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ZERO-G REPORT

BUBBLE ACCUMULATION IN SIMULATED BOILING

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S U M M A R Y

The aim of the investigation described in this report was to determine if fuel would escape through a Centaur center vent during a venting period in zero gravity. Model tests were performed both with drop tests of liquid/gas boiling and with liquid/liquid simulated boiling. The liquid/liquid tests showed that the boiling equilibrium was reached after venting gas amounting to less than 3% of the tank volume, while a volume of at least 28% must be vented before any liquid can be lost.

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BUBBLE ACCUMULATION IN SIMULATED BOILING

29507

1.0 INTRODUCTION:

The primary aim of the investigation described herein was to determine if fuel would escape through a Centaur center vent during a venting period in zero gravity. A secondary aim was to develop a scaling law for bubble population development in zero garvity. The problem was approached from an empirical point of view, since no really convincing general theory had been suggested. Boiling was simulated in drop tests and in liquid/liquid tests, using scale models of the Centaur LH_2 tank.

2.0 BACKGROUND DISCUSSION:

2.1 The Centaur vent cycle begins with a period of coasting in zero-g (lasting about one hour) with the vent closed while pressure builds-up from about 18½ to 21 psia. The vent then opens to return the pressure to 18½ (this takes about 15 minutes).

2.0 BACKGROUND DISCUSSION: (Cont)

2.2 In order to consider the boiling and the bubbles in a consistent manner, we adapted a bubble birth-population-death cycle from the Rev. T. R. Malthus. When the Centaur is vented, the pressure drop will cause boiling to take place (birth of bubbles). The bubbles will establish a population and will finally break into the ullage bubble (death). The equilibrium time, Te, is taken as the time needed to establish a stable population. This aspect of the problem was studied with the liquid/liquid models and with high-speed motion pictures of liquid/gas models in zero-g during 1 sec drop tests. The time needed to establish a stable population was then compared to the Centaur vent times in order to predict whether liquid fuel would be lost through the center vent tube.

2.3 It was thought that a very large number of nucleation points, such as would be found in the Centaur tank, could be simulated by a much smaller number of water inlets. If small bubbles are formed at the nucleation points around the edge of the bulkhead, these bubbles will coalesce quickly into larger bubbles. The major force acting on these growing bubbles is the surface tension which keeps them spherical. This force pushes the bubbles out of the confining space near the bulkhead. As the bubbles grow, the come into contact with each other and eventually with the large ullage bubble. In the ideal case these bubbles, if of uniform size, would arrange themselves as a symmetrical necklace in the fuel space at the aft end of the tank (similar to those shown in Figures 1 and 2). At the maximum size, they would touch simultaneously the bulkhead, the outer wall, the ullage bubble (which just touches the bulkhead), and each other. Between ten and eleven such bubbles would fill the space. Ten such maximum bubbles would occupy about 0.05 tank volumes.

(Continued)

2.0 BACKGROUND DISCUSSION: (Cont)

2.3 If any more gas were introduced, immediate coalescence into the ullage would occur. Experimentally (or in the Centaur) this theoretical maximum volume will never be reached since the gas will not be generated symmetrically. Ten equally spaced orifices could simulate an infinite number of nucleation points on the aft end of the tank,if the ten orifices were generating "gas" at equal flow rates. The simulated gas bubbles were formed by introducing the water as near to the peripheral joint of the bulkhead as possible. This should be the worst condition since any bubbles generated on the walls or the bulkhead could reach the ullage more easily. These bubbles would have a shorter distance to travel and consequently should have shorter equilibrium times than the bubbles formed in the peripheral joint of the bulkhead.

2.4 In earlier drop and aircraft zero-g tests bubbles of hydrogen coalesced immediately upon contact. Freon bubbles in the drop tests also broke together immediately, but the water droplets in the liquid/liquid models did not coalesce so easily. The drops would sometimes bounce off or lean on one another without combining. The liquid/liquid models were made originally to demonstrate static configurations. Inevitably small liquid "bubbles" were produced which certainly looked and generally behaved like the gas bubbles seen in the drop tests and the airplane tests.

2.5 It was found that a 60-cycle electric field across the model promoted the coalescence of the water bubbles. At approximately 75 volts/inch the bubbles coalesced when the surfaces came in contact, but did not attract one another. At a lower voltage gradient the bubbles would bounce off each other and at a higher voltage gradient the bubbles would attract each other. We must admit that using the electric field is not truly rigorous, i.e., we do not try to explain it or to justify the value of voltage used, except on the basis that the effect does exist and produces, as judged visually, the desired conditions in the models.

3.0 PROCEDURE:

3.1 Drop Tests:

A simple package containing a movie camera, a Plexiglas Centaur model containing Freon 114, and a solenoid valve was used for the drop tests. The Freon (normal boiling point 38°F) was allowed to warm up to ambient temperature (about 65°F) prior to the drop (producing a 10 psi pressure rise). At the time of release the solenoid valve opened, allowing the Freon to boil. Details of a similar drop package and the techniques of its use can be found in Ref. A.

3.2 L/L Models:

3.2.1 The liquid/liquid zero-g simulation was produced by Plexiglas models filled with two immiscible liquids of the same density. See Reference B for further details. A mixture of Freon TF and Stoddart solvent simulated the fuel, and distilled water simulated the ullage gas and the bubbles formed by boiling. Water injecting orifices and center vents were added to 1/140th, 1/35th, and 1/10th scale models.

3.2.2 Water droplets were injected at various flow rates up to ten tank volumes per hour into liquid/liquid models containing 30% "fuel". Data was taken with the 1/140th, 1/35th, and the 1/10th scale models in order to get a wide range of sizes and to reduce the effects of data scatter as much as possible. The "gas bubbles" were introduced through orifices close to the peripheral joint. These water injecting orifices were made from AN fittings with spaced layers of 100 mesh brass screen on the end. When the water flowed through the screen, it produced bubbles of small sizes such as would be produced at a nucleation point. Without the screens over the end of the orifices the water would not break into small bubbles.

(Continued)

3.0 **PROCEDURE:** (Cont)

3.2.2 Instead the water would form one large bubble which would remain attached to the orifice until it coalesced with the ullage. The number of orifices was varied in each model. Data was taken with 1, 2, and 4 orifices on the 1/140th; 2, 4, and 8 orifices on the 1/35th; and 2, 8, and 20 orifices on the 1/10th. The orifice diameter was 0.098 in. on the 1/140th, 0.169 in. on the 1/35th, and 0.173 in. on the 1/10th scale model.

3.2.3 The flow through each orifice was controlled by a needle valve. The valves, manifolded together, were connected to a reservoir about six feet above the model. A tube from the center vent drained the "boil-off" into a container. The height of this container could be changed to vary the head pressure and thus the total flow.

3.2.4 The elapsed time from the start of flow until the large bubbles, formed from many small ones, broke into the ullage was defined as the equilibrium time, Te.

3.2.5 The 60-cycle electric potential of up to 3000 volts was supplied to plates on opposite sides of the models by an x-ray transformer.

4.0 RESULTS & DISCUSSION:

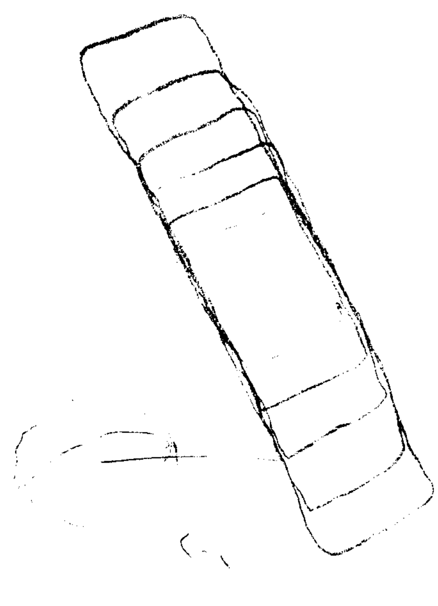
4.1 Boiling Comparison:

In order to show that the liquid/liquid boiling simulation looks essentially the same as liquid boiling in zero-g, still photos were made from movies of Freon 114 boiling during a drop test. These pictures were compared with photographs of the liquid/liquid models during tests. Figure 1 shows zero-g boiling in a 1/140th model. Figure 2 shows liquid/liquid boiling simulation in the 1/10th scale model. (The 1/140th liquid/liquid model looked essentially the same as the 1/10th, but was more difficult to photograph due to the arrangement of the orifices. The fine bubbles shown in the 1/10th model were residual bubbles from previous runs and were not typical of the appearance while data was being taken). No numerical data could be obtained from the drop tests because of the difficulty of measuring gas flow rates.

4.2 Liquid/Liquid Results:

4.2.1 The injected water formed small bubbles which grew larger by coalescence until they broke into the ullage. The bubbles were forced out of the peripheral joint by surface tension trying to keep them spherical. When the flow rate was increased, the time needed to reach equilibrium was decreased. The time was recorded and multiplied by the flow rate to determine the equilibrium bubble-accumulation volume. Data taken under the same conditions were averaged. These averages are plotted against flow rate in Figure No. 3. Note that all the points fall significantly below the necklace limit discussed in paragraph 2.3 and far below the quantity vented during a Centaur vent period.

4.2.2. Several seemingly reasonable attempts were made to organize the data. These included various methods of compensating for model size, flow rate, injection velocity, surface tension, and the probable effects of minor density unbalance. No presentation was devised which appreciably reduced the overall data scatter.



5.0 CONCLUSION:

5.1 During the first coast period the Centaur fuel tank will contain 70% gas and 30% liquid. Barring mechanical disturbances, the ullage (i.e., the bubble from which gas is being vented) would have to be reduced at least to a 120 inch sphere before any liquid could be lost. This conclusion is evident from tank geometry and the assumption of a 6-foot center-vent tube. This reduction in size requires 0.28 tank volumes to be vented. (The tank volume of course remains constant and it is assumed that 0.28 tank volumes are introduced into the liquid but do not join the main ullage bubble.) However, only 0.17 tank volumes will be vented during the 15 minute vent period, and since both the necklace limit and the experimental data fall well below even this volume, the margin of safety is apparent (See Figure 4). We can expect that the equilibrium condition will be established well before the ullage bubble shrinks too much and that the Centaur liquid fuel will not be vented from the center vent.

5.2 Although there are differences in viscosity and surface tension between the liquid/liquid models and the LH_2/GH_2 Centaur, we feel that these differences will not affect our conclusions. The primary influencing factors seem to be the flow rate and the geometry. Since the models we used were geometrically the same as the Centaur, our conclusions concerning the number of tank volumes needed to reach equilibrium can be applied to the Centaur.

R E F E R E N C E S

A) O'Hanlon, T. W.; Zero-G Report; "LH_2 Nucleate Boiling"; Test Laboratories Report# 55D859-1; January, 1962.

B) Wood, G. B.; Zero-G Report: "Liquid/ Liquid Models"; Test Laboratories Report# 55D859-9; May, 1962.

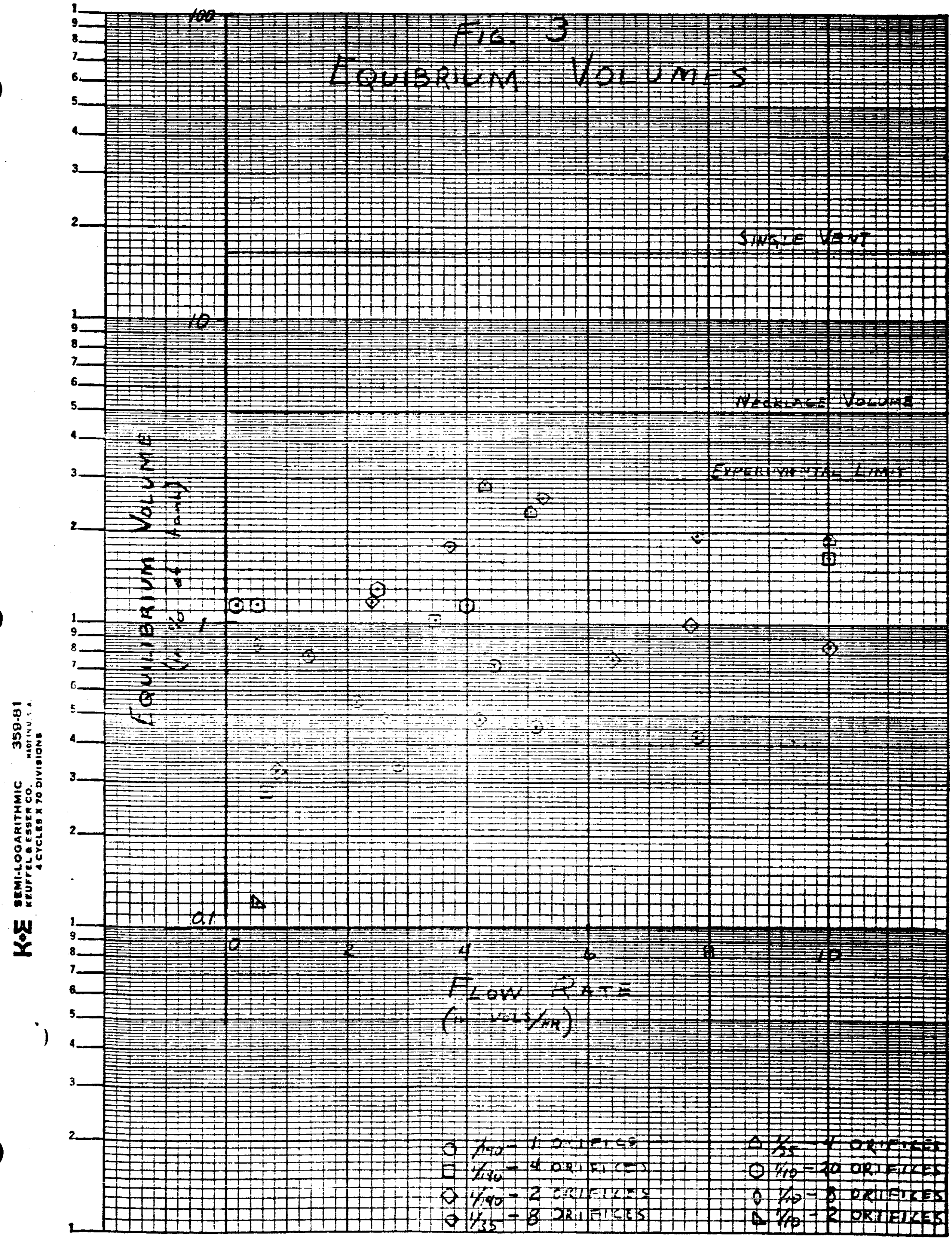
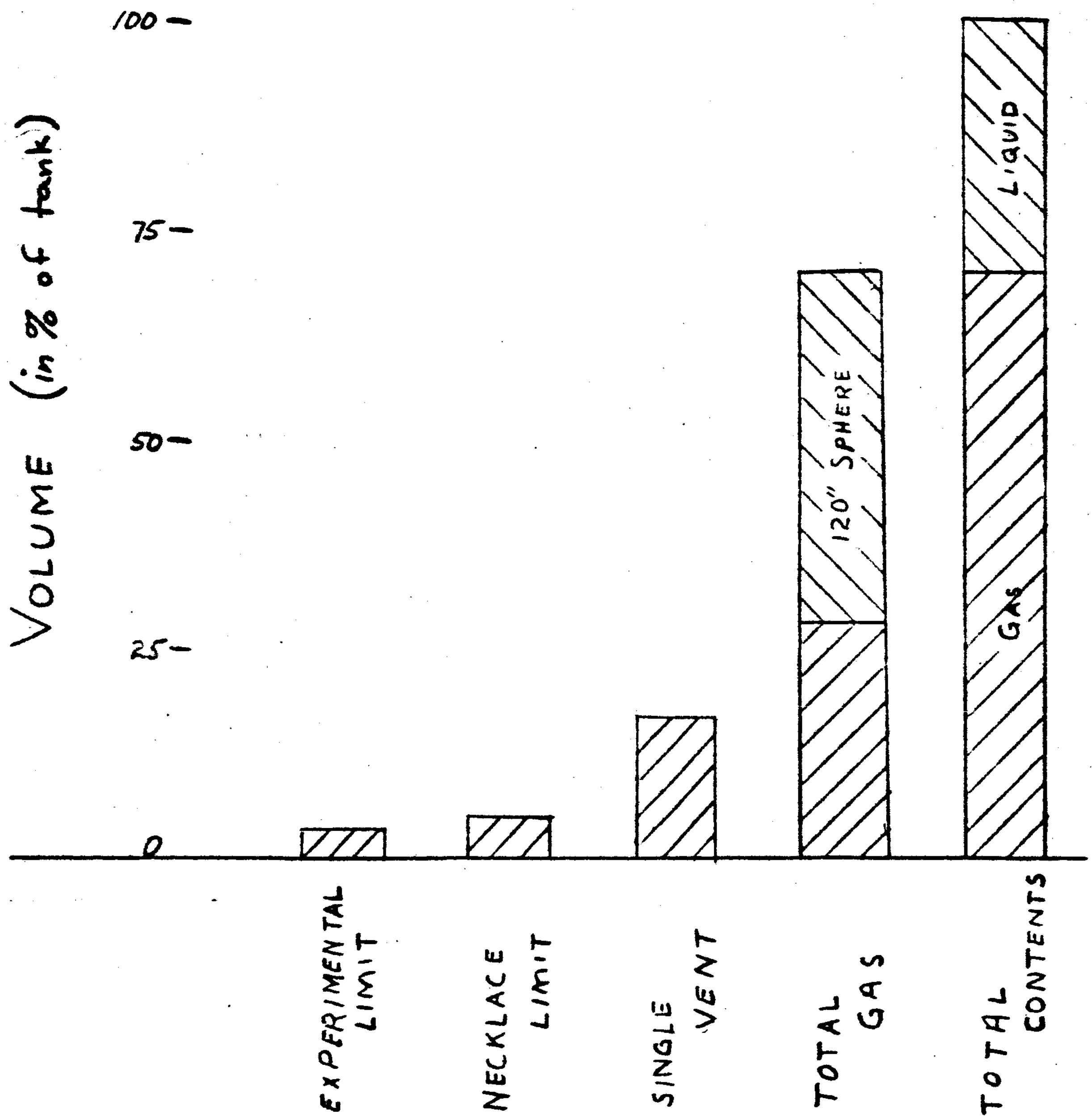


FIG. 3
EQUIBRIUM VOLUMES
SINGLE VENT
NECKLACE VOLUME
EXPERIMENTAL LIMIT
EQUILIBRIUM VOLUME
100
10
1
.01
0
2
4
6
8
10
FLOW RATE
○ 1/40 - 1 ORIFICES
□ 1/40 - 4 ORIFICES
◇ 1/40 - 2 ORIFICES
◇ 1/35 - 8 ORIFICES
△ 1/35 - 4 ORIFICES
⬡ 1/10 - 20 ORIFICES
1/10 - 8 ORIFICES
1/10 - 2 ORIFICES
K+E SEMI-LOGARITHMIC 359-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS

FIG. 4
VOLUME COMPARISON



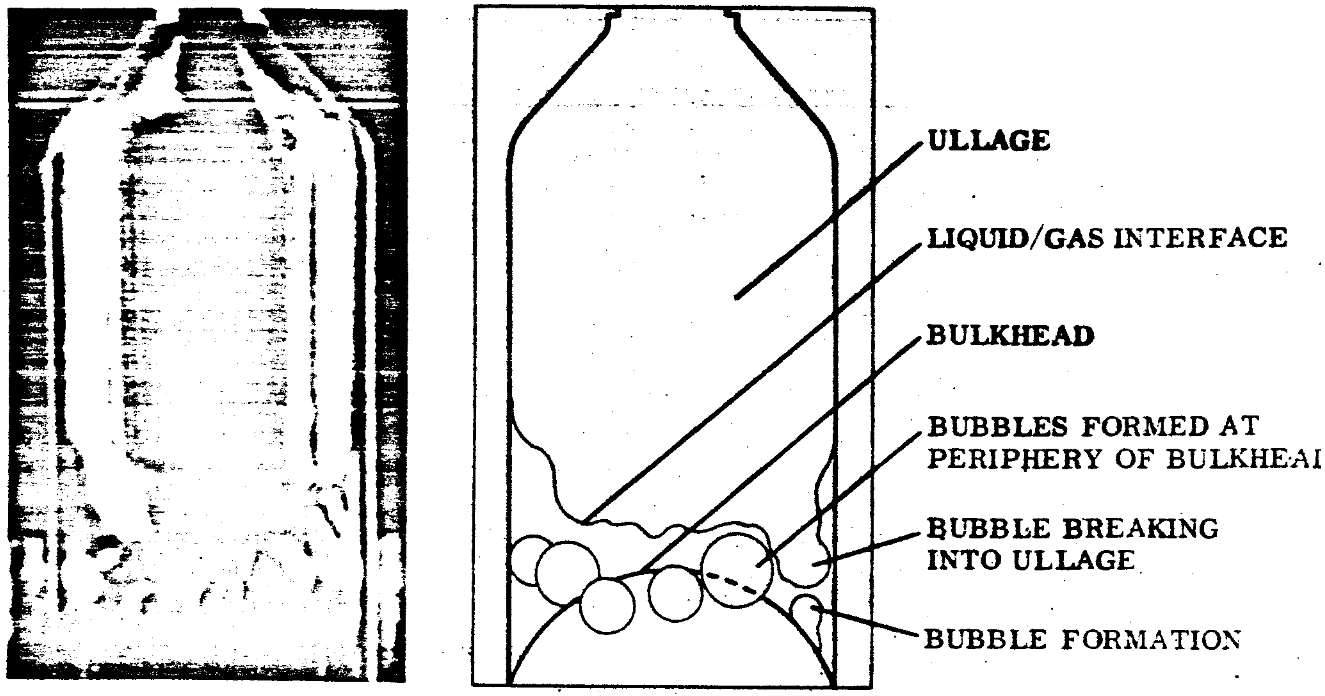


FIG. 1. FREON 114 BOILING IN 1/140th MODEL IN DROP TEST.

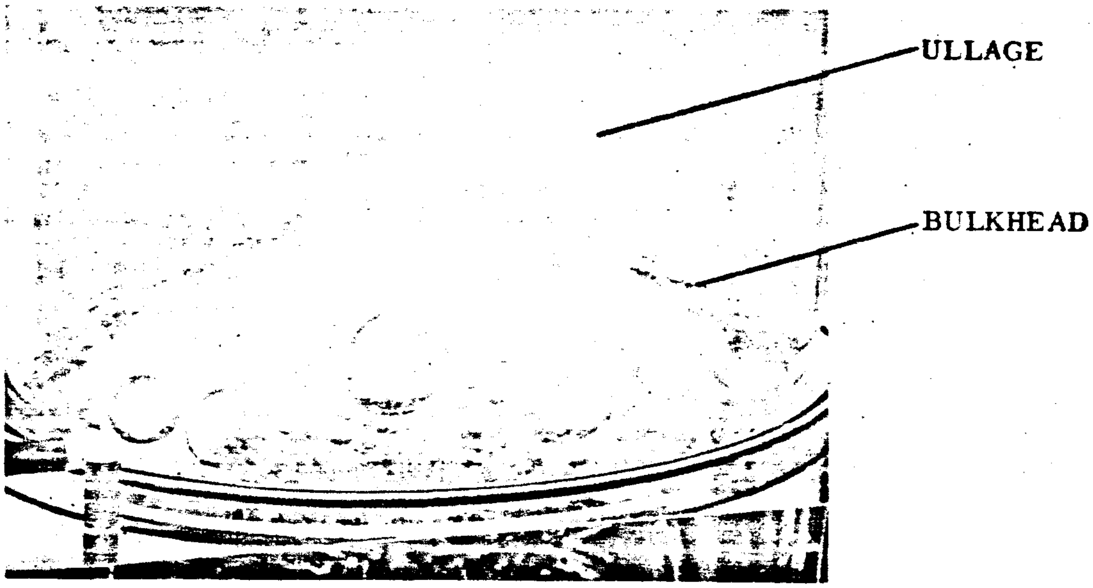


FIG. 2. LIQUID/LIQUID BOILING SIMULATION IN 1/10th SCALE CENTAUR MODEL WITH 20 ORIFICES.

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