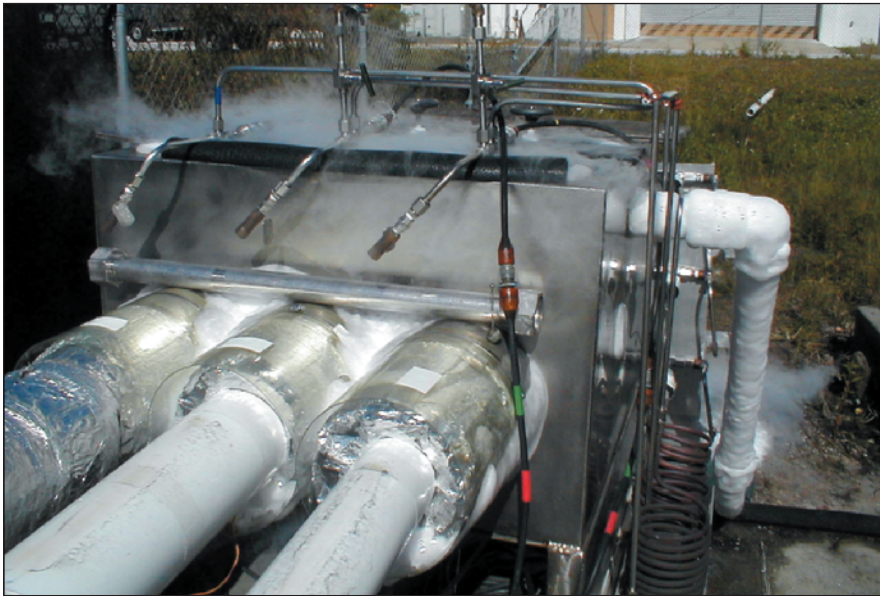
The thermal guard boxes keep the ends of the pipes at the lower interior temperature to prevent spurious lengthwise leakage of heat into the pipes. It is important to prevent this spurious heat leakage because, if it were allowed to

occur, it could contribute a large error in the measured heat-leak power. The upstream thermal guard box includes a heat exchanger through which liquid flowing into the pipe(s) is subcooled to the saturation temperature corresponding to the ambient pressure. Conversely, this heat exchanger can also be used to warm the flowing liquid to a desired fixed temperature.

The apparatus includes a temperature control device that is placed around each pipe under test. Each device is operated under thermostatic control to maintain the outer surface of the pipe insulation at the specified test temperature. All measurements are recorded on a portable data-acquisition system.

This work was done by James E. Fesmire of Kennedy Space Center and Stanislaw D. Augustynowicz and Zoltan F. Nagy of Dynacs, Inc. Further information is contained in a TSP (see page 1).

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Technology Programs and Commercialization Office, Kennedy Space Center, (321) 867-8130. Refer to KSC-12205.



Thermal Guard Boxes at the ends of a pipe under test are used to make the fluid connections to the pipe. In addition, a temperature control device imposes a specified temperature on the outer surface of the pipe insulation.

Electrical-Impedance-Based Ice-Thickness Gauges

Compact, inexpensive gauges provide early warnings of accretion of ice.

Langley Research Center, Hampton, Virginia

Langley Research Center has developed electrical-impedance-based ice-thickness gauges and is seeking partners and collaborators to commercialize them. When used as parts of active monitoring and diagnostic systems, these gauges make it possible to begin deicing or to take other protective measures before ice accretes to dangerous levels. These gauges are inexpensive, small, and simple to produce. They can be adapted to use on a variety of stationary and moving structures that are subject to accumulation of ice. Examples of such structures include aircraft, cars, trucks, ships, buildings, towers, power lines (see figure), power-generating equipment, water pipes, freezer compartments, and cooling coils.

A gauge of this type includes a temperature sensor and two or more pairs of electrically insulated conductors embedded in a surface on which ice could accumulate. The electrical impedances of the pairs of conductors vary with the thickness of any ice that may be present. Somewhat



Ice Accumulating on Power Lines poses a hazard. Gauges like those described in the text can provide early warnings of the buildup of ice.

more specifically, when the pairs of conductors are spaced appropriately, the ratio between their impedances is indicative of the thickness of the ice. Therefore, the gauge includes embedded electronic circuits that measure the electrical impedances, plus circuits that process the combination of temperature and impedance measurements to determine whether ice is present and, if so, how thick it is. Of course, in the processing of the impedance measurements, the temperature measurements help the circuitry to distinguish between liquid water and ice.

The basic design of a gauge of this type can be adapted to local conditions. For example, if there is a need to monitor ice over a wide range of thickness, then the gauge can include more than two sets of conductors having various spacings.

This work was done by Leonard Weinstein of Langley Research Center. Further information is contained in a TSP (see page 1). LAR-16093