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AIR-WATER TESTS

IN SUPPORT OF LLTR SERIES II TEST A-4

by

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DISCLAIMER

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1.0 INTRODUCTION

A series of tests injecting air into a tank of stagnant water was conducted in June 1980 utilizing the GE Plenum Mixing Test Facility in San Jose, California. The test was concerned with investigating the behavior of air jets at a submerged orifice in water over a wide range of flow rates. The main objective was to improve the basic understanding of gas-liquid phenomena (e.g., leak dynamics, gas bubble agglomeration, etc.) in a simulated tube bundle through visualization. The experimental results from these air-water tests will be used as a guide to help select the leak size for LLTR Series II Test A-4 because air-water system is a good simulation of water-sodium mixture.

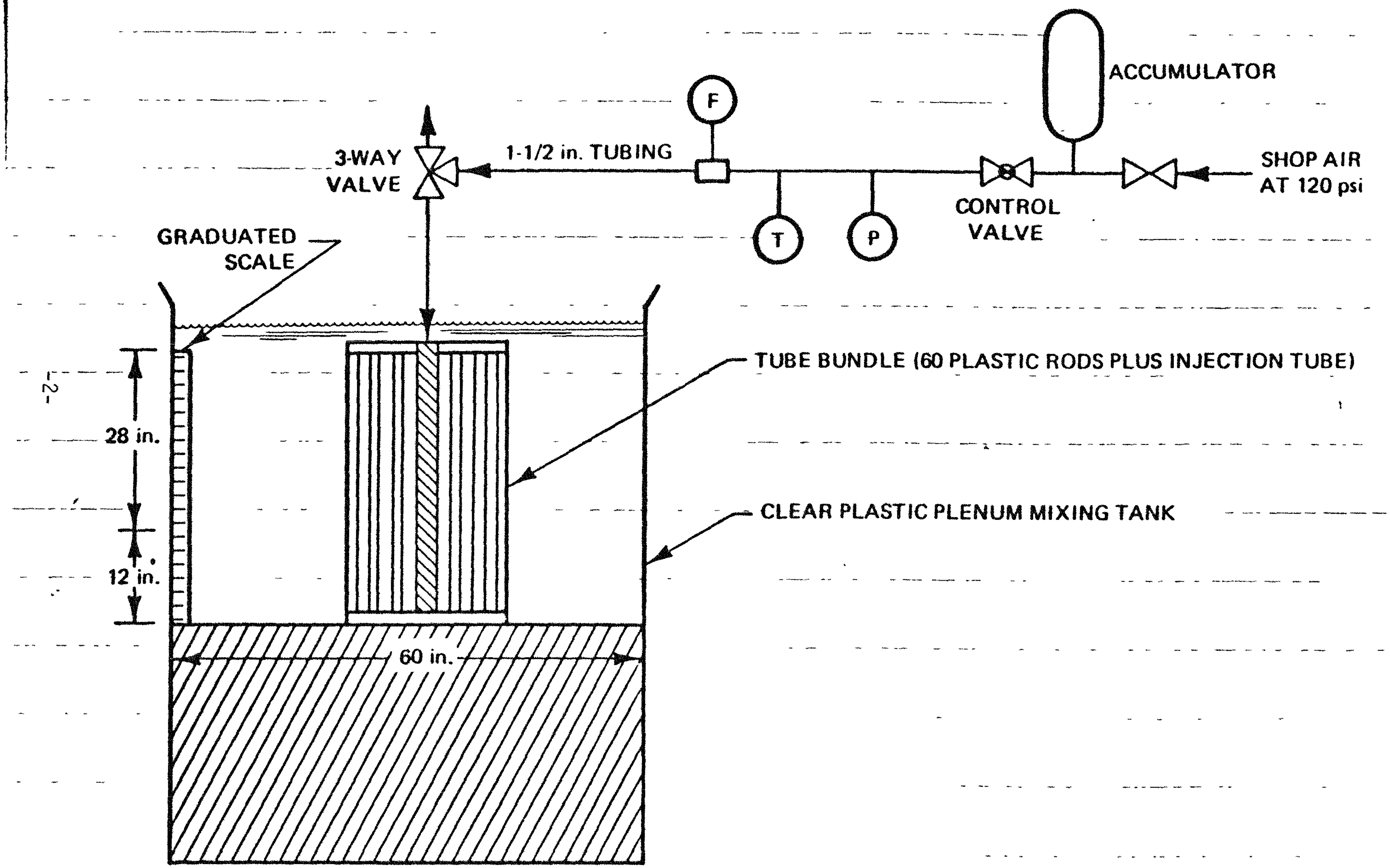
2.0 TEST FACILITY AND TEST DESCRIPTION

The air-water test facility is shown schematically in Figure 1. Pictures of the facility are also shown in Figure 2. The facility consists of the following main items: flow meter, transparent water tank, tube bundle, needle valve, gas supply, and injection tube. The tube bundle consists of 61 transparent tubes which have the same sizes and are arranged in the same pitch as those of CRBRP. The injection tube is located in the center of the tube bundle. The air is injected into the water through a hole in the side of the injection tube with a direction pointed horizontally. Two sizes of injection tubes and six different injection hole sizes were tested. They are listed in Table 1. The injection tube is located approximately 12 inches from the bottom of the water tank.

Different air flow rates were injected into the water. The range of the air flow rates tested and the injection tube locations are listed in

Figure 1

SCHEMATIC FOR AIR-WATER TESTS IN SUPPORT OF LLTR SERIES II TEST A-4



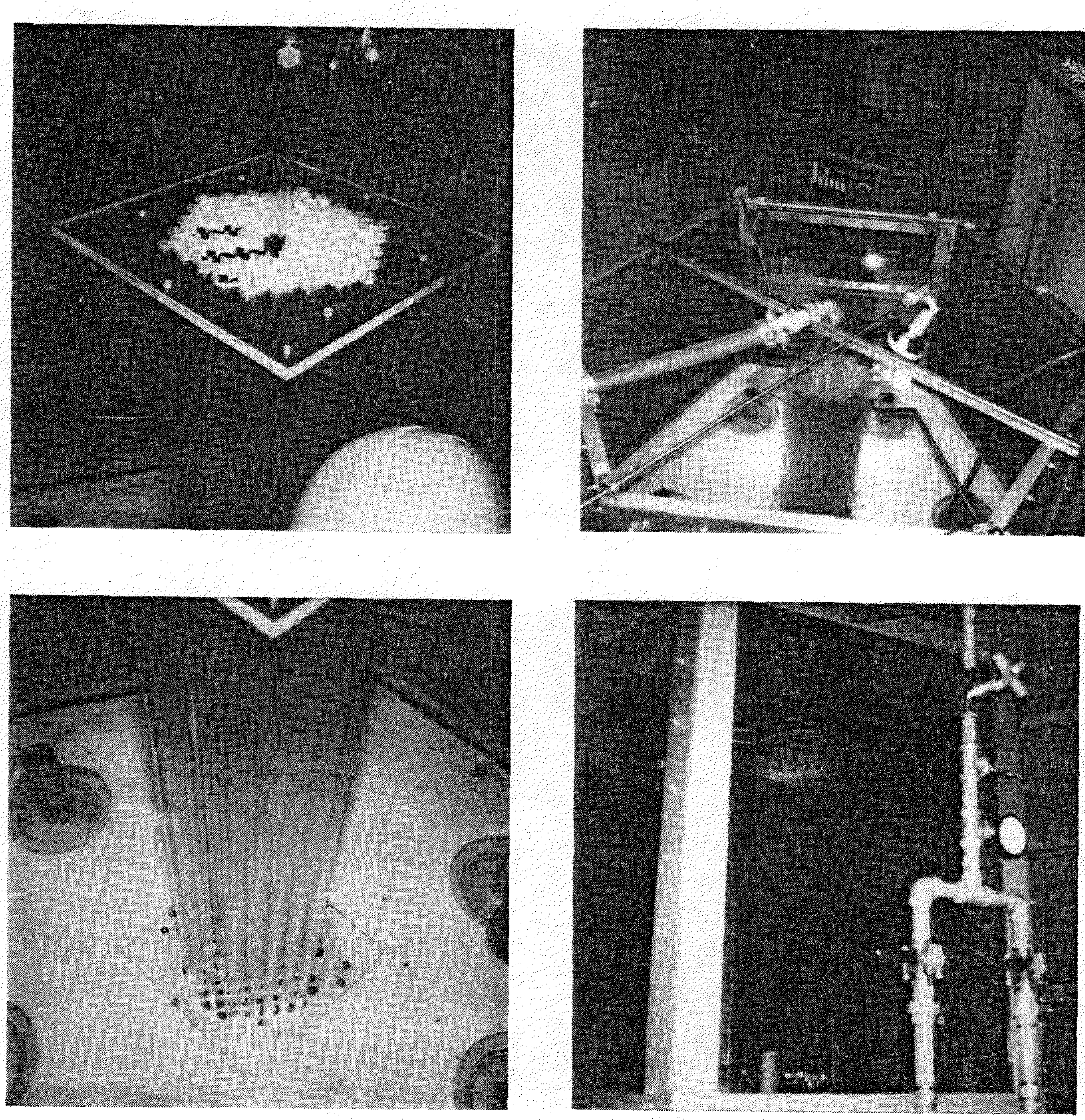


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Figure 2. TUBE BUNDLE AIR-WATER INJECTION TESTS

Table 1. The Sizes of Injection Tube and Hole

O.D. OF INJECTION TUBE, INCHES	DIAMETER OF INJECTION HOLE, INCHES
1	0.93
1	0.625
1	0.397
5/8	0.397
5/8	0.3
5/8	0.2
5/8	0.1

Table 2. The water and air temperatures were in the range of 65-70°F and the water pressure was kept at 1 atmosphere throughout the tests.

In total, thirty-seven tests were conducted and recorded by movie films. Figures 3-6 show the still pictures taken from Test No. 1 to No. 7 movie films. Similar behavior was noted for the other hole sizes and injection tube locations.

3.0 DISCUSSION OF TEST RESULTS

At very low rates of air flow (approximately less than 10 scfh for all the different injection hole sizes), the formation of discreet bubbles is very regular. The behavior of air jets described above was concerned with air flow rates where the jet was discharged from the orifice as discreet bubbles. This phenomena can be called "bubbling." This was shown clearly in Figure 3.

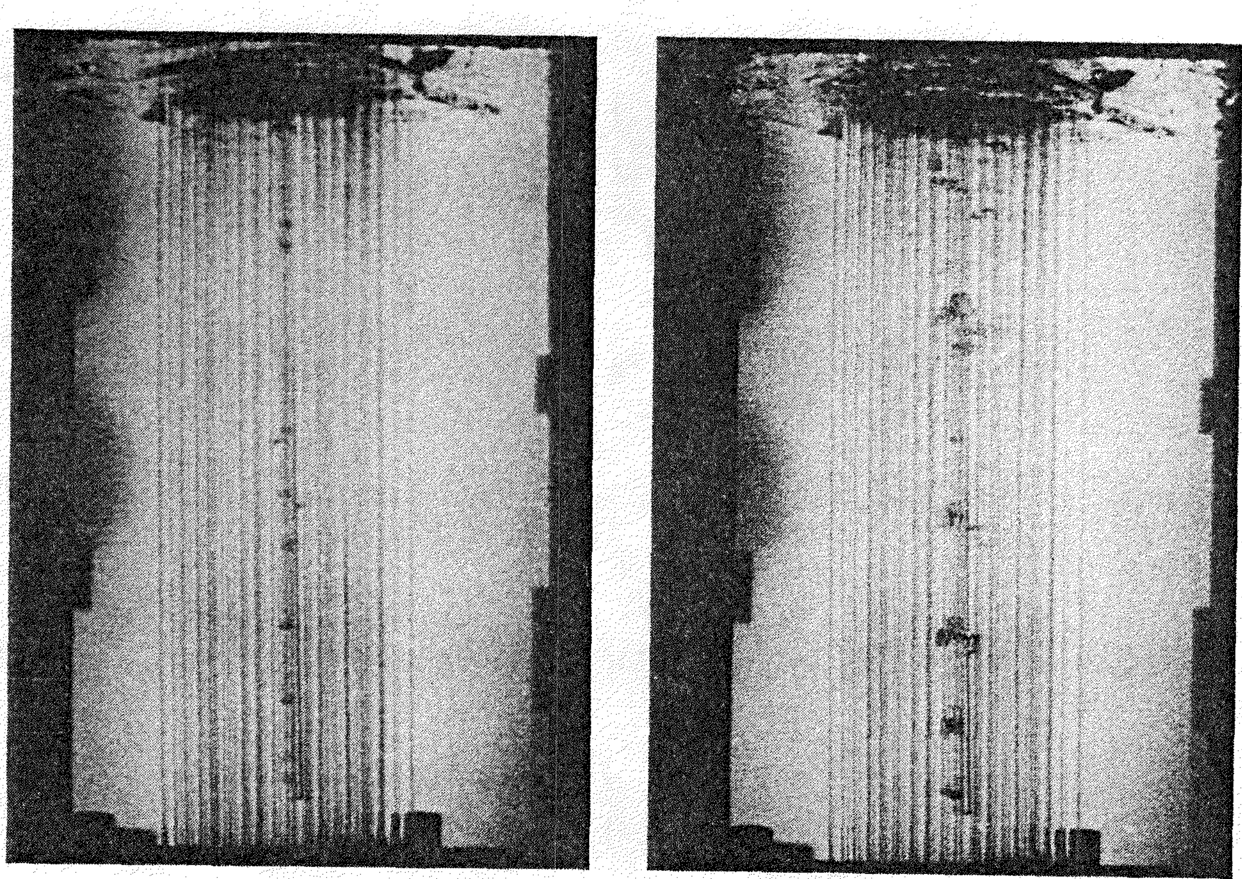
With increased air flow rates, high-speed motion pictures revealed another behavior of air jets. That is, a continuous jet of air beginning to form at the orifice. This phenomenon can be called "jetting." The phenomena was observed to occur at air flow rates larger than 12 scfm independent of the injection hole size tested. This was shown in Figures 5 and 6. The air jet first penetrated horizontally some distance from the injection hole, then rose vertically as a plume due to the buoyancy force. The horizontal penetration distance was dependent on the air flow rate as was the width of the rising plume. However, compared with a submerged air jet without the presence of a tube bundle, the air jet within the tube bundle was observed to be much confined in size. This was probably caused by the blocking effect of the multiple tubes around the injection hole. Another observation was the air jet did not expand very much radially as it traveled upward, which is distinctly different from a free jet (a jet without the presence of a tube bundle). It is believed that the surrounding water is continuously entrained into the jet through the boundary of the jet. This is shown schematically in Figure 7.

Table 2. Air Flow Rates Tested

Test No.	Injection Tube Size (ins.)	Injection Hole Size (ins.)	Location of Injection Tube	Air Flow Rate	Injection Direction From the Angle of the Camera
1	5/8	0.1	Center	1 scfh	Side View of Air Jet
2				10 scfh	
3				30 scfh	
4				90 scfh	
5				6 scfm	
6				12 scfm	
7				40 scfm	
8	5/8	0.1	Center	1 scfh	Front View of Air Jet
9				10 scfh	
10				30 scfh	
11				90 scfh	
12				6 scfm	
13				40 scfm	
14	5/8	0.1	Periphery	1 scfh	Side View of Air Jet
15				10 scfh	
16				30 scfh	
17				90 scfh	
18				6 scfm	
19				40 scfm	
20	5/8	0.397	Center	1 scfh	Side View of Air Jet
21				10 scfh	
22				30 scfh	
23				90 scfh	
24				6 scfm	
25				40 scfm	

Table 2. Cont.

Test No.	Injection Tube Size (ins.)	Injection Hole Size (ins.)	Location of Injection Tube	Air Flow Rate	Injection Direction From the Angle of the Camera
26	5/8	0.20	Center	1 scfh	Side View of Air Jet
27				10 scfh	
28				30 scfh	
29				90 scfh	
30				6 scfm	
31				40 scfm	
32	1	0.30	Center	1 scfh	Side View of Air Jet
33				10 scfh	
34				30 scfh	
35				90 scfh	
36				6 scfm	
37				40 scfm	



1 SCFH
(24 FRAMES/sec)

10 SCFH
(400 FRAMES/sec)

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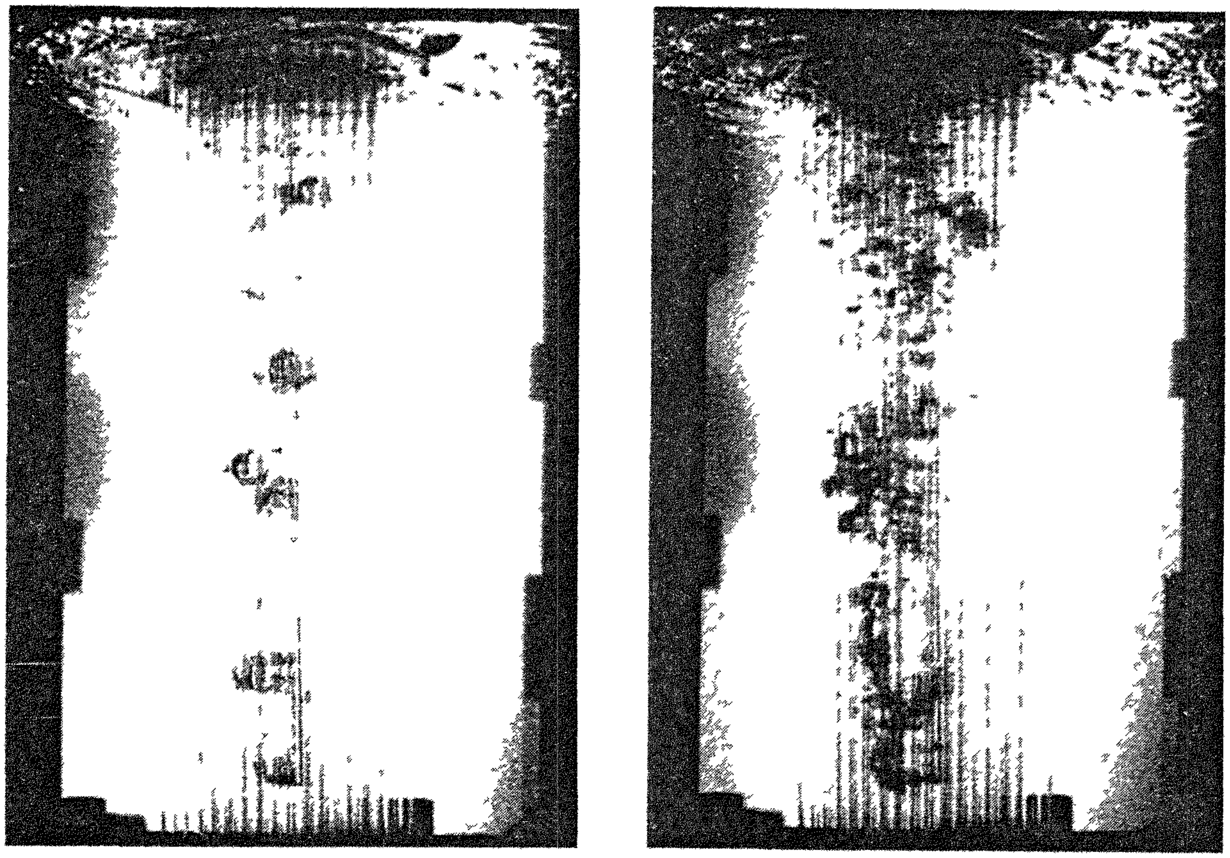
Figure 3. TUBE BUNDLE AIR-WATER INJECTION TESTS



30 SCFH
(400 FRAMES/sec)

90 SCFH
(400 FRAMES/sec)

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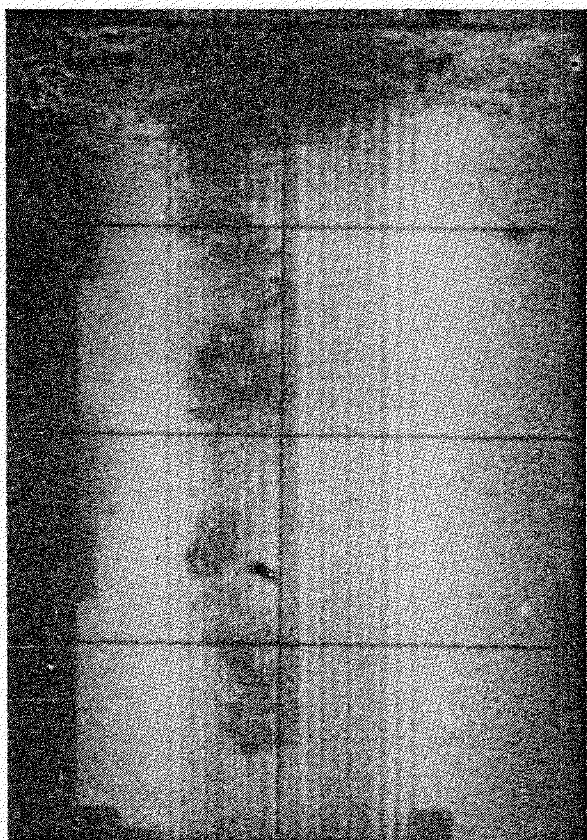
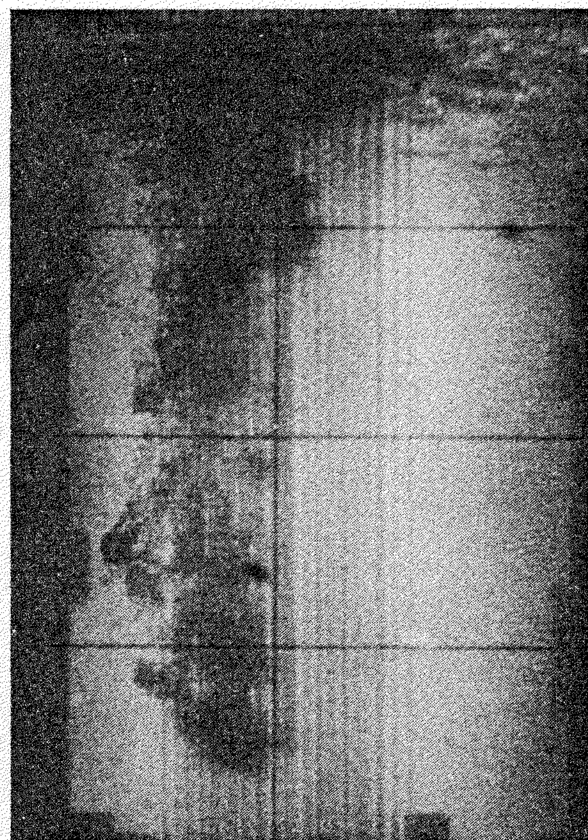
Figure 4. TUBE BUNDLE AIR-WATER INJECTION TESTS



6 SCFM
(1000 FRAMES/sec)



12 SCFM
(1000 FRAMES/sec)

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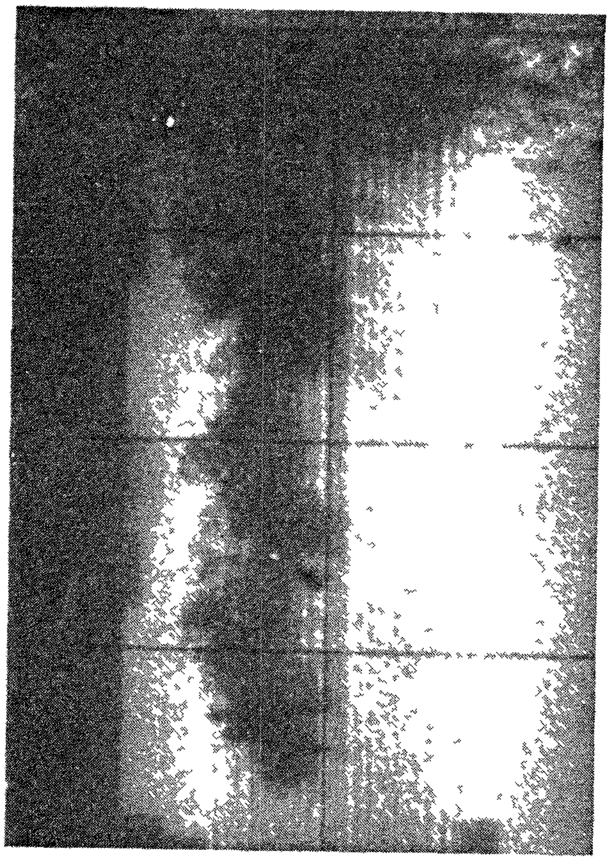
Figure 5. TUBE BUNDLE AIR-WATER INJECTION TESTS



40 SCFM
(1000 FRAMES/sec)

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Figure 6. TUBE BUNDLE AIR-WATER INJECTION TESTS

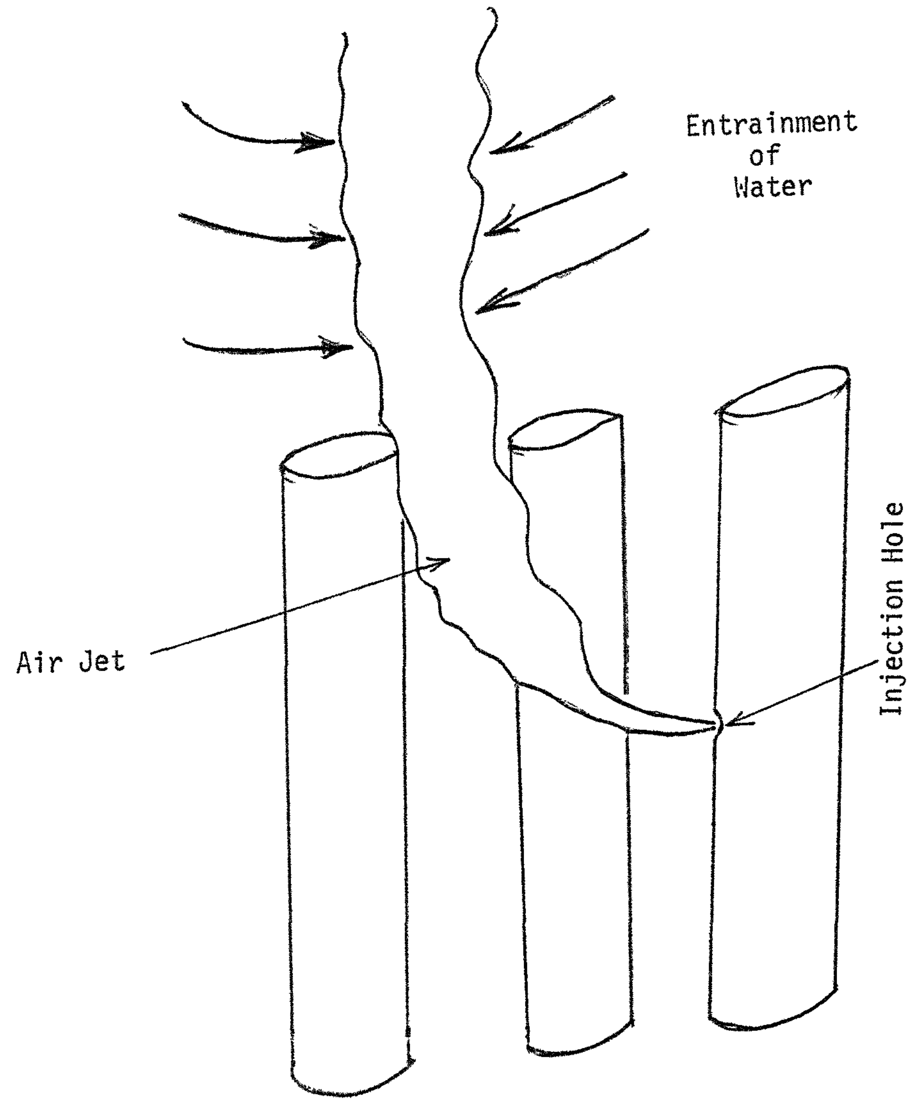

Figure 7. Sketch of Jet Process

From the movie pictures taken, it was observed that the jet boundary oscillates with respect to certain mean position. The extent of the oscillation seems to be dependent on the air flow rates. The higher the rates, the more violent the oscillation.

However, through the tests, the phenomenon of the transition size as defined in LLTR Series II test request was not once observed. Therefore, from the air-water tests, it can thus be concluded that the air will be in forms of discreet bubbles at very low flow rates. The pattern changes into plume-like jets as the flow rates increase. For the present test conditions, the transition point for the two patterns was observed to occur at approximately 12 scfm.

4.0 CONCLUSION OF TEST RESULTS

The behavior of the submerged air jet tested under the water conditions of 1 atm, 65-70°F was observed to change from bubbling phenomenon to jet phenomenon. The change occurred approximately at a rate of 12 scfm air flow rate and was independent of the injection hole sizes and the location of the injection tubes. Under no condition was a large "standing" bubble formed in the vicinity of the leak site.

5.0 RELATING EXISTING DATA TO LLTR SERIES II TEST A-4 CONDITIONS

For the LLTR test conditions, it was thought that the following mechanisms and parameters play important roles in the behavior of the gas jet or bubbles:

1) Volumetric flow rate of steam into the reaction zone.
2) Consumption of part of this steam volume in the production of hydrogen when then joints the steam in the voiding process.
3) Bubble forces consisting of surface tension, internal vs. external pressure loads, bouyancy forces, drag forces as the bubble grows into the sodium, and displacement forces required to move sodium through the system to make room for the bubble.

As a rough approximate approach to the problem, the list of variables above was studied and the most important parameter appeared to be in the volumetric flow rate of steam/hydrogen into the reaction zone. Bubble bouyancy would vary slightly with gas and/or vapor density in the bubble, but the effect is second order when compared to sodium density. Bubble dynamics for the same volumetric flow rate should be very similar.

In order to avoid the question of what fraction of hydrogen and steam exists in bubbles, the equivalent leak rate under LLTR test conditions was extrapolated from the air-water test data based on all steam and then all hydrogen.

5.1 Based on 100% Steam in Bubbles

The volumetric production of steam, Q, is related to flow, W, and specific volume, v, by the simple relationship.

$$Q = Wv \quad (1)$$

The blowdown of steam through an orifice, if taken after velocity recovery, is an adiabatic, or constant enthalpy process. This process involves the blowdown of subcooled water for which the enthalpy, h, upstream of the break can be approximated as the saturation enthalpy at the subcooled liquid temperature, i.e.,

$$h = 588 \text{ Btu/lb for LLTR condition } (580°F) \quad (2)$$

Downstream of the leak, the enthalpy is still h from which the steam quality in the exit jet of steam can be calculated.

$$x = \frac{h-h_f}{h_{fg}} = \frac{588 - 324.96}{868.04} = 0.3 \text{ for LLTR condition} \quad (3)$$

In Equation (3) h_f and h_{fg} are the saturated liquid and heat vaporization enthalpies, respectively, for the steam evaluated at the local sodium pressure at the leak site. The initial enthalpy, h, is obtained from Equation (2).

The specific volume of the steam jet prior to reaction with sodium is:

$$V = v_f + \chi v_{fg} = 0.01803 + 0.30 \times 3.2 = 0.9748 \frac{ft^3}{lb} \quad (4)$$

Where x is obtained from Equation (3) and v_f and v_{fg} are the specific volumes of liquid and evaporation, respectively, for the steam evaluated at the sodium pressure.

Equations (1) through (4) provide the means for calculating the volumetric displacement rate for the steam jet in sodium assuming no reaction with the sodium. Based on the assumption of volumetric displacement, the equivalent water leak rate from the air-water test data can be calculated from the following relationship:

$$W_{H_2O} = \frac{V_{air}}{V} = \frac{V_{air}}{0.9748} \left(\frac{lb}{sec}\right) \qquad (5)$$

Where V_{air} is the air flow rate in the air-water test, expressed in $\frac{ft^3}{sec}$. The calculated results are shown in Table 3.

5.2 Based on 100% Hydrogen in the Bubble

There are two principal sodium-water reactions which produce different amounts of hydrogen as indicated below:

$$\begin{aligned} Na + H_2O &\rightarrow NaOH + 1/2\ H_2 \\ 18\#H_2O &\rightarrow 1\#H_2 \\ 2Na + H_2O &\rightarrow Na_2O + H_2 \\ 18\#H_2O &\rightarrow 2\#H_2 \end{aligned} \qquad (6)$$

The hydroxide reaction is most likely at the sodium temperature of Test A-4. Thus, 18 lbs. of water are required to produce 1 lb. of H_2.

The gas law can be used to calculate the specific volume of hydrogen.

$$v_{H2} = RT/P$$

where: $R = 766.8$ for hydrogen

Thus: $v_{H2} = 766.8\ T/P$ (7)

The volumetric production of hydrogen, Q, can be obtained from

$$Q = W_{H2}\ v_{H2} \tag{8}$$

Substituting Equations (6) and (7) into (8)

$$Q = (1/18) W_{H_2O}\ (766.8\ T/P)$$

or

$$Q = 42.60\ W_{H_2O}\ (T/P)$$

Assuming the hydrogen temperature will be 1900°F after the reaction.

$$Q = 1.0054 \times 10^5\ W_{H_2O}/P$$

Therefore, the equivalent water leak rate from the air-water test data can be calculated by the following relation:

$$W_{H_2O} = W_{air} \times \frac{P_{LLTR}}{P_{air}} = W_{air} \times \frac{140}{14.7} = 9.50\ W_{air}$$

where: W_{air} = air mass flow rate in the air-water test

P_{air} = the pressure for the air-water test

P_{air} = 14.7 psia

P_{LLTR} = sodium pressure for LLTR test

P_{LLTR} = 140 psia

The calculated results are shown in Table 3.

Table 3. Equivalent Water Flow Rate Based On The LLTR Test Conditions From The Air-Water Tests

Air Flow Rate	Air Mass Flow Rate in lb/sec	Equivalent Water Rate, lb/sec, Based on LLTR Test Conditions	
		Based on 100% Steam	Based on 100% Hydrogen Gas
10 scfh = 0.17 scfm	0.00021	0.00291	0.002
30 scfh = 0.5 scfm	0.00062	0.00855	0.0059
90 scfh = 1.50 scfm	0.00186	0.02565	0.0177
6 scfm	0.00743	0.1025	0.07
12 scfm	0.01485	0.20517	0.141
30 scfm	0.037	0.50	0.35
40 scfm	0.04951	0.684	0.471

As discussed before, the air pattern changed from discreet bubbles to plume-like jet when the flow rate was greater than 12 scfm. Based on Table 3 results, this corresponds to approximately 0.2 - 0.15 lb/sec of water leak rate under LLTR test conditions. Therefore, it can be extrapolated that under LLTR test conditions, the hydrogen gas generated and the residue steam would form discreet bubbles for a leak rate less than the range of 0.15 - 0.2 lb/sec. They would form plume-like jet for leak rates larger than the range of 0.15 - 0.2 lb/sec.

6.0 ACKNOWLEDGEMENTS

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