NASA TECHNICAL MEMORANDUM

NASA TM X-1654

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LIGHTING IN CRYOGENIC AND NONCRYOGENIC FLUIDS

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Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1968

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ABSTRACT

An experimental study provided conditions for operating standard light bulbs that were submerged in ordinary and cryogenic fluids. Successful operation occurred whenever the light source came to thermal equilibrium with its environment.

Technical Film Supplement C-260 available on request.

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SUMMARY

In fluid flow and heat-transfer studies, it is often necessary to illuminate the fluid for visual observations or for photography. This experimental investigation provided conditions for making feasible the operation of standard light bulbs that were submerged in ordinary and cryogenic fluids. Such operation would eliminate the necessity of requiring a secondary observation window with all its associated problems. The fundamental premise was that as long as the bulb could attain thermal equilibrium with its environment, it would perform satisfactorily.

INTRODUCTION

In the course of acquiring heat-transfer data, peculiar phenomena are observed and recorded in motion pictures that require some special lighting techniques. Usually the lighting of a cryogen, and sometimes noncryogens, for photographic purposes requires a secondary observation window, with which are associated problems of leakage and proper lighting. In many cases, the lighting should be internal for both general observation and photography, and in some cases, the bulbs could serve the dual purpose of providing localized heating and lighting.

Generally, one would suppose that an off-the-shelf light bulb could not withstand the thermal shock associated with being dunked in a cryogen; however, submerged lighting and heating in a cryogenic or a noncryogenic fluid is both theoretically feasible and experimentally practical.

Motion picture supplement C-260, which shows the lamps operating and/or being dunked in various fluids, has been prepared and is available on loan. A request card and a description of the film are included at the back of this report.

LIGHTING IN FLUIDS

General

An unlighted bulb can be submerged in most fluids or equilibrium mixtures provided that the temperature difference between it and the fluid is not too great. When the bulb is subsequently lighted, it simply achieves thermal equilibrium with its fluid environment, the most familiar fluid being, of course, air. A simple thermal balance between the bulb and its environment will indicate the degree to which the bulb disturbs it. With a suitable choice of bulb voltage and wattage, the bulb should function satisfactorily.

Caution must be exercised in placing a bulb in a conducting or explosive medium or in a medium that permits large changes in the thermal balance for long periods of time. Here again, however, compensations can be made (e.g., a lower voltage bulb) to permit operation in a hazardous or conducting environment.

Cryogenic

The ease with which a water droplet skates around on a very hot skillet is familiar to most people, and perhaps most know that a thin layer of water vapor (gas) exists between the hot surface and the water droplet. This thin gas layer permits the drop to float around on a gas cushion. As long as the temperature difference between the water drop and the heater surface is sufficiently large, the drop will continue to float around until it is evaporated. This phenomenon is termed film boiling and is illustrated as it would occur on the surface of a light bulb (fig. 1). As the temperature difference is diminished, the vapor layer disappears, and transition to nucleate boiling occurs. The surface temperature at which the transition occurs is called the Leidenfrost temperature T_L. The following table gives the Leidenfrost temperature for a few representative fluids:

Fluid	Leidenfrost temperature, T_L, K	Difference between Leidenfrost temperature and saturation temperature, $\Delta T = T_L - T_S$, K
Liquid nitrogen	108	31
Water	593	220
Ethanol	453	100

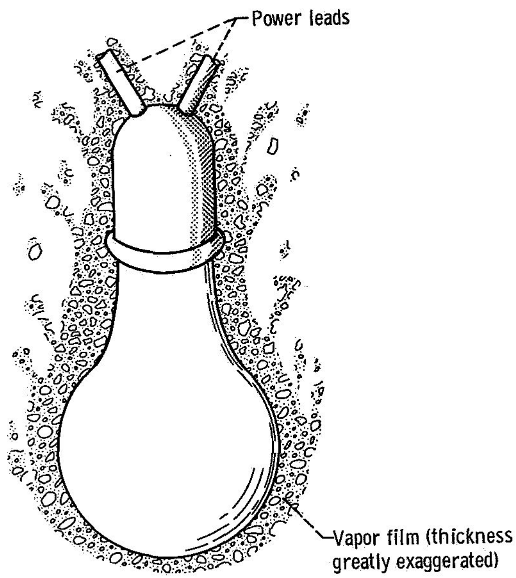


Figure 1. - Film boiling at surface of light bulb submerged in cryogen.

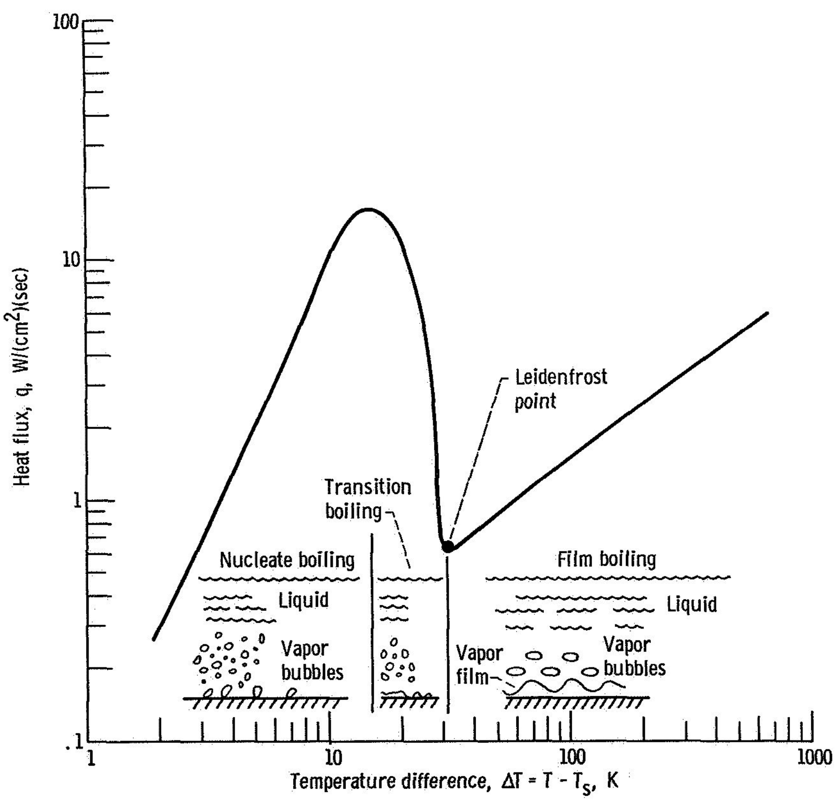


Figure 2. - Conventional boiling curve for liquid nitrogen.

As long as the entire surface temperature is above the Leidenfrost temperature, and the fluid subcooling (temperature of fluid-saturation temperature) is not more than $\Delta T = 6$ K, the temperature differences between the various components of the light bulb will be relatively small; thus, the thermal stresses in the bulb will be reasonably small. Only in the event that part of the bulb is in nucleate boiling and part in film boiling far above the Leidenfrost temperature will the thermal stress distribution be large. The large temperature difference between nucleate and film boiling is illustrated in figure 2. However, even in this extreme case, some conventional off-the-shelf light bulbs possess sufficient strength to stand the resulting thermal stresses. Since the bulb element is encapsulated in a vacuum or low-density gas, the filament reaches equilibrium with the base through conduction losses.

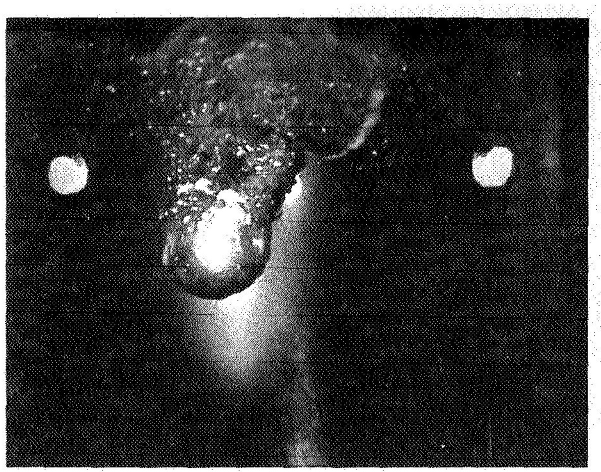
EXPERIMENTAL RESULTS

Cryogenic Fluids

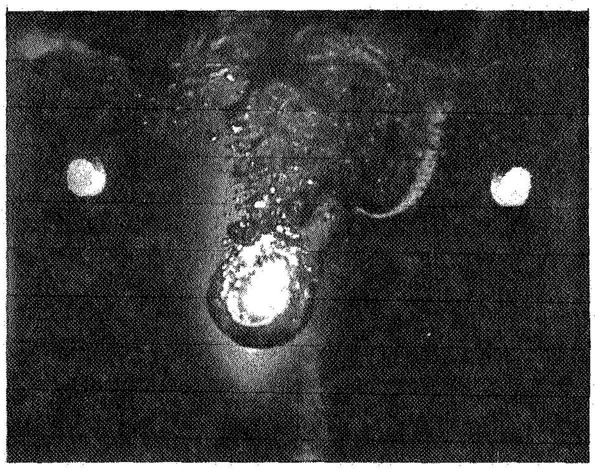
A lighted 18-watt, 6-volt bulb (General Electric 1493) was submerged in liquid nitrogen. Stages of the submersion are shown in figure 3. At first, film boiling occurs around the bulb (fig. 3(a)). However, as the bulb cools, the temperature difference decreases below the Leidenfrost point, and transition boiling occurs in a circular pattern on the bulb (fig. 3(b)). As the bulb cools further, thermal equilibrium is reached when the temperature difference enters the nucleate boiling regime (see fig. 2). In this regime the steady-state heat generated by the bulb is removed by nucleate boiling. This regime is marked by sporatic bubbles from nucleation sites on the bulb surface, as shown in figure 3(c). Cyclic dunking and/or bulb lighting seemed to have no effect on its performance. Similar results were obtained with a 75-watt household bulb. The same sequence of boiling stages is shown in figure 4 for this bulb.

The experiment was repeated with a 1-kilowatt iodine-gas high-intensity bulb (General Electric DXW). Sequences of this bulb operating in liquid nitrogen are illustrated in figure 5. These photographs were difficult to obtain because of the high intensity of the bulb; however, it functioned properly under cyclic lighting and dunking and a cold soak followed by cyclic lighting. The boil-off rates with this bulb are quite high because of the high wattage.

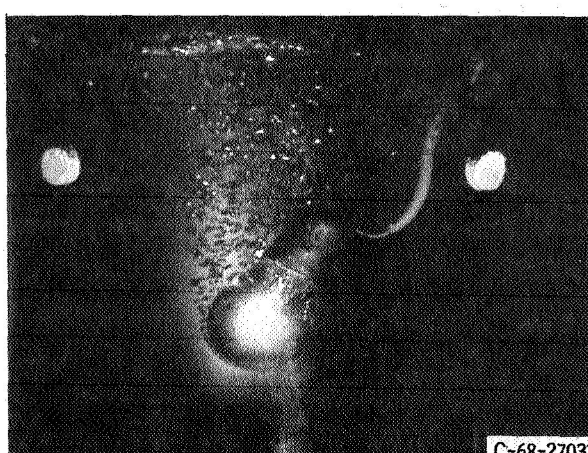
Boil-off control for the high-wattage bulbs can be effected through the use of a chimney-type shield to collect and channel the vapor to the liquid surface. The boil-off in nitrogen, for low-wattage bulbs is primarily at the base where the heating element wire must achieve equilibrium with the line wire and the fluid.



(a) Film boiling at surface of lighted bulb.

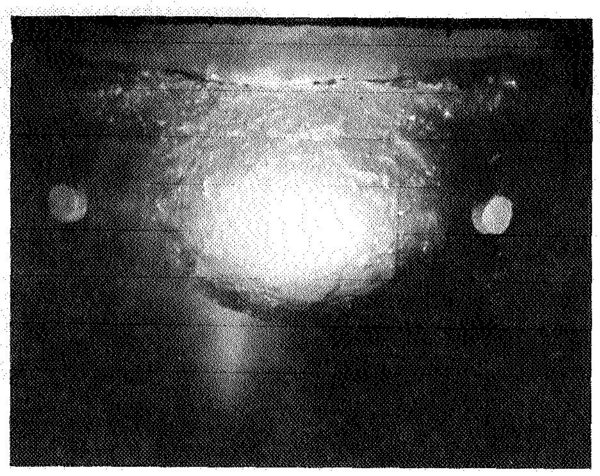


(b) Transition boiling (open patch in bright area).

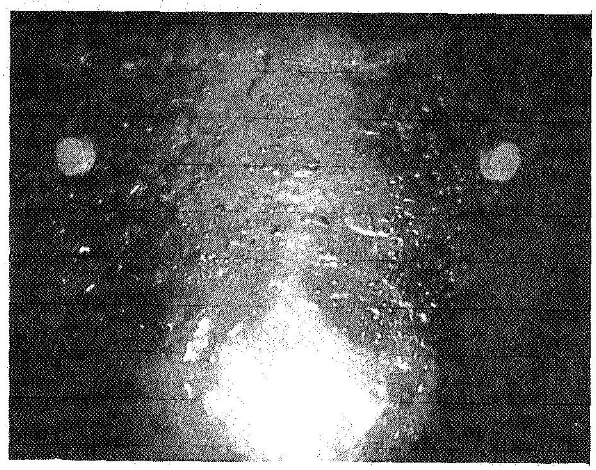


(c) Nucleate boiling at surface of lighted bulb.

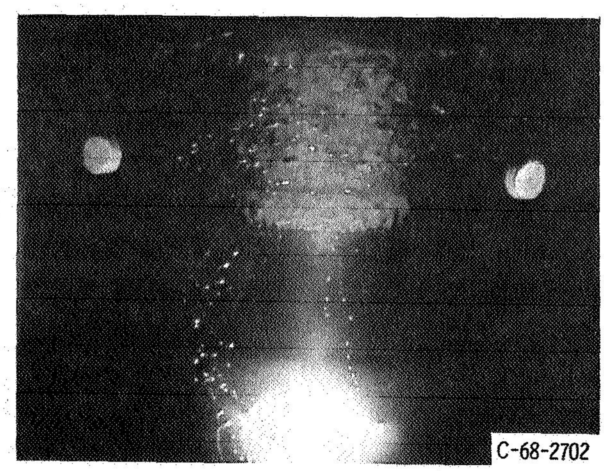
Figure 3. - Cool-down stages of lighted 6-volt bulb submersed in liquid nitrogen.



(a) Film boiling on bulb surface upon submersion.

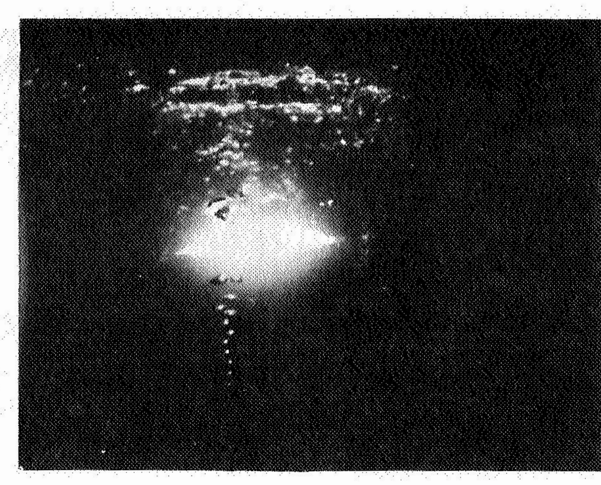


(b) Transition boiling around bulb surface.

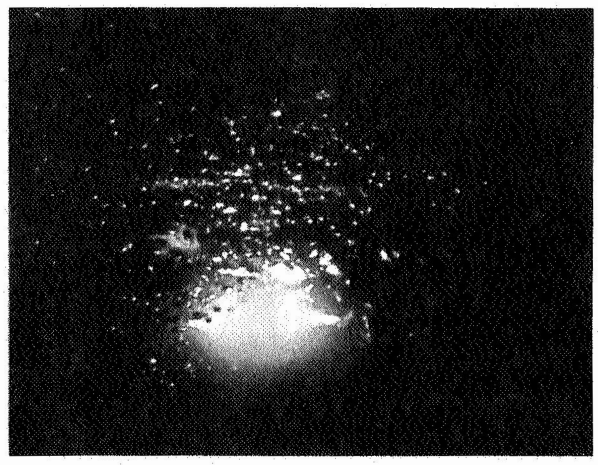


(c) Steady-state nucleate boiling.

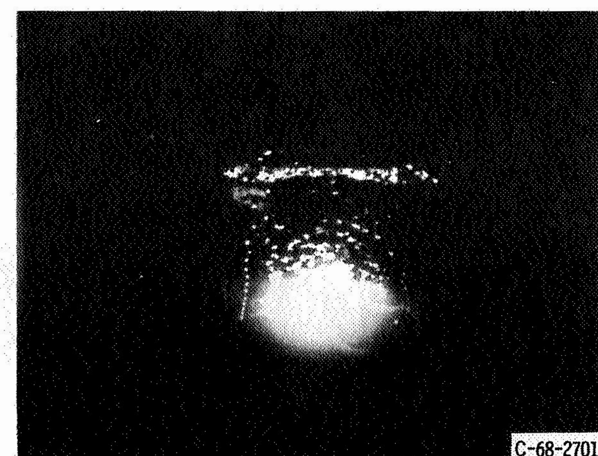
Figure 4. - Cool-down stages of lighted 75-watt household bulb submersed in liquid nitrogen.



(a) Film boiling.



(b) Transition boiling.



(c) Steady-state boiling.

Figure 5. - Operation of 1-kilowatt lighted iodine-gas high-intensity bulb in liquid nitrogen.

Noncryogenic Fluids

An 18-watt, 6-volt bulb (General Electric 1493) was placed in a beaker of distilled water and subsequently lighted. The bulb functioned properly and simply acted as a water heater. When the lamp was placed in n-heptane and again lighted, it functioned properly and served as a heater. Although other fluids were not tried, similar results can be anticipated - the lamp would come to thermal equilibrium with its environment.

This same bulb was lighted and then dunked into room-temperature water with no perceptible change in performance, which indicates that some bulbs may be able to withstand severe thermal shock, that is, they are capable of being submerged in a subcooled fluid lighted or not.

The 1-kilowatt iodine-gas bulb was also placed in a distilled water bath and subsequently lighted. The environmental fluid did not alter the performance of the bulb but perhaps enhanced it because of the lower surface temperature. Boiling over the bulb surface was evident, and it performed well as a water heater.

Effect of Pressure

An 18-watt, 6-volt bulb (Westinghouse 88) submerged in liquid nitrogen was operated in a cryogenic Dewar to a pressure of 155 newtons per square centimeter (the limit of the Dewar) with no noticeable effects. The pressure limit of these bulbs has not been established. The shape of the bulb and its material would certainly affect such a limit, although the bulb would be expected to function properly at moderate and subatmospheric pressures.

HAZARDS

The explosion characteristics of bulbs have not been investigated. However, when a bulb is submerged in a pure fluid, avoiding an explosion should not be a serious problem as long as the ignition limits are maintained with respect to the oxidation or reduction content of the bulb. Submerging or splashing the bulb with a highly subcooled fluid can lead to an explosive shattering of the glass which is caused by excessive localized cooling. Making compensations for current, voltage, wattage, and lamp materials should be carefully considered in view of the operating environment.

APPLICATIONS

In a research project, lamps submerged in cryogenic or noncryogenic fluids can function as a source of light for observations and/or photography or as a source of heat to perform experiments or simple energy addition.

In an industrial application, intermittent or continuous operation of high-duration lamps submerged in a compatible fluid environment (e.g., water, freon, nitrogen, or air) could function as a source of energy and light for climate control of large volumes such as arenas, buildings, food processing tanks, and aquatic facilities.

In the home, low-voltage lamps could be used for illuminating and warming aquariums, for special aquatic lighting in interior decorating, and for novelties such as food warmers and lighted coffee cups.

SUMMARY OF RESULTS

Under the experimental conditions described in this report, light bulb operation in cryogenic and noncryogenic fluids can be summarized as follows:

1. Off-the-shelf light bulbs were operated in saturated liquid nitrogen.
2. Unlighted bulbs were emersed in noncryogenic fluids and were subsequently lighted. They functioned properly.
3. Cyclic operation and dunking in cryogens did not appear to affect the performance of the bulb.
4. Bulbs may be submerged in cryogenic and noncryogenic fluids, then lighted, and can function as a source of light for observation and photography and as a source of heat for performing experiments or making simple energy additions.
5. Continuous operation of high-duration bulbs could function as a source of energy and light for climate control of large volumes, such as buildings, and acquatic facilities.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, July 29, 1968,
129-01-01-05-17-22.

NASA-Langley, 1968 —— 14 E-4487

Motion-picture film supplement C-260 is available on loan. Requests will be filled in the order received. You will be notified of the approximate date scheduled.

The film (16 mm, 8 min, color, sound) shows three different light bulbs with powers to 1 kilowatt, lighted or unlighted, being submerged in saturated liquid nitrogen. The light bulbs operate cyclically or continuously in this environment and withstand minor mechanical shock with no apparent loss in performance. Unlighted light bulbs, placed in two highly subcooled fluids, room-temperature water and n-heptane, and then lighted, are shown to function properly. Hazards involved in a nonequilibrium system are shown by the shattering of a photoflood bulb. Emphasized throughout the film is the principle that a light bulb appears to function properly provided it can achieve thermal equilibrium with its environment.

Film supplement C-260 is available on request to:

Chief, Technical Information Division (5-5)
National Aeronautics and Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

CUT

Date ____________

Please send, on loan, copy of film supplement C-260 to TM X-1654

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Title ______________________

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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