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ENVIRONMENTAL
TESTING TO 2000°F

by

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As we enter the space age, environmental engineers are faced with many new problems in environmental testing. For example, supersonic carriers and their interior components must be able to withstand extremely severe environmental conditions -- conditions that must be simulated so that the components and carriers can be tested. Often this requires drastic changes and new designs for testing equipment and techniques. It is a relatively simple matter to attain high thermal inputs on what might be considered extremely small samples. The solar furnace and the common oxy-acetylene flame will produce very high temperatures on sample sizes below one square inch in area. More elaborate and less well-known systems such as the plasma jet have produced densities estimated at several thousand BTU/Ft²-second over quite small samples. Environmental testing engineers at Sandia are not immediately concerned with the production of extremely high thermal densities over small samples, but with the production of several hundred BTU/Ft² second over relatively large areas. The purpose of this paper is to explain some of Sandia's techniques and apparatus, to discuss in detail some specific tests, and to discuss plans for future tests.

Tungsten filament lamps in quartz envelopes are, at present, widely used to obtain outputs of 0.200 kilowatts per inch of filament for relatively short times. Sandia is now experimenting with a tungsten filament tube rated at 1.1 kilowatts per inch of filament which, it is hoped, can be utilized in future tests. Present tubes are limited to about 0.600 to 0.700 kilowatts per inch, providing a thermal density of approximately 350 BTU/Ft² seconds, and it is felt that this is the immediate upper limit of capabilities using tubes of this rating.

The guiding factor in the use of quartz lamps is not only the limitation imposed on the end seal, but also the melting or softening point of the quartz envelope. This occurs around 3200°F. After extended use at low energy levels, or short time use at high energy levels, some of the material from inside the lamp is deposited on the quartz in the form of a black or apparent gray deposit, an occurrence that is also noticeable in used household lamps. This blackening reduces the output of the lamp, and certainly must absorb some radiation, resulting in a cumulative shortening of lamp life. Another result of operating at excessively high energy levels is softening. In this case, the bulb expands as a result of excessive pressure from the inert gas contained within; of course this expansion destroys the element.

Figure 1 is a cylindrical heater for the simulation of aerodynamic heating on a cylindrical component. The water containers to which the infra-red tubes are connected are built of copper for good thermal and electrical conductivity. With the safe operating temperature of the tube end seal being 600°F, the nickel envelope of the end seal can be kept at 300° - 400°F on tests of several minutes duration at low intensities, or short tests at high intensities. The cost of these heater elements justifies some good design to extend their life. Not visible in the photograph is the stainless steel reflector, supported on porcelain stand off insulators so that air from natural convection will cool the back of the reflector. Stainless steel is not the best reflector for infra-red radiation at the wave lengths of present operation; however, it is relatively economical, retains a polish for some time, and is readily available.

Figure 2 shows a high density plane element, designed by Sandia engineers, which uses slotted brass bar contacts bolted to aluminum channels. For periods up to 20 seconds and at maximum power outputs of 350 BTU/ft² second, this design keeps the end seals below 400°F. This design uses a

20 gage gold-plated copper reflector. The plating will take and retain a high polish. Since the melting point of the plating may be as low as 1900 to 2000°F, it is believed that the high thermal conductance of copper is one reason for the long life of this plating. It has been used for a total time of about 15 minutes at what is considered high thermal densities.

Figure 3 depicts a test sample and several reflectors used with the heater element shown in Figure 2. The purpose of the reflector shown by the arrow is to re-radiate the thermal energy escaping near the ends of the lamps back to the reflector behind the lamps. This was the only way to achieve the 350 BTU level mentioned previously. In this test plate the lamps were spaced 30 to the foot. This is the same spacing used by some commercially-produced elements with waterwick cooling of the end seals. It is apparent that, by a slight re-design, one may achieve a spacing of 36 to the foot. At such densities, air cooling of the quartz envelopes should be considered. The cost of the lamps again justifies good design to extend lamp life.

In some test requirements, the aerodynamicist may specify energy input to a device in BTU/square foot-second or expected temperature rise on the surface of the material. When this material surface is exposed to high density thermal radiation from source temperatures of several thousand degrees Fahrenheit, treatment of the surface temperature sensing element becomes one of the most important aspects of the whole system. Most engineers are familiar with the problems of measuring temperatures on surfaces exposed to convective fluid flow. The mass and discontinuities occasioned by the temperature sensing element upset the convective flow, and transfer heat away from or into the contact area at a greater rate than may be experienced in cases where the discontinuity does not exist.

The contact problem is magnified by several factors in attempting to measure surface temperatures under radiant field conditions. If the sensing

element is brought into the field from the back or unheated side of a sample, then the temperature gradient along the sensing element lead wires is excessive, tending to cool the pickup point. If the rate of surface rise is several hundred degrees per second, this high temperature gradient "compounds the felony" in cooling faster than would be experienced under low rates of rise. Disturbance of the heat sink material by drilling a hole from the back or unheated side likewise may give erroneous results by changing the heat conductive properties at the point of contact. This same problem would be encountered when one uses a different material than the heat sink and sets the material into the exposed face of the heat sink.

Apparently, the most logical solution to this problem is to arrange the temperature sensing device in an isothermal field on the exposed surface of the test item. It is then necessary to insure that the sensing element is not exposed directly to thermal flux unless it is an integral part of the surface and has the same absorptivity as the surface. Naturally, a thermocouple material which will answer these requirements cannot be acquired. There are ceramic insulators and ceramic cements which have high conductivity, good bonding abilities, and coefficients of expansion close enough to that of the material being tested to get two or more tests before the bond is loosened. Figure 4 is an illustration of tests done on nickel-plated steel having a ground finish. The couple insulators used were McDanel Porcelain flat oval type cemented to the surface with No. 32 Sauereisen cement in one case, and No. 1 Sauereisen in the other case. Results of testing were compared with other means, which are illustrated in Figures 5 and 6.

In the case of Figure 5, a milled "V" slot 0.010 inch by 0.010 inch was cut into the material, and a 30 gage couple was fitted into the slot. Since this was a test of the reflectivity of gold plating, the whole surface was then cyanide plated, including the thermocouple leads. The slot was peened slightly to

provide intimate contact between the couple and base material. Treatment of the chromel alumel couple in the lower part of Figure 5 was somewhat different. It was flattened to 0.006 inch in thickness and spot welded to the surface. The temperature reading from this sensing element was higher than expected. This was probably caused by less intimate contact between the ceramic insulator and the surface of the test material. The conductance through a weld is not known, so there is a possibility that the couple contact was not transferring heat to the base material, resulting in an additional source of error in temperature in the higher reading direction. A comparison of transient temperatures attained by the several methods described above is listed in Table I. The results agree with the calculated results from the one dimensional heat flow equation. Further study of this problem is justified to determine the effects of direct radiation on the sensing elements in the V slots. Figure 6 is similar to the preceding photograph, except that the measuring elements were placed in a slot 0.015 inch deep, instead of 0.010 inch deep. This was done to prove that a temperature gradient did exist and to determine the effect of radiation. Reference to Table I again will reveal that the temperature gradient between the 0.010 inch and 0.015 inch slotted mounting agreed closely with anticipated results.

TABLE I
TEMPERATURES ON SURFACE AND IN "V" SLOTS ON
GOLD-PLATED STEEL SAMPLE
DEGREES F

<u>Time in Seconds</u>	<u>Surface</u>	<u>Slot 0.10"</u>	<u>Slot 0.015"</u>
0	76	76	76
10	253	123	113
20	288	211	197
30	420	361	342
40	530	439	430
50	580	490	477
60	610	536	490
70	700	556	510
80	785	569	520
90	870	588	542
100	926	624	549
110	953	636	556
120	980	647	562

Measurements from a 1750°F source radiating to steel receiver.

Figure 7 illustrates the attachment of thermocouples by spot welding. Thirty gage chromel-alumel couples were flattened slightly and spot welded, using 22 watt-seconds of energy for each weld. For most alloys, this type of welding is successful. On some aluminum alloys, an inert atmosphere helps to prevent excessive oxidation. This figure also illustrates the use of ceramic cements to protect the thermocouple leads. Sauereisen No. 29 and Sauereisen No. 1 were used here; the No. 29 retained the better bond.

It is not generally possible to measure thermal energy input to test items except by time consuming means involving complex physical systems. The time response of such systems is too slow for most measurements involving rockets or missiles. Even if high response systems were available, the difference in surface conditions and emissivity between the calorimeter and test items would lead to erroneous conclusions.

The most satisfactory results are usually attained by solution of the basic differential heat flow equation, either by analog means or analog computers. Sandia engineers have access to a thermal analyzer which is an electrical analogy of a mechanical problem. Also the analog computer has been used where variations in conductivity and specific heat with temperature may be set into the computer. The heat input may be programmed in as another function. The computer solves the differential heat flow equation and a time temperature curve is read out. In problems where physical constants and "q" change rapidly, an analog or digital computer solution is the only logical approach to calculate the expected temperature.

These are some of the apparatus and techniques being used in order to simulate environmental conditions to test supersonic vehicle components.

In the future, Sandia will have newly designed apparatus. The Sandia radiant heat facility, which is now in the construction stage (Figure 8) will have a maximum capability of 13,500 kilowatts input to the specimen heaters. It will consist of 8 channels, either time-temperature controlled, or computer controlled, permitting the heat input to be varied axially along a cylindrical specimen in conformance with either one of four functions.

1. The first function is for the solution to the equation relating heat transfer between a surface and a fluid in contact with the surface. This is the basic aerodynamic transfer equation.

2. The second is for the solution to the differential equation for one-dimensional heat flow into a material where the BTU input and material constants are given.

3. The third is for time temperature programming in which the solution to the basic conduction equation is already known.

4. The fourth is for timed heat-soak of a specimen for several minutes.

The large number of channels is necessary to simulate the heat gradients along the axis, which is a physical function of the aerodynamics of the specimen.

Figure 9 outlines the basic operation of the radiant heating systems. The desired thermal input is fed into a programmer-computer from the function generator, which in turn supplies control signals to the power regulator. A temperature feedback signal from the specimen is recorded and is also used to indicate to the programmer-computer that the specimen is following the desired temperature curve.

There are a great many advantages to be gained from the simulated heating of specimens. But in order to make a closer approach to realism, it is necessary to test under conditions of combined environments. Sandia is performing acceleration or deceleration loading of vehicles while heating to the anticipated

temperatures. A test of this nature requires very good control of the parameters to achieve the simultaneous load and temperature characteristics expected on a full scale test.

It is possible to avoid the expense of flight testing in the initial design stages by simulation of heating and loading. No telemetry equipment is required in this type of test, and complete temperature and load data may be acquired without recourse to radio transmission. Further, we can duplicate the environment in order to check our results. No missile carrier components are involved and analysis of results is simplified. Most important of all is the fact that early testing may be performed on engineering designs without awaiting full scale flight tests.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

RADIANT HEAT FACILITY
(AREA 3)

Figure 8

PROPOSED RADIANT HEATING SYSTEM

Figure 9