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TEMPERATURE AND LIQUID-LEVEL SENSOR FOR LIQUID-HYDROGEN PRESSURIZATION AND EXPULSION STUDIES

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SUMMARY

In experimental studies of the pressurization and expulsion of liquid hydrogen, temperature-measuring systems are needed to understand the effectiveness of a particular pressurization system. Existing state-of-the-art temperature-measuring systems are considered inadequate to meet the rather stringent design requirements necessary for accuracy and precision in the measurement of ullage gas temperatures.

A temperature-measurement technique that uses thermopiles (i.e., thermocouples in series) as sensors was therefore developed. The results of this development indicate (1) that an instrument rake using measurement stations constructed of thermopiles can measure temperatures to within ±1.65° K (for gas temperatures between 20° and 300° K) and (2) that, in addition to their use as temperature sensors, thermopile units can be used as point liquid-level sensors for subcooled liquid during liquid outflow. Tests indicate that thermopiles can detect liquid level to within ±0.453 centimeter.

INTRODUCTION

In experimental studies of the pressurization and expulsion of liquid hydrogen, measurements of wall, liquid, and gas temperatures are needed to understand the effectiveness of a particular pressurization system. Several commercial sensors are capable of measuring tank-wall and liquid temperatures.

The ullage gas temperatures are used to determine the amount of gas in the tank ullage. To achieve the accuracy and precision required for research on hydrogen expulsions, temperature-measuring systems are needed which generally meet the following design requirements:

(1) The sensors must be accurate over a large range of temperatures (usually between liquid-hydrogen (approx. 20° K) and inlet-gas (165° to 390° K) temperatures).

(2) The sensors and their support structure must withstand temperature cycling and (where it might affect sensor calibration) pressure cycling inherent in tank-pressurization experimental work.

(3) The measurement system must be of minimum mass to be a negligible heat sink when compared to the tank walls and other necessary internal tank hardware. A reasonable goal would be a measurement-system heat capacity that is less than 1 percent of the heat capacity of the tank walls and internal hardware.

(4) The measurement system must also be of minimum cross-sectional area. Otherwise, it tends to disturb the normal environmental conditions in the ullage.

(5) The sensors must have a sufficient change in output signal for 1° K change in temperature to keep the readout equipment within the limitations of ordinary test-cell apparatus.

(6) The sensors must have a fast response to changes in temperature.

In past experimental studies at Lewis, most of the temperature-measuring-system design requirements were realized. However, the poor response characteristics of temperature sensors has been a major difficulty in the accurate measurement of rapid changes in temperature, particularly near the moving liquid-gas interface. During an expulsion, a film of liquid adheres to a sensor as it passes from the liquid propellant into the ullage gas. The sensor indicates true temperature only after this film of liquid has evaporated.

In view of this difficulty, Lewis undertook to develop a ullage gas temperature-measurement system which would satisfy the above mentioned range, structural, and output-signal requirements. Moreover, the goal is a system capable of measuring temperatures to within 1 percent of the absolute values and that has a time constant of less than 1 second going from saturated liquid to saturated vapor.

A survey was made to evaluate the characteristics of various temperature sensors. A transducer was chosen and built into a measurement system. This system was then used in a 0.82-cubic-meter cylindrical tank during liquid-hydrogen expulsion studies. This report discusses the considerations which led to the choice of the particular sensor and the construction of the measurement system. It also discusses the accuracies obtained with this system during the expulsion studies.

The original function of the measuring system was to determine ullage gas temperature profiles. During the testing, however, it was found that the system could also be used to determine liquid level during expulsion. A photographic calibration of the system was made to verify one of the system output characteristics with the actual location of the liquid surface. This calibration, as well as the resulting expected accuracy of liquid-level indication, is discussed herein.

SYMBOLS

E	thermoelectric potential (emf)
J	total number of individual errors
K	thermopile position
ΔL	accuracy of liquid-level determination
n	number of thermocouples in series
R	readability of oscillograph
T	temperature, $^{\circ}K$
$\dot{T}$	slope of temperature-time curve
V	velocity of test configuration
Δx	precision in locating variable-speed shaft assembly
σ	standard deviation

Subscripts:

b	bulk
ref	reference
sat	saturation

SELECTION OF SENSORS FOR ULLAGE GAS TEMPERATURE MEASUREMENT

The response time of a temperature sensor is directly proportional to sensor mass and inversely proportional to exposed surface area. Therefore, the survey of temperature-measurement sensors was restricted to units which have a low mass-to-surface-area ratio. The results of the survey showed that the following three major types of sensors could possibly be used: (1) carbon resistors (0.1-W, 100-Ω units, which are widely used at Lewis), (2) miniature platinum resistance sensors, and (3) thermocouples. Two techniques were considered for measuring the ullage gas temperature profile. The first was to obtain a series of absolute temperature measurements (sensor types (1) and (2)). The second was to obtain a series of differential temperature measurements relative to either a single or several known reference temperatures (sensor type (3)).

Absolute Temperature-Measurement Sensors

Carbon resistors. - Investigators (ref. 1) have used carbon resistors for temperature measurements in a hydrogen environment. Through proper selection and periodic calibration, an accuracy within 1 percent of the absolute temperature can be obtained between 20° and 55° K. However, because of the high negative temperature coefficient of carbon, large errors could result when measuring temperatures greater than 55° K. For increasing temperatures, this characteristic of carbon results in a lower resistance and, thus, in reduced sensitivity (i.e., reduced change in signal/°K). For instance, the sensitivity of a carbon resistor, in maximum percent change in signal, is 3 percent per °K at 20° K and only 0.025 percent per °K at 300° K. Therefore, in recording this signal with a system that has an accuracy of 1/2 percent of full scale, the temperature uncertainty would be ±0.17° K at 20° K and ±20° K at 300° K. The carbon resistor has an analytically estimated time constant between 0.2 and 2.0 seconds for a step change in temperature of less than 110° K in a single-phase fluid, but time constants between 2.0 and 10.0 seconds are estimated when going from a saturated liquid to a saturated vapor. As a result, temperature measurements near the liquid surface during a liquid discharge would not be representative of the true temperatures at the instant of time they were taken. The correction of each carbon resistor for its particular time lag would be difficult because of the varying environmental conditions existing above the liquid interface.

The carbon-film sensor, under development by several industrial firms, shows improvement in response time over the commercial carbon resistor. However, it is still usable only over a limited temperature range. In view of these difficulties, the carbon resistor was dropped from further consideration as a sensor for the test objectives of this program.

Miniature platinum resistor sensors. - This type of sensor has approximately the same physical dimensions (approx. 0.13 cm in diam., and 1.27 cm long) as the 0.1-watt carbon resistor. This sensor can be used over the entire temperature range encountered in pressurization and expulsion testing. The sensitivity of a platinum sensor is 14 percent per °K at 20° K and 0.38 percent per °K at 300° K. For a ±1/2 percent measuring system, the expected uncertainty would be ±0.036° K at 20° K and ±1.32° K at 300° K. (These sensitivities were taken from a sensor which has a resistance of 1000 Ω at 280° K.)

The 14 percent per °K sensitivity at 20° K for platinum resistance sensors can be misleading. A sensor that has 1000 ohms resistance at room temperature has only 4.0 ohms at 20° K. Thus, the 14 percent per °K sensitivity means a change of about 0.60 ohm per °K. Readout equipment accuracy of ±0.01 percent of full scale would be necessary in order to measure temperatures to within ±1 percent over the entire range expected (20° to 390° K). This readout equipment requirement can be reduced by using sensor and bridge systems designed to given certain outputs over various temperature ranges. Thus, redundant sensors each with a different bridge network could be necessary to obtain a satisfactory balance between readout equipment accuracy and temperature-measurement accuracy.

The platinum sensors have better reproducibility because they are not as subject to aging effects caused by temperature and pressure cycling as are the carbon sensors. Since the physical dimensions of the platinum sensor are similar to the carbon resistor, the calculated time constants are approximately the same order of magnitude (2.0 to 10.0 sec going from saturated liquid to saturated vapor).

The platinum resistance sensors were also discarded as a major ullage gas temperature sensor (1) because these time constants are considered too long for accurate measurements of rapid temperature changes and (2) because the cost would be great for redundant sensor and bridge systems to cover a rather fine network of points in the ullage volume.

Differential Temperature Sensors

Thermocouples. - Thermocouples, like platinum resistance sensors, can be used over a wide temperature range with increasing output as temperature is increased. However, the following thermocouple features limit their use at liquid-hydrogen temperatures: (1) low signal level, a factor which requires sensitive readout equipment and (2) poor repeatability of output signal (caused by inhomogeneities in the thermocouple wire).

Thermopiles. - The low signal level of a single thermocouple can be overcome by using several thermocouples in series (i.e., a thermopile). The use of thermopiles reduces the requirement for sensitive readout equipment and also increases the signal-to-noise ratio over that of a single thermocouple.

Theoretically, a 2n element thermopile (n thermocouples in series) produces n times the electromotive force of a single thermocouple. Moreover, since the electromotive forces due to inhomogeneities in the leads of various elements are just as likely to cancel each other as to add, the probable resultant electromotive-force error from inhomogeneities is only $\sqrt{n}$ times as large as with a single thermocouple. Hence, the probability of a temperature-measurement error due to inhomogeneities will be reduced by a factor of $1/\sqrt{n}$.

For consistency in comparison, the same definition for sensitivity is used (i.e., percent change in signal per $^{\circ}$K from a 0° K base). It must be kept in mind, however, that this definition may be misleading when applied to thermocouples systems because of their low signal level at low temperatures. When this definition is used, however, the thermocouple and/or thermopiles compare favorably with the carbon and platinum resistance sensors. From an accuracy standpoint, thermopiles may conceivably be used for ullage gas temperature measurements in warm-gas-pressurized propellant tanks.

The main advantage of using thermopiles is that they have a calculated response time that is approximately an order of magnitude lower than those of carbon resistors and commercially available platinum resistors. As a practical consideration, fabrication of small-diameter-wire thermopiles is readily accomplished at low cost.

Based on the above advantages and disadvantages of the three types of temperature probes considered, it was decided that small-diameter-wire thermocouples appeared to be the best-suited sensors for the transient temperature measurements desired.

Thermocouple Material Combinations

In the selection of the best thermocouple pair for this application, the following material combinations were considered: gold-cobalt - copper, copper-constantan, and Chromel-constantan. These three thermocouple pairs have approximately the same sensitivity. Their sensitivities vary between 9 and 10 percent per $^{\circ}$K at 20° K and 0.4 and 0.6 percent per $^{\circ}$K at 300° K.

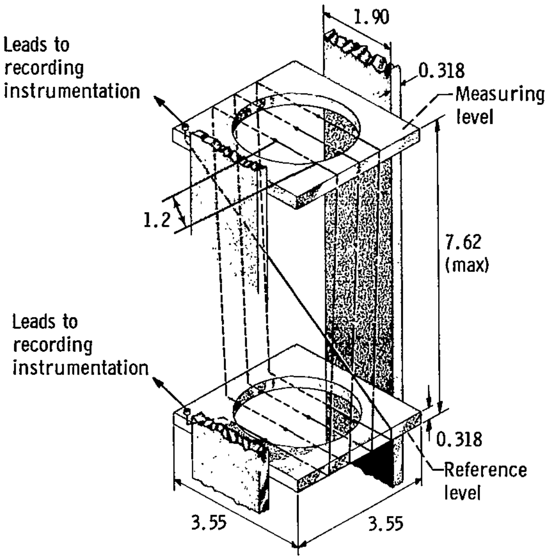
The signal level of the gold-cobalt - copper combination is almost three times that of copper-constantan at 20° K. The real disadvantage of gold-cobalt - copper is that errors of 10 percent at 20° K are possible if published calibration tables are used instead of calibrations of each thermocouple. This error is caused by deviations of thermoelectric power between wires from different lots or even from the same lot (ref. 2).

The copper-constantan combination, although having a lower signal level, has greater thermoelectric stability relative to the gold-cobalt - copper combination (ref. 2). The Chromel-constantan combination has approximately a 50 percent increase in signal level over a copper-constantan combination at liquid-hydrogen temperatures.

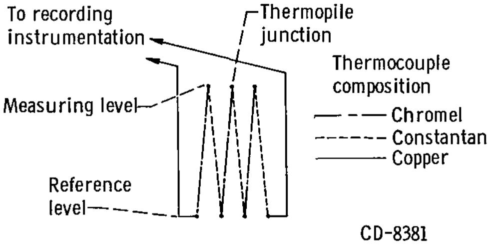
The necessity of calibrating each gold-cobalt - copper thermocouple eliminated this combination from further consideration. From the remaining two combinations, the Chromel-constantan thermocouple was selected. The main considerations in this choice were the 50 percent higher signal level and the fact that both Chromel and constantan are alloys of low thermal conductivity. The low thermal conductivity minimizes errors caused by heat conduction through the wires.

Construction

A typical unit and wiring diagram for a three-element Chromel-constantan thermo-



(a) Typical thermopile unit. (Dimensions are in cm.)

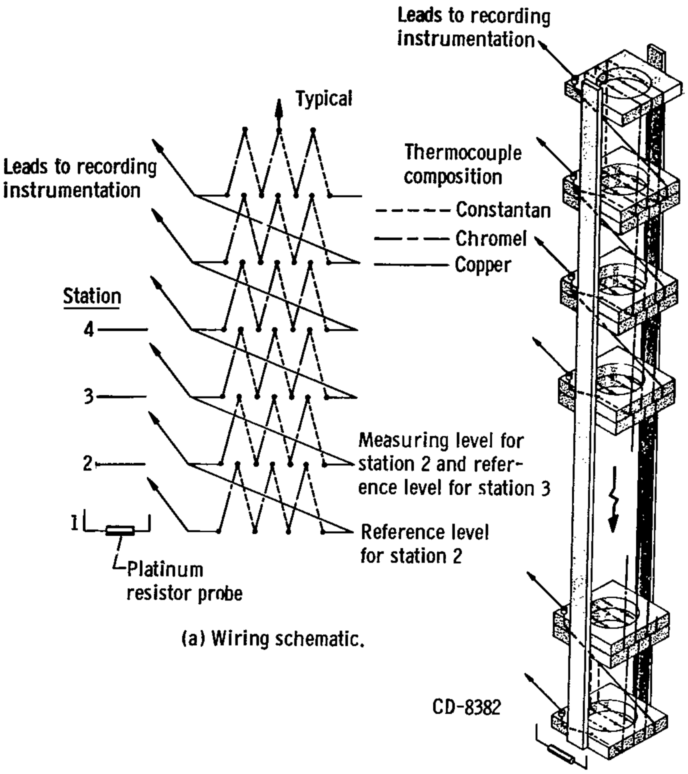


(b) Wiring diagram.

Figure 1. - Three-element thermopile unit.

pile are shown in figure 1. If the three individual couples have identical temperature against electromotive-force calibrations, the output of the unit will be three times the output of a single couple. (Similarity in calibration can be obtained by using material from the same spool of wire.)

By stacking the individual thermopile units (as shown in fig. 2), a series of differential temperature measurements can be made. The thermopile technique shown does not use one temperature reference for all differential measurements. A series of "floating" reference temperatures are used (i.e., the measuring station of any one thermopile unit is used as the reference for the unit directly above). Much smaller temperature differences can be measured by keeping the reference junctions inside the test tank and near the temperature range of the measuring junction. This technique improves the accuracy over the more conventional technique which uses a single reference junction located outside the experimental apparatus. It also keeps temperature gradients along the thermocouple wire to a minimum and thereby decreases the parasitic wire inhomogeneity voltages. Only the copper lead wires, which are relatively free of parasitic inho-



(a) Wiring schematic.

(b) Sketch.

Figure 2. - Thermopile rake.

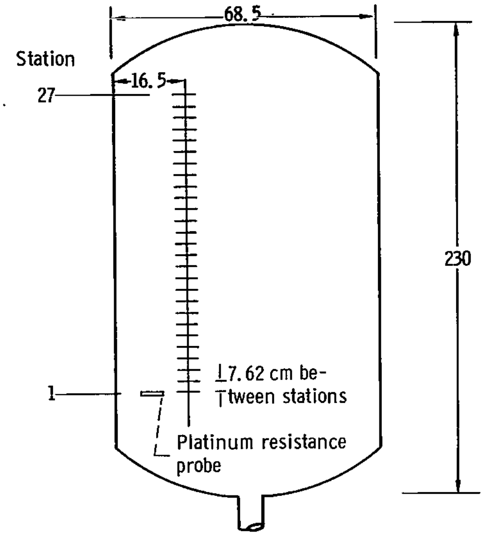
mogeneity voltage, will experience large temperature gradients.

The support structure (fig. 1(a)) for the thermopiles was constructed of 0.318-centimeter-thick laminated thermoplastic. The distance between each reference and measuring junction was 7.62 centimeters. A nominal 1.20-centimeter spacing between thermocouple junction and laminated thermoplastic support was used to keep the conduction errors less than 0.10° K when the temperature difference between the gas and support is 100° K. The thermocouple wires were installed with enough slack to prevent any straining due to thermal contraction.

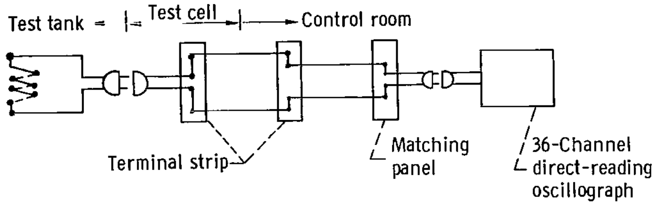
It must be kept in mind that the temperature - electromotive-force characteristic is not linear for thermoelectric type sensors; thus, the actual temperature difference depends on the absolute temperature level. The initial reference temperature (i.e., the temperature at station 1, fig. 2) may be obtained in a number of ways. The technique employed was the use of a commercial platinum resistance sensor with a bridge range of 20° to 39° K. By keeping the platinum sensor submerged in the liquid-hydrogen propellant during all testing, a relatively constant reference temperature is obtained.

Application

The installation of the thermopile rake in a 0.82-cubic-meter cylindrical liquid-hydrogen tank is shown in figure 3(a). A schematic diagram of the complete measuring circuitry for a typical instrumentation channel is shown in figure 3(b). At any instant of time during a test expulsion, the absolute temperature T_K at any thermopile station K above the platinum resistance sensor may be obtained in the following manner:



(a) Installation of thermopiles inside test tank. (Dimensions in cm.)

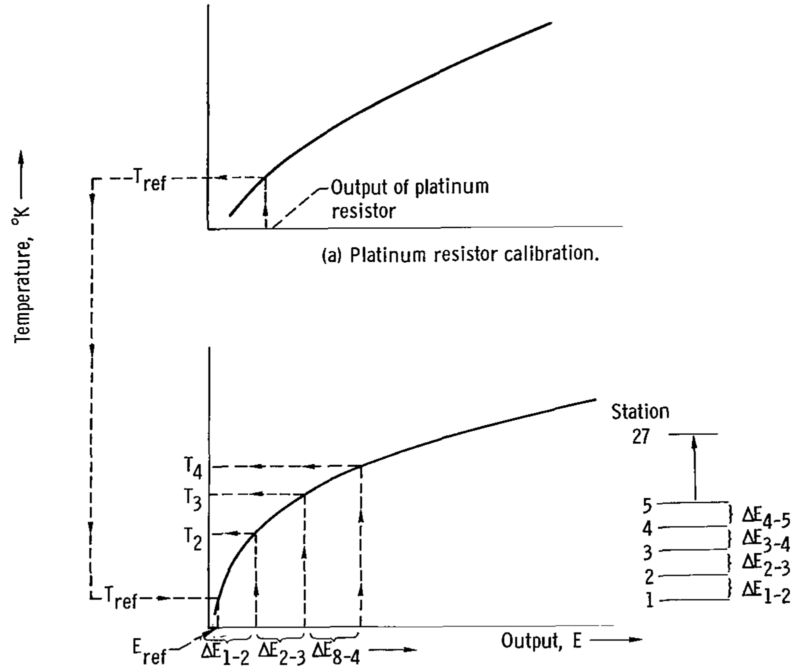


(b) Complete thermopile instrumentation channel.

Figure 3. - Test-tank instrumentation.

(1) Determine the reference voltage on the Chromel-constantan claibration curve from the temperature of the platinum sensor (fig. 4(a)).

(2) Add to this voltage the summation of the individual differential voltage of each thermopile unit between the platinum sensor and the measurement station being considered (fig. 4(b)). This procedure can be expressed by the following relation:



(a) Platinum resistor calibration.

(b) Thermopile calibration.

Figure 4. - Determination of temperature profiles. $T_K \propto E_{ref} + \sum_{i=1}^{K-1} \Delta E_{i \rightarrow i+1}$ for $2 \leq K \leq 27$; $T_K = T_{ref}$ for $K = 1$.

$$T_K \propto E_{ref} + \sum_{i=1}^{K-1} \Delta E_{i \rightarrow i+1} \quad \text{for} \quad 2 \leq K \leq 27$$

Temperature - electromotive-force data existing in the literature (ref. 3) for Chromel-constantan thermocouples were extended down to 20° K. These data were then used for temperature reduction.

Results and Discussion

Approximately 60 liquid-hydrogen expulsion tests were conducted in which the thermopile rake was used to determine vertical temperature profiles in the ullage. These temperatures were then used to calculate the mass and internal energy of the ullage gas.

An error analysis was performed on a typical thermopile measuring circuit (fig. 3(b)) to determine the uncertainty of a temperature measurement. The following factors were considered in the error analysis:

(1) Thermopile calibration error
(2) The uncertainty of determining the absolute reference temperature (i.e., platinum resistance sensor)
(3) Circuitry errors such as parasitic electromotive force in lines and connectors
(4) Noise
(5) Field calibration errors
(6) Accuracy of the readout equipment

The probable temperature error ΔT for a single thermopile circuit was obtained from the relation

$$(\Delta T)^2 = \sum_{i=1}^{J} \left(\frac{\partial T}{\partial E} \Delta E_i \right)^2$$

$$\Delta T = \frac{\partial T}{\partial E} \left(\sum_{i=1}^{J} (\Delta E_i)^2 \right)^{1/2}$$

where J is the total number of individual errors, $\partial T / \partial E$ is the slope of the calibration curve at the measured temperature, and ΔE is the electromotive-force errors from the six factors mentioned previously. The value of

$$\left(\sum_{i=1}^{J} (\Delta E_i)^2 \right)^{1/2}$$

for the thermopile circuit was determined to be ±39 microvolts. The value of $\partial T / \partial E$ at 32° K is 0.0253° K per microvolt. The probable temperature error would then be $\pm 1.0^\circ$ K at a measured temperature of 32° K. (Although this error does not meet the 1 percent goal stated in the INTRODUCTION, it is considered acceptable in light of other qualifications of the transducer.) This temperature error decreases for increasing absolute temperature because $\partial T / \partial E$ decreases with increasing temperature (i.e., at 167° K, $\partial T / \partial E = 0.0076$ and, therefore, $\Delta T = \pm 0.30^\circ$ K). The temperature error at any station K above the platinum reference temperature is obtained by summing the individual temperature variances of all thermopile units to station K, that is,

$$\Delta T_K = \left(\sum_{i=1}^{K} (\Delta T_i)^2 \right)^{1/2}$$

Since the probable error for any station is dependent on (1) the absolute temperature at that station and (2) the probable error of each thermopile unit below that station, the accuracy of this measurement technique depends on the particular temperature profile existing in the tank ullage.

Figure 5 represents two extremes in ullage gas temperature profiles that have been obtained during testing. Profile A resulted when a multiple-screen injector was used; profile B resulted when a straight-pipe injector was used. Each profile was obtained at the end of a 130-second expulsion. The band around each profile represents the probable error associated with the measured temperature. The uncertainty at the thermopile farthest from the platinum reference sensor (i.e., station 27) is ±1.65° K for profile A

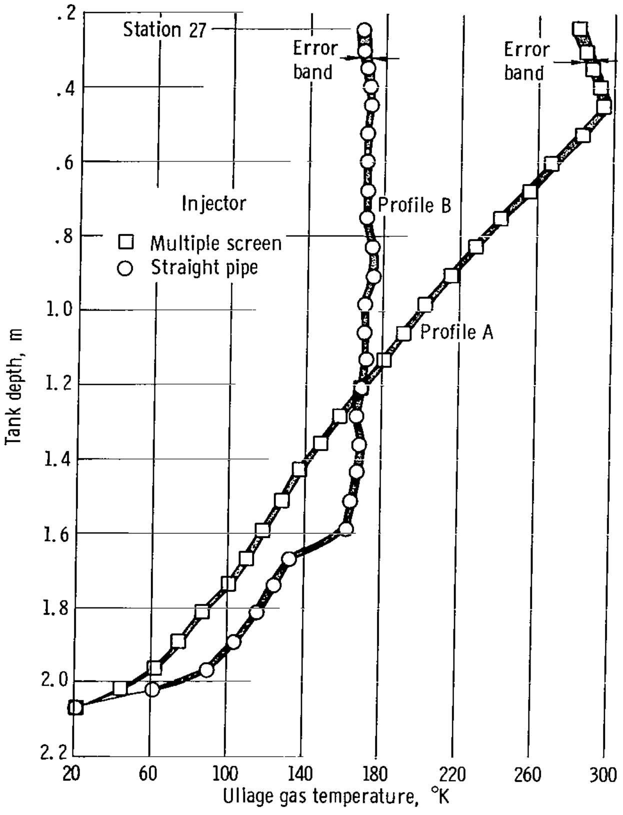


Figure 5. - Vertical temperature profiles in ullage at end of 130-second expulsion.

and $\pm 1.56^{\circ}$ K for profile B. The uncertainty in ullage mass based on these temperature uncertainties was 0.43 percent for profile A and 0.17 percent for profile B (ref. 4). The results of the complete error analysis as given in reference 4 indicate that the thermopile technique was adequate for the test objectives.

However, rather large errors can result when measuring temperature profiles for small ullages, in which case a large number of the thermopile units are in liquid hydrogen. Since $\partial T/\partial E$ is largest at liquid temperatures, the summation of temperature errors would be the greatest. Platinum reference sensors should be placed at the thermopile stations immediately below the desired liquid levels to overcome this problem. This placement would provide an absolute reference temperature near the liquid surface which would minimize the summation errors through the liquid.

USE OF THERMOPILES AS POINT LIQUID-LEVEL SENSORS DURING PRESSURIZED DISCHARGE OF LIQUID HYDROGEN WITH GASEOUS HYDROGEN

In addition to their use as temperature sensors, thermopiles can be used as point liquid-level sensors for subcooled liquid during tank outflow. It is not intended to propose that a thermopile be used primarily as a liquid interface detector, but rather to show its capability in making liquid-level detection a secondary measurement along with its primary temperature-measurement function.

Figure 6 is a typical temperature-time characteristic of a thermopile measurement station as the liquid interface drops in the tank. The plot has been broken into four segments for purposes of discussion. During time interval A, when the measurement station is submerged in a relatively constant temperature zone, there is a bulk liquid temperature indication. As the stratified temperature zone immediately below the liquid-gas interface passes the sensor, there is a corresponding increased output, as shown

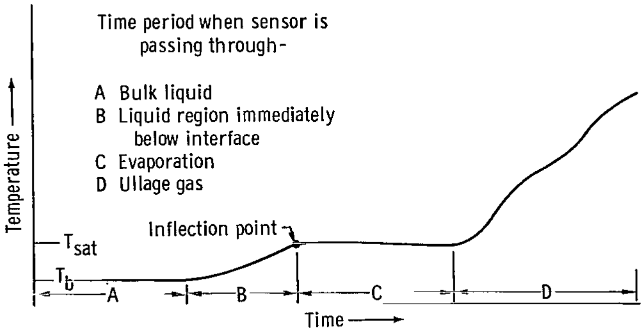


Figure 6. - Typical temperature - time characteristic of thermopile measurement station. Saturation temperature T_{sat}, approximately 28.9° to 32.2° K; bulk temperature T_b, approximately 20.6° K.

during interval B. When the thermopile breaks through the interface, a period (interval C) begins during which any liquid clinging to the measurement station thermocouples evaporates. When using gaseous hydrogen as the pressurant, this interval is marked by a relatively constant indication of saturation temperature corresponding to tank pressure. After the evaporation period has been completed, the sensor follows the temperature variation in the ullage gas.

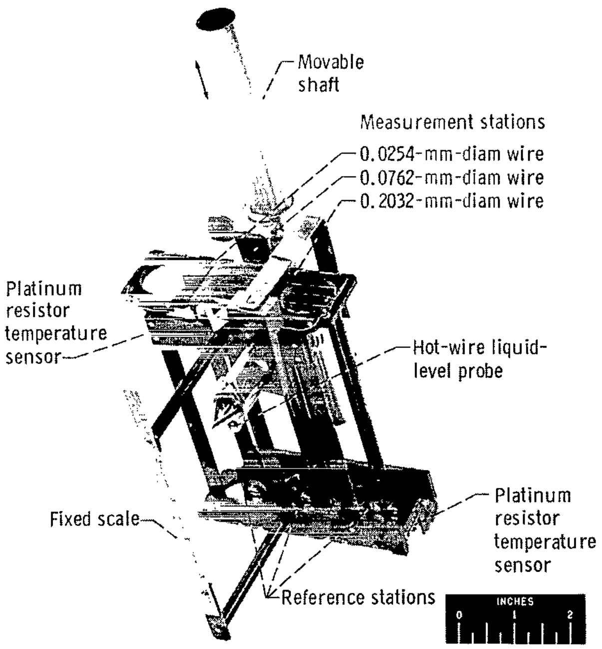
Because of the repeatability of this general temperature history, an attempt was made to obtain a working calibration, at various liquid-interface velocities and tank pressure levels, of the distance relation between the inflection point characteristic of the thermopiles and the actual liquid level. In this experiment only gaseous hydrogen was used as the pressurant.

When gaseous helium is used to expel the propellant, the partial pressure of the gaseous hydrogen in the tank ullage is necessarily less than the actual tank pressure. The liquid-hydrogen-propellant interface temperature is, therefore, less than the saturation temperature corresponding to test-tank pressure. For this case, then, the temperature of the sensor during the evaporation period could be anywhere between the bulk liquid temperature and the saturation temperature corresponding to actual tank pressure. Since no experimental work was done during this test phase using a tank pressurized with gaseous helium, this case is not given further consideration.

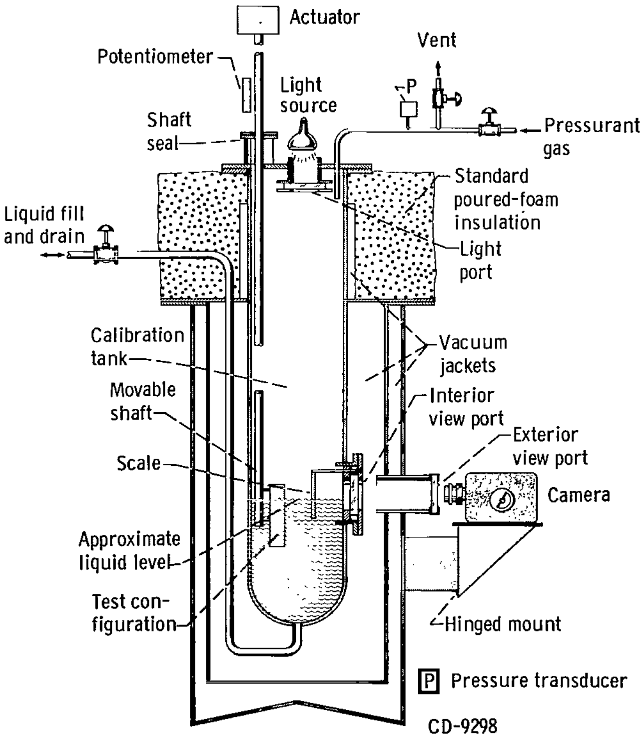
Apparatus and Procedure

The test configuration (fig. 7(a)) consisted of three thermopile units with a platinum resistance temperature sensor mounted in each of the horizontal planes passing through the reference level and measurement level of the thermopiles. (In an attempt to evaluate the structural integrity of several thin-wire thermopiles, wires of three different diameters (0.2032, 0.0762, and 0.0254 mm) were used in constructing the test configuration.) In addition, for operational purposes, a commercial hot-wire liquid-level probe was mounted as part of the test configuration so that its sensing wire was in the same horizontal plane as the measurement level of the thermopiles. A scale fixed to the test configuration was used to visually determine the displacement of the measurement level of the thermopiles with respect to the level of liquid hydrogen in the calibration tank.

The test-tank assembly (fig. 7(b)) consisted mainly of an inner liquid-carrying calibration tank, which was partly surrounded by a vacuum jacket. The upper third of the calibration tank was covered with a standard poured-foam type of insulation. Both filling and draining of the inner tank were accomplished through a bottom port. A two-section viewport arrangement allowed visual observation of the liquid hydrogen in the calibration tank. The interior of the calibration tank was illuminated through a viewport in the cover



(a) Configuration. C-66-984



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(b) Apparatus.

Figure 7. - Thermopile test configuration and apparatus.

plate. During test runs a photographic record of liquid-level height was made on 70-millimeter film. A remotely controlled variable-speed shaft assembly enabled vertical movement of the test configuration through the liquid-hydrogen interface.

The calibration tank was approximately half filled by using the movable hot-wire sensor as a level indicator. The tank was then partly drained until the liquid level was visually observed to be near the bottom of the interior view port. The recording camera was then positioned, and the tank was pressurized using gaseous hydrogen. The data runs consisted of first positioning the thermopile measurement stations in the bulk liquid and then cycling them through the liquid interface at a predetermined velocity. During data runs, the reference stations of the thermopiles remained submerged in the bulk liquid. Additional instrumentation required for the testing is also shown in figure 7(b). Time histories of all measurements were recorded on a direct-reading oscillograph.

An analysis was performed to determine the probable error expected in the measurement of each parameter. The analysis included the effect of the complete instrumentation channel (transducer to recorder), as well as the effect of calibration procedures. Results of the analysis are shown in table I.

Results and Discussion

Verification of absolute temperature level of inflection point. - The data discussed in the following paragraphs and shown in table II are the results obtained using the 0.2032-millimeter-diameter wire. A time history of actual liquid level was obtained from the photographic record made during each test run. During the downstroke of each cycle (when the measurement level of the test configuration was lowered through the gas-liquid interface), the temperature of the top platinum resistor sensor was determined at the point in time coinciding with penetration of the actual liquid level, as determined from the photographic data. This temperature coincided within 0.16° K of the theoretical saturated liquid temperature corresponding to test-tank pressure. During the upstroke of each cycle (when the measurement level was passed upward through the liquid-gas interface), the same temperature reading (within 0.56° K) was again obtained from the top platinum sensor, and, at the same time, the inflection point was reached on the thermopile time histories. This exercise verified that (within the $\pm 1.064^{\circ}$ K accuracy of the thermopiles being calibrated) the inflection point was the temperature of saturated liquid hydrogen. Once the temperature level of the inflection point had been verified, the calibration reduced to the following three steps: (1) locating the inflection point in time on the recorded histories, (2) reducing this value to a vertical location of the thermopiles in the test tank, and (3) comparing the location so obtained with the visual history of the actual liquid level.

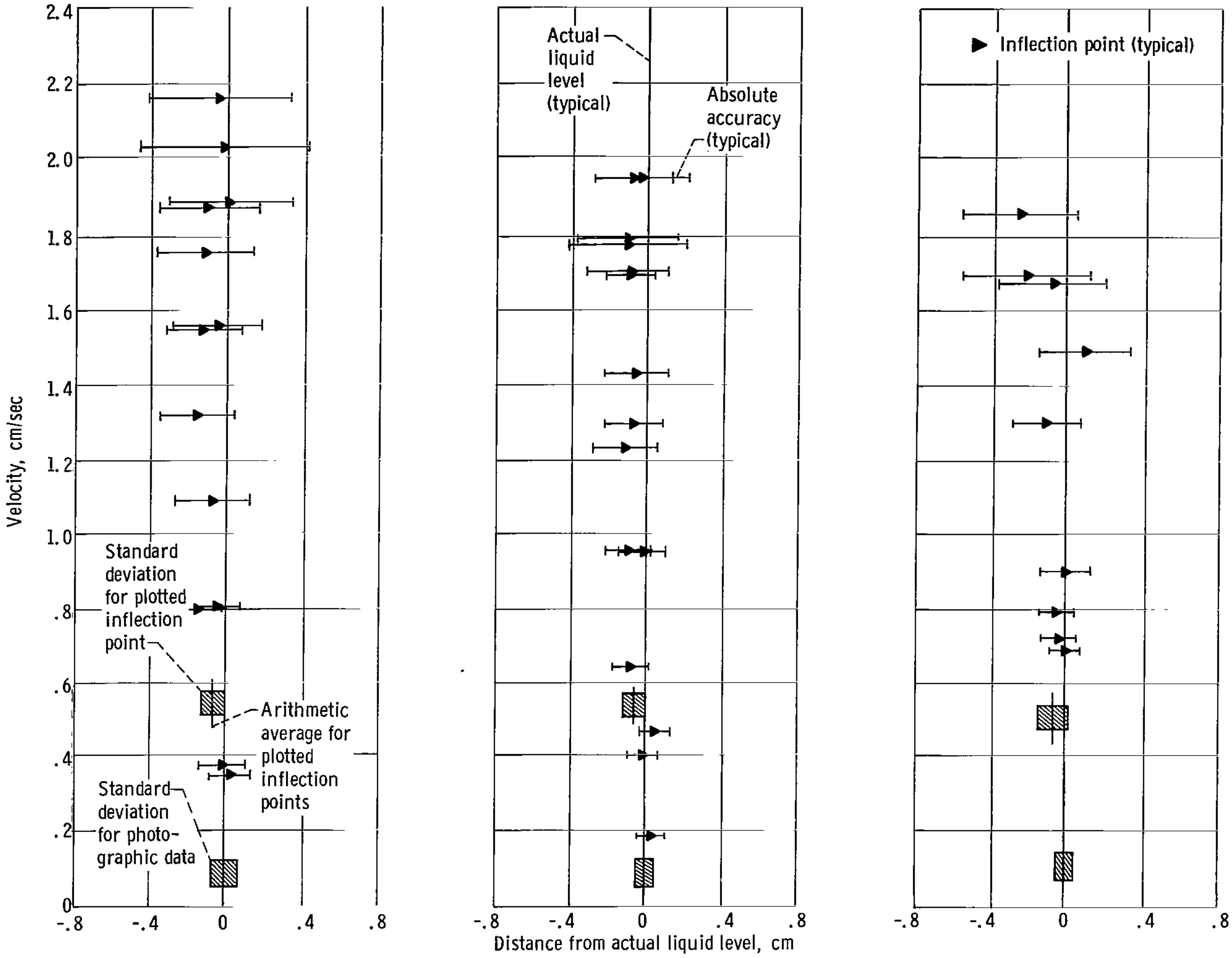
Conversion of inflection point characteristic to liquid-level measurement. - Determination of the thermopile inflection point in the temperature-time history and the resulting effect on the precision of determination of liquid-level location was dependent on the following parameters:

(1) The readability of the recorded time histories
(2) The actual liquid-temperature profile in the immediate neighborhood of the interface
(3) The velocity of the test configuration
(4) Precision in locating variable-speed shaft assembly

The readability of the oscillograph used in the testing was 0.025 centimeter which, when combined with the recording span of the thermopiles, yielded a resolution of ±0.01 millivolt. As can be visualized, the greater the slope of the actual temperature-time profile measured by the thermopile, the smaller will be the error in locating the inflection point in time because of oscillograph resolution. Conversely, the greater the test configuration velocity, the larger will be the error in locating the test-configuration position in the calibration tank. The slopes of the actual temperature-time curves during the transient period (fig. 6, interval B) were determined for the runs reported in the following paragraph. An absolute accuracy of liquid-level determination was then computed for each run as follows:

$$\Delta L = \left[\left(\frac{RV}{\dot{T}}\right)^2 + (\Delta x)^2\right]^{1/2}$$

A curve of the liquid-level height as a function of time was obtained by discrete photographs in the calibration tank to obtain a best fairing for the actual liquid level during each test series. The relation between this best fairing of actual liquid level and the inflection points obtained is shown as a function of test-configuration velocity in figure 8. The standard deviation (± σ) of the photographic data from the actual liquid-level curve fit and the standard deviation of the inflection points from their arithmetic averages are shown near the bottom of the figure. In addition, the computed values of the variation of liquid-level determination are also shown by the horizontal bars. For the range of test velocities (0 to 2.29 cm/sec), the data show no identifiable dependence of the inflection point characteristic on test-configuration velocity. Also, for the range of test conditions, the data substantiate the fact that the relation between the actual liquid level and the inflection point characteristic shows no pressure dependence. From the data taken, it was therefore concluded that within the range of test conditions, the inflection point characteristic in the thermopile temperature-time histories can indicate true liquid level to within ±0.453 centimeter without regard to the operating tank pressure level or the thermopile - liquid-level relative velocity.



(a) Series 1; average tank pressure, 152.5 psia (1.052 N/m^2).

(b) Series 2; average tank pressure, 153.2 psia (1.056 N/m^2).

(c) Series 3; average tank pressure, 97.8 psia (0.674 N/m^2).

Figure 8. - Distance of inflection point from actual liquid level as function of test-configuration velocity.

Comparison of thermopiles. - A qualitative comparison of the three thermopiles tested showed the thermopile constructed of 0.0254-millimeter wire to be completely unacceptable. The sensor was quite fragile and did not stand up under ordinary field installation handling. Further, the much greater thermopile resistance (i.e., the resistance of the 0.0254-mm sensor as compared with the 0.0762-mm and 0.2032-mm thermopiles) produced such a large source impedance that noise in the data system became a problem. These difficulties were less pronounced with the 0.0762-millimeter thermopile and were not encountered at all with the 0.2032-millimeter-wire thermopile.

CONCLUDING REMARKS

Existing state-of-the-art temperature sensors are considered inadequate for experimental studies of pressurization and expulsion of liquid hydrogen. Therefore, a temperature-measurement technique that uses thermopiles as the sensors was developed. From the results of this development the following conclusions were reached:

1. An instrumentation rake using measurement stations constructed of thermocouples in series (i.e., thermopiles) can measure temperatures to within $\pm 1.65^{\circ}$ K (for gas temperatures between 20° and 300° K). We consider this accuracy to be adequate for pressurization and expulsion testing.

2. In addition to their use as temperature sensors, the thermopile units can also be used as point liquid-level sensors for subcooled liquid during tank outflow. Tests indicate that thermopiles can detect liquid level to within ±0.453 centimeter, which, again, we consider adequate for expulsion testing.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 18, 1967,
180-31-02-01-22.

REFERENCES

1. Gluck, D. F.; and Kline, J. F.: Gas Requirements in Pressurized Transfer of Liquid Hydrogen. Advances in Cryogenic Engineering. Vol. 7. K. D. Timmerhaus, ed., Plenum Press, 1962, pp. 219-233.
2. Powell, R. L.; Bunch, M. D.; and Corruccini, R. J.: Low Temperature Thermocouples-1. Gold-Cobalt or Constantan Versus Copper or Normal Silver. Cryogenics, vol. 1, no. 3, Mar. 1961, pp. 139-150.
3. Shenker, Henry; Lauritzen, John I., Jr.; Corruccini, Robert J.; and Lonberger, S. T.: Reference Tables for Thermocouples. Circ. 561, National Bureau of Standards, Apr. 27, 1955.
4. DeWitt, Richard L.; Stochl, Robert J.; and Johnson, William R.: Experimental Evaluation of Pressurant Gas Injectors During the Pressurized Discharge of Liquid Hydrogen. NASA TN D-3458, 1966.

TABLE I. - RESULTS OF ERROR ANALYSIS

Parameter	Probable error
Photographic determination of liquid level	±0.025 cm
Location of variable-speed shaft assembly	±0.056 cm
Platinum resistor temperature sensors	$\pm 0.10^{\circ}$ K at 29.9° K $\pm 0.22^{\circ}$ K at 20.6° K
Tank pressure	±11.62 kN/m (±1.686 psi)
Thermopiles	$\pm 1.064^{\circ}$ K

TABLE II. - TEST MEASUREMENTS AND RESULTS OF COMPUTATIONS

Cycle	Tank pressure		Test configuration velocity, cm/sec	Difference between inflection point and best fairing of actual liquid level, cm	Slope of temperature against time curve during transient period, mV/sec	Absolute accuracy of liquid-level determination, cm	Difference between photographic data and best fairing of actual liquid level, cm
	psia	MN/m^2					
			(a) Series 1				
1	152.3	1.050	0.363	0.028	0.035	±0.118	0.023
2	152.3	1.050	.394	-.015	.033	±.132	-.020
3	152.3	1.050	.833	-.050	.064	±.142	.030
4	152.8	1.054	.826	-.152	.056	±.158	.028
5	152.8	1.054	1.130	-.079	.057	±.206	-.030
6	152.8	1.054	1.367	-.168	.068	±.208	.064
7	152.3	1.050	1.608	-.127	.079	±.211	-.025
8	152.3	1.050	1.618	-.053	.068	±.244	-.091
9	152.8	1.054	1.824	-.124	.070	±.266	-.140
10	152.3	1.050	1.946	-.104	.073	±.272	.041
11	152.3	1.050	1.963	.018	.060	±.332	.003
12	152.3	1.050	2.116	-.023	.047	±.453	-.013
13	152.3	1.050	2.253	-.048	.060	±.379	.082
							.023
							.051
							.086
			(b) Series 2				
1	152.8	1.054	0.483	0.058	0.091	±0.077	0.084
2	154.3	1.064	.193	.038	.037	±.076	-.107
3	155.3	1.071	.417	-.013	.052	±.098	0
4	154.3	1.064	.663	-.081	.069	±.111	.018
5	152.8	1.054	.986	-.023	.078	±.139	-.041
6	152.8	1.054	.988	-.097	.081	±.134	.005
7	152.8	1.054	1.339	-.074	.089	±.160	-.013
8	152.4	1.051	1.273	-.119	.073	±.183	.033
9	152.8	1.054	1.484	-.058	.088	±.178	.048
10	153.1	1.056	1.768	-.107	.081	±.225	.025
11	153.1	1.056	1.755	-.094	.132	±.144	-.025
12	153.1	1.056	2.027	-.079	.100	±.209	-----
13	152.8	1.054	2.027	-.033	.080	±.259	-----
14	152.8	1.054	1.859	-.112	.069	±.275	-----
15	153.1	1.056	1.842	-.109	.059	±.316	-----
			(c) Series 3				
1	97.8	0.674	0.302	-0.015	0.052	±0.060	-0.094
2	97.3	.671	.691	-.005	.083	±.085	.064
3	99.3	.685	.729	-.033	.080	±.093	.046
4	96.8	.667	.912	0	.070	±.131	0
5	97.3	.671	.800	-.046	.084	±.097	-.013
6	97.3	.671	1.328	-.102	.073	±.182	-.013
7	97.8	.674	1.547	.104	.064	±.243	.051
8	97.9	.675	1.715	-.076	.060	±.291	-.069
9	97.9	.675	1.737	-.213	.052	±.338	-.010
10	97.9	.675	1.910	-.254	.062	±.313	-.048
							.081
							.033
							.013
							-.013

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