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Publisher’s version / Version de l'éditeur:
https://doi.org/10.4224/40003561
Laboratory Technical Report (National Research Council Canada. Division of Mechanical Engineering. Engine Laboratory); no. LTR-ENG-17, 1972-12

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ENGINE LABORATORY

LABORATORY TEST REPORT

LTR-ENG-17

SOME ICING TESTS ON SELECTED SCREEN SAMPLES

by

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DECEMBER 1972

Summary

A brief series of icing tests was conducted on a number of wire mesh screens. The screen samples were to be evaluated for suitability as protective engine inlet screens. The icing environments created in these tests were similar to those likely to be encountered at gas turbine ground installations. Both glaze and rime ice formed a strong lattice which was firmly attached to the upstream side of the screen wires. The ice did not shed, and no runback ice on the downstream side of the screen was encountered. The recommended screen, a one-inch mesh of 1/8-inch wires, presented a good balance between a small increase in pressure loss from ice formations and adequate protection against hard ice build-ups shed from plenum components above the engine intake.

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1.0 Introduction

Gas turbine engines, both industrial and aircraft types, are widely used in stationary power installations. In particular, they are employed as prime movers for compressors along natural gas pipelines. In recent winters, a series of compressor blade damages occurred which were traced to ice ingestion. Because of a continuing N.R.C. Engine Laboratory interest in aircraft gas turbine anti-icing, Trans Canada Pipelines Limited have consulted N.R.C. relative to this problem. One possibility of protecting the engine from hard ice ingestion is the installation of a screen in front of the engine air intake, see Figure 1.

2.0 Purpose

The Engine Laboratory undertook to carry out a limited series of icing tests on a variety of wire mesh screens supplied by Trans Canada Pipelines. The aims were: the establishment of icing characteristics under probable icing conditions; determination of the possibility of ice shedding from the screens; and evaluation of the increase in static pressure losses resulting from ice formations on the screens. For various reasons, the investigation had to be brief, with test results to be available for implementation this winter.

3.0 Test Installation

The icing tests were conducted in the 4.5-foot icing tunnel of the Low Temperature Laboratory, assisted by that Laboratory's personnel. Screens were mounted in two attitudes: perpendicular to the air flow and inclined at 45 degrees. All screens were cut to the cross-sectional shape of the tunnel (4.5 x 4.5 feet with 1 foot straight fillets at the corners). Thus, when placed vertically, the screens extended over the whole tunnel cross-section, while at the inclined position they were mounted centrally on a plywood frame, see Figures 2, 3 and 8. Uniform icing conditions at the test screen surface were obtained by the use of two pneumatic spray nozzles, mounted six inches apart, placed near the duct central axis, approximately 4.5 feet ahead of the screen, pointing upstream, see Figure 8. This uniform water droplet distribution was maintained even when the screen was positioned on an inclined frame. Large windows and well-placed flood lights facilitated screen observation throughout the test.

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4.0 Test Procedure

In order to obtain meaningful results from the limited number of tests possible, certain test parameters were kept constant throughout the series. Based on a screen design proposed by TCPL and a typical gas turbine air flow rate, the tunnel air velocity was maintained at 25 fps. The icing environment consisted of 15-micron water droplets (volume median diameter) with a liquid water content (LWC) of .75 gm/m^3. The three remaining variables were:

(i) type of screen (see Table 1)

(ii) tunnel air temperature (-5°C and -1°C)

(iii) screen attitude (vertical and 45° inclined)

The LWC was purposely selected high so as to condense a probable icing condition of many hours' duration into an acceptable test period. After test No. 4, which lasted 2.5 hours, all test periods were arbitrarily chosen to be two hours.

Ambient liquid water concentrations at stationary gas turbine sites are unlikely to exceed 0.3 gm/m^3. After passing through the inertial filter elements, the maximum LWC at the proposed screen location within the plenum will be significantly reduced. Thus the two-hour test period at 0.75 gm/m^3 is believed to represent at least 10 hours of actual operation under the worst environmental conditions.

The inertial filters will also affect the median volumetric droplet diameters in the plenum. Large droplets will be more effectively separated and caught within the filter than will the smaller droplets. Thus the median droplet diameter of the icing condition which reaches the proposed screen location will be smaller than in the outside environment. Hence the volumetric median droplet diameter for these tests was set at 15 microns, the smallest that could readily be generated with the available simulation equipment.

Furthermore, it is believed that dry snow and ice crystals will not adhere to a cold screen, but will pass through it harmlessly. Moreover, the static temperature drop related to the low velocities in the plenum and through the proposed screen will be insufficient to create any significant amount of condensate icing.

Static pressure drop, measured by a micromanometer connected between tappings on either side of the test screen, was recorded every 30 minutes after the icing sprays were turned on. Photographs of ice formations on the screen were usually taken after the first hour into the test; a detailed photographic record of the iced screen was taken immediately following the test. Visual observations made during a run were entered into a log sheet.

5.0 Test Results and Discussion

5.1 General

A total of nine test runs were made, involving five of the seven screens supplied, as shown in Table 1. The information was gathered in such a way that gaps could be filled by interpolation. Only relatively high icing temperatures were explored, at which the air is capable of carrying significant amounts of moisture and where hard glaze ice may form. While the two screen attitudes tested may prove to be inadequate for a quantitative assessment, they may suffice to indicate the trend. Considering the layout of a typical plenum chamber and the placement of the proposed conical intake screen in it, see Figure 1, it seems certain that the air will pass through the screen at a wide range of angles. These angles will alter as ice forms on the screen changing its drag profile.

5.2 Ice Formations

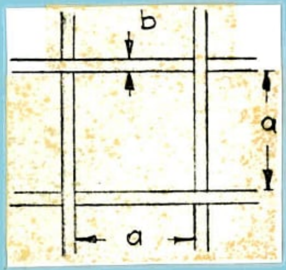
The ice actually created in the tunnel was glaze, rime, or intermediate ice, sometimes referred to as glime. The type of ice formed in aircraft turbine engine anti-icing work is primarily a function of air temperature and velocity. In the present tests, ice which formed at -5°C was judged to be mostly rime ice, with perhaps some cases of glime ice mixed with the rime, see Figure 4. As can be seen, the rime ice formed (on the upstream screen face) in a ragged spearhead shape, somewhat blunter at the leading edge than is usually found at higher velocities.

At a tunnel temperature of -1°C, glaze ice invariably formed on the screens, see Figure 5. This glaze ice, which at typical flight velocities freezes into hammerhead-shaped cross sections causing excessive drag, had an unfamiliar knife-edge profile. Because of the low tunnel velocity and the absence of any above-freezing temperatures, no runback ice formed behind the screen, see Figures 6, 9, and 10. At the upper portion of the screen, where the temperature was close to freezing, a few small frozen globules formed of, typically, 1/4-inch diameter, see Figure 7.

TABLE 1

SCREEN CODES AND TEST SUMMARY

Screen Code	Screen Sizes (Inches)		Test Summary			
			Temperature = -1°C		Temperature = -5°C	
	Nominal a x b	Actual a x b	Vertical	Inclined	Vertical	Inclined
A	1/2 x 1/16	15/32 x 1/16			Test 5	Test 10*
B	3/4 x 1/16	25/32 x 1/16				
C	1 x 1/16	1 x 1/16			Test 7	
D**	1 x 1/8	1 1/32 x 1/8	Test 8	Test 12*	Test 4	Test 9
E	1 x 3/16	1 x 3/16		Test 11*		
F	1 1/2 x 1/8	1 9/16 x 1/8				
G	2 x 1/8	2 1/16 x 1/8			Test 6	



For All Tests:
Free Stream Tunnel Velocity = 25 fps
Volumetric Median Droplet Dia. = 15μ
Liquid Water Concentration = 0.75 gm/m^3
Duration (except Test 4 = 2.5 hours) = 2 hours in icing condition

* With pieces of pipe strapped behind screen to simulate structure.

** Taken as comparison.standard.

In tests in which the screens were inclined rearward 45 degrees, the attitude of the ice formations on the horizontal wires changed over the length of the screen, approximately as shown in Figure 8.

All ice formations, rime, glime, or glaze, formed a strong lattice which was firmly bonded to the screen. Although a quantitative assessment was not made, it took considerable effort in all cases to break a piece out of this structure. Once the lattice was breached, subsequent pieces could be dislodged with somewhat less effort. As one would expect, the strength of the ice formations increased with decreasing screen pitch. No ice shedding was recorded during any of the tests. These observations lead to the conclusion that aerodynamic forces and/or engine vibrations present at a field site are unlikely to induce any appreciable shedding of ice accretions similar to those created in the icing tunnel. If icing conditions were followed by above-freezing temperatures, it is predicted that the ice would commence to melt with some sections possibly sliding off the screen once the bond were sufficiently weakened. The ice accretions on the screen, even after the severe conditions of these tests, were definitely not heavy enough to damage compressor blading should they be inhaled by the engine. Furthermore, under these warming conditions, there is no evidence or expectation of runback or refreezing causing dangerous glaze ice accretions behind the screen.

For the last three tests, pieces of pipe were strapped behind the screen to simulate structural members. Ice formed on impact in the cavity between pipe and screen, but no runback icing occurred, see Figures 9 and 10. The ice buildups, being behind the screen, could possibly be shed, if rising air temperatures should loosen the bond, and be ingested. This possibility should be taken into consideration when designing the support structure of the screen.

5.3 Static Pressure Loss

When thinking of protecting an engine intake with a screen, total pressure loss is of primary concern. While the screen itself will cause a certain small pressure drop, this drop can increase considerably in an icing environment. In order to prevent compressor stall in case the screen should be severely blocked by heavy ice accretions, it has been proposed to leave the bottom of the screen open. This should be acceptable, since the screen's main function is the protection against ingestion of ice formations detached from the ceiling or upper parts of the plenum walls. Notwithstanding the foregoing, severe pressure loss across even a partial intake screen can cause engine problems by distorting the flow into the gas turbine compressor.

In vertical attitude (tests No. 4 to 8), the dry screen losses were approximately 1/16 inches WG for all specimens, see Figure 11. The two-inch screen (G), even though heavily iced, did not affect the pressure drop noticeably during the two-hour test. The loss across the 1/2-inch screen (A), on the other hand, increased about four-fold. The increase was gradual, however, and the final difference across the screen did not exceed 1/4-inch WG. The knife-edge glaze ice formations of test No. 8 actually decreased the drag of the screen resulting in a slightly lower pressure drop in the iced condition. For no apparent reason, the smaller wire of screen C caused a greater pressure drop during the second hour of the test period than the "standard" mesh of screen D.

The dry screen losses at the inclined attitude varied from .20 to .25 inches WG. This higher initial drop must be attributed largely to the plywood frame and the higher air velocity through the screen. Tests No. 9, 11, and 12 (see Table 1) compared well with the pattern of the previous tests. The 1/2-inch screen (A) of test No. 10, however, collected a heavy rime ice lattice and closed up rapidly during the latter half of the test, see Figure 12. At the termination of the run, the screen was about 75% blocked, resulting in a static pressure difference of nearly 1.1 inches WG, or more than five times the dry value. While the absence of screen material at the bottom would assure an adequate air inlet flow, the severe inlet flow distortion may not be acceptable to the engine. Operation in a less severe icing environment but over much longer periods may conceivably produce ice formations comparable to the ones observed in the tunnel, which would preclude the use of a screen of 1/2-inch openings. Time and tunnel availability did not permit checking the 3/4-inch screen; it must be considered marginal with respect to pressure loss in icing.

6.0 Conclusions

From the brief test series conducted, the following conclusions evolved:

(i) Wire mesh screens which were exposed to small supercooled water droplets, carried by a low-velocity air flow, at temperatures between -1 and -5°C, formed a strong lattice of glaze, glime, or rime ice, firmly attached to the upstream face of the screen.

(ii) No shedding of ice took place during any of the tests.

(iii) No runback ice formed on the downstream side of either the various screens or the simulated structural members attached to some of the screens.

(iv) The static pressure difference across screens with one-inch openings or larger increased only insignificantly during the test period. In the case of the 1/2-inch screen, the pressure drop had increased four and five-fold by the end of the tests.

7.0 Recommendations

(i) If a protective screen is to be installed in front of a stationary gas turbine engine, inside a plenum chamber, it should be of basket-type with the bottom open.

(ii) The opening of a square-mesh ingestion protection screen should be one-inch with a wire size of 1/8 inch. If the wire contact points are not welded, the screen should be inspected periodically for fretting.

(iii) No water should drop onto the screen, e.g. through a leaky roof, which could become the source of runback ice.

(iv) In order to prevent the formation of runback ice on the inside of the screen, the screen should be kept uniformly cold, preferably at ambient air temperature. This implies minimal thermal connection between the screen (and its supporting structure) and any potentially warm surfaces. It is especially important to insulate the plenum wall against heat transfer from the compressor house. Snow could melt on a warm wall and form runback ice on a cold screen.

(v) If thermal protection of the screen is provided, it must be assured that all parts of the screen are maintained at above-freezing temperatures at all times.

Acknowledgement

The advice received from J. Stallabrass and the assistance given by P. Hearty in operating the icing wind tunnel are gratefully acknowledged by the authors.

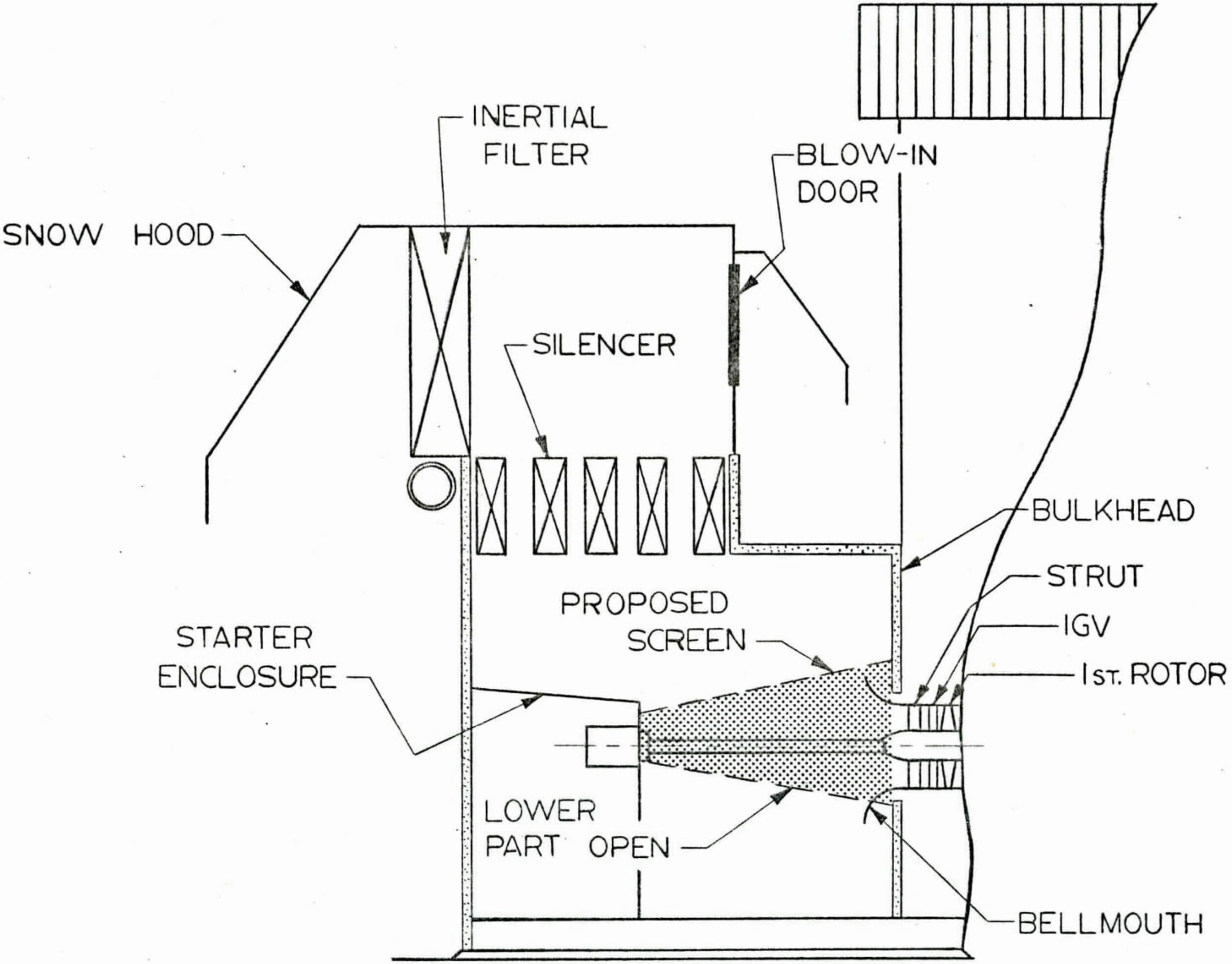


FIG. 1 : TYPICAL STATIONARY GAS TURBINE INTAKE SYSTEM

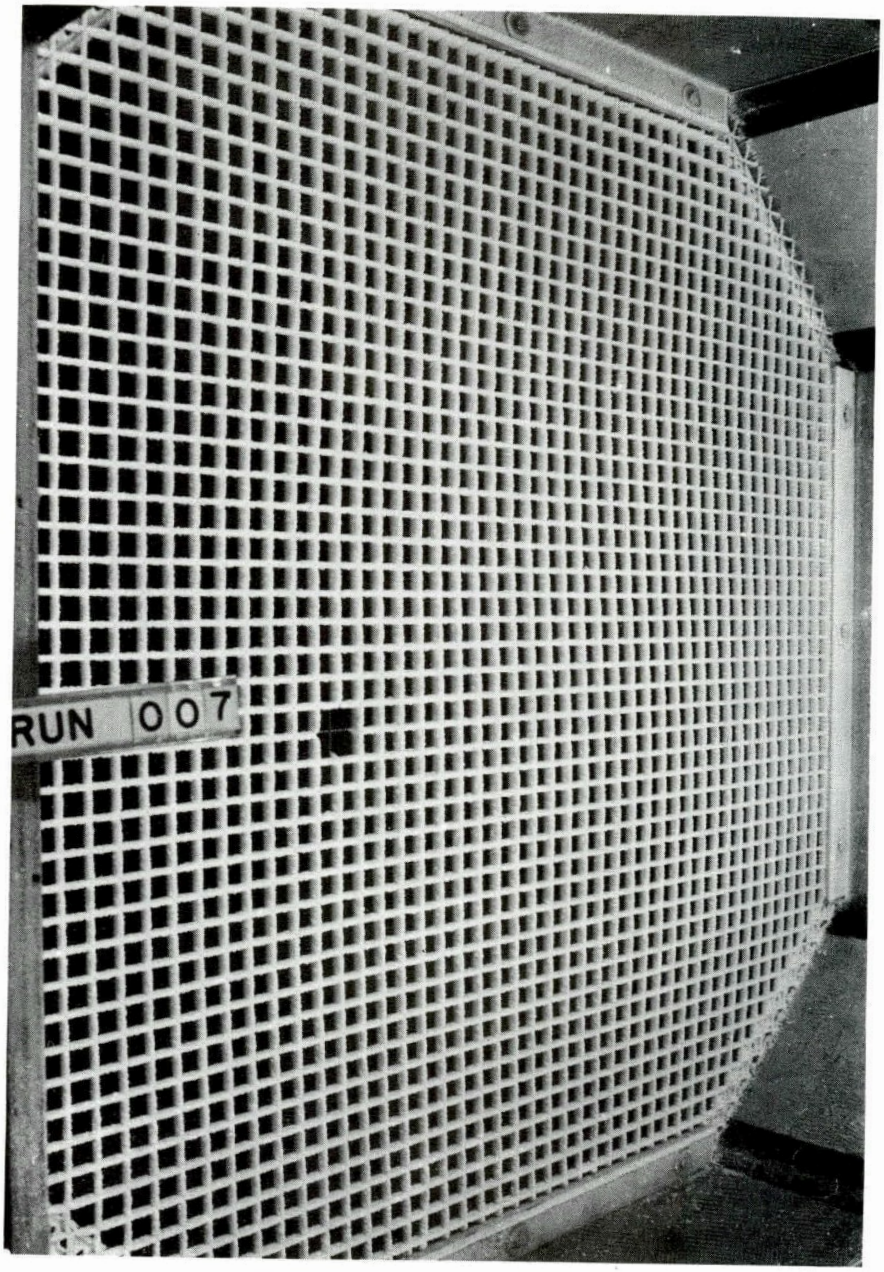


FIG. 2: SCREEN AT VERTICAL ATTITUDE IN TUNNEL

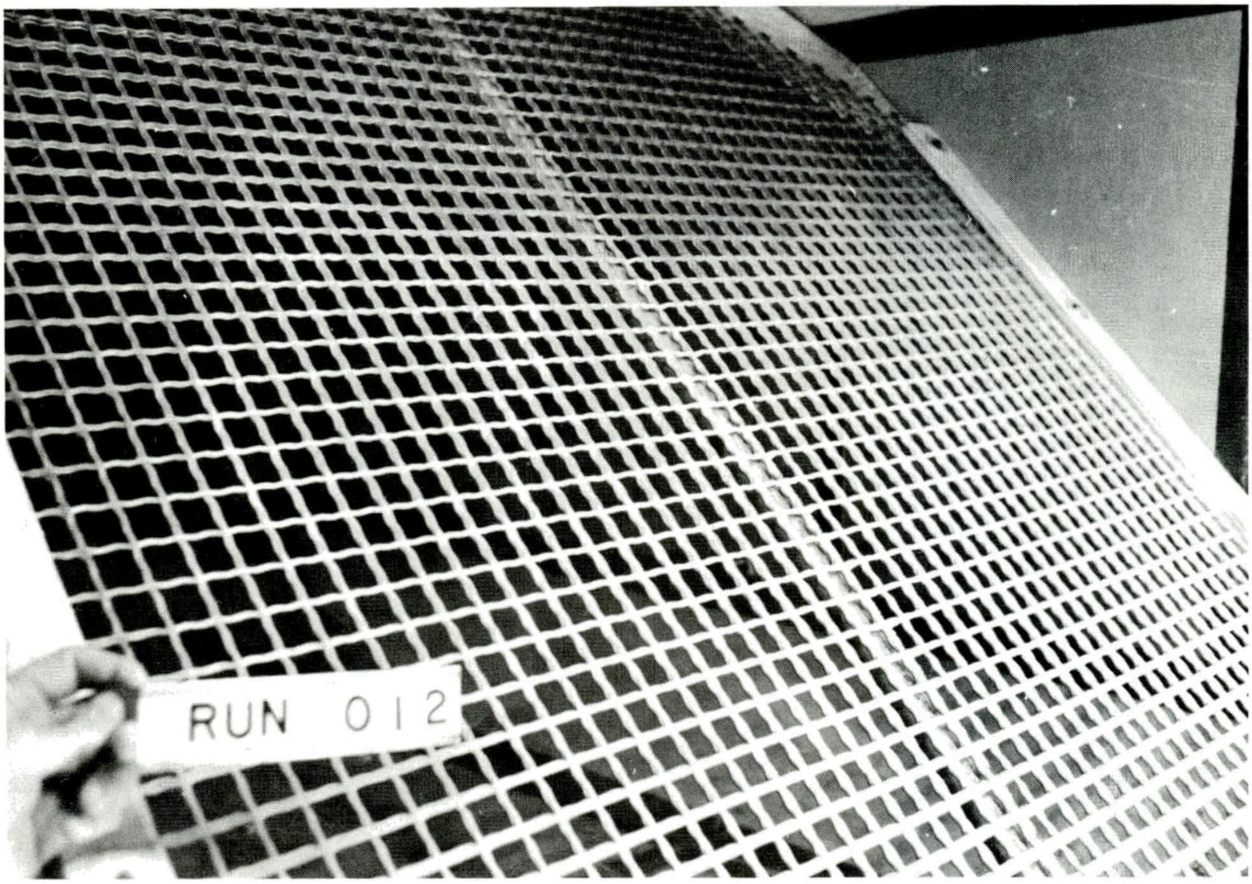


FIG. 3: SCREEN AT INCLINED ATTITUDE (45°) IN TUNNEL

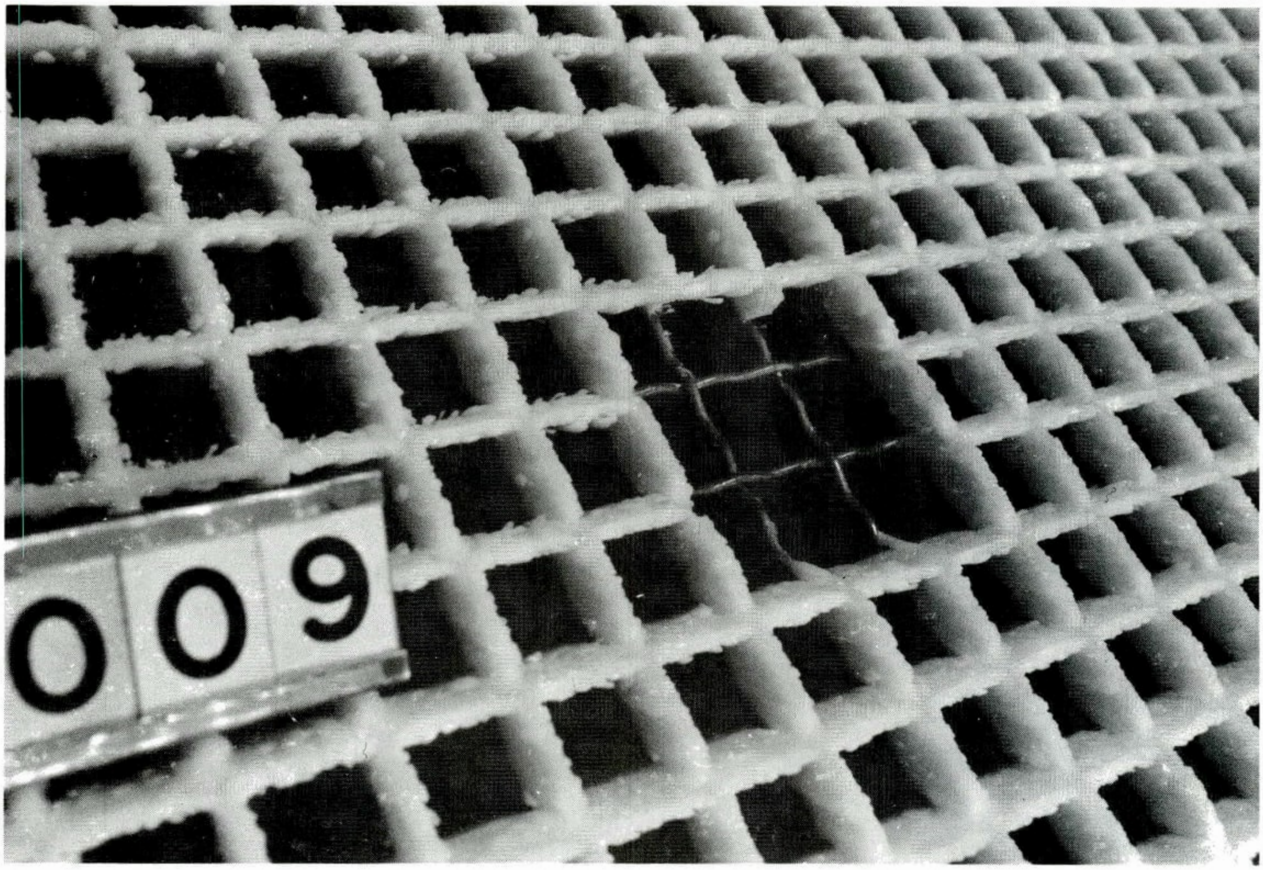


FIG. 4: TYPICAL RIME ICE FORMATION ON SCREEN

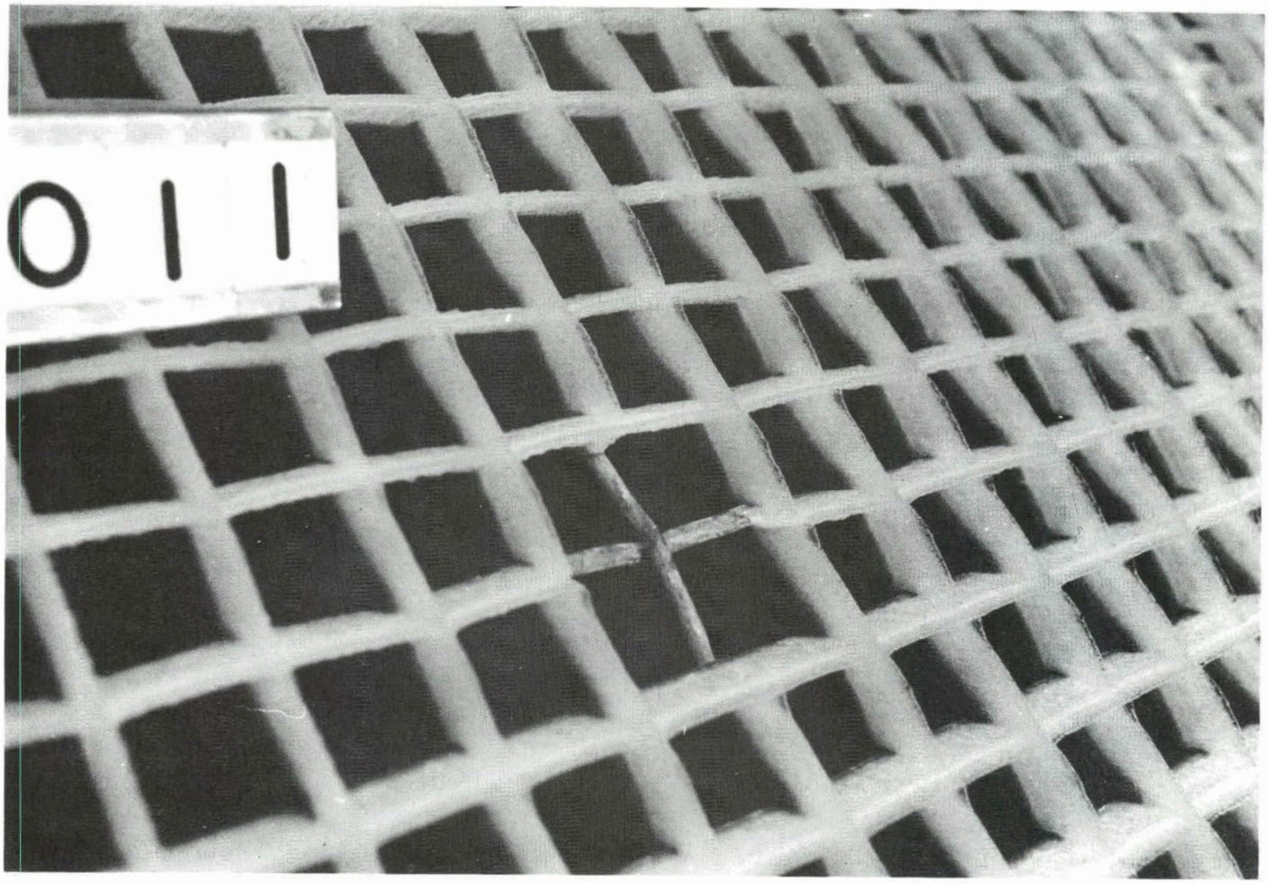


FIG. 5: KNIFE-EDGE GLAZE ICE FORMATION ON SCREEN

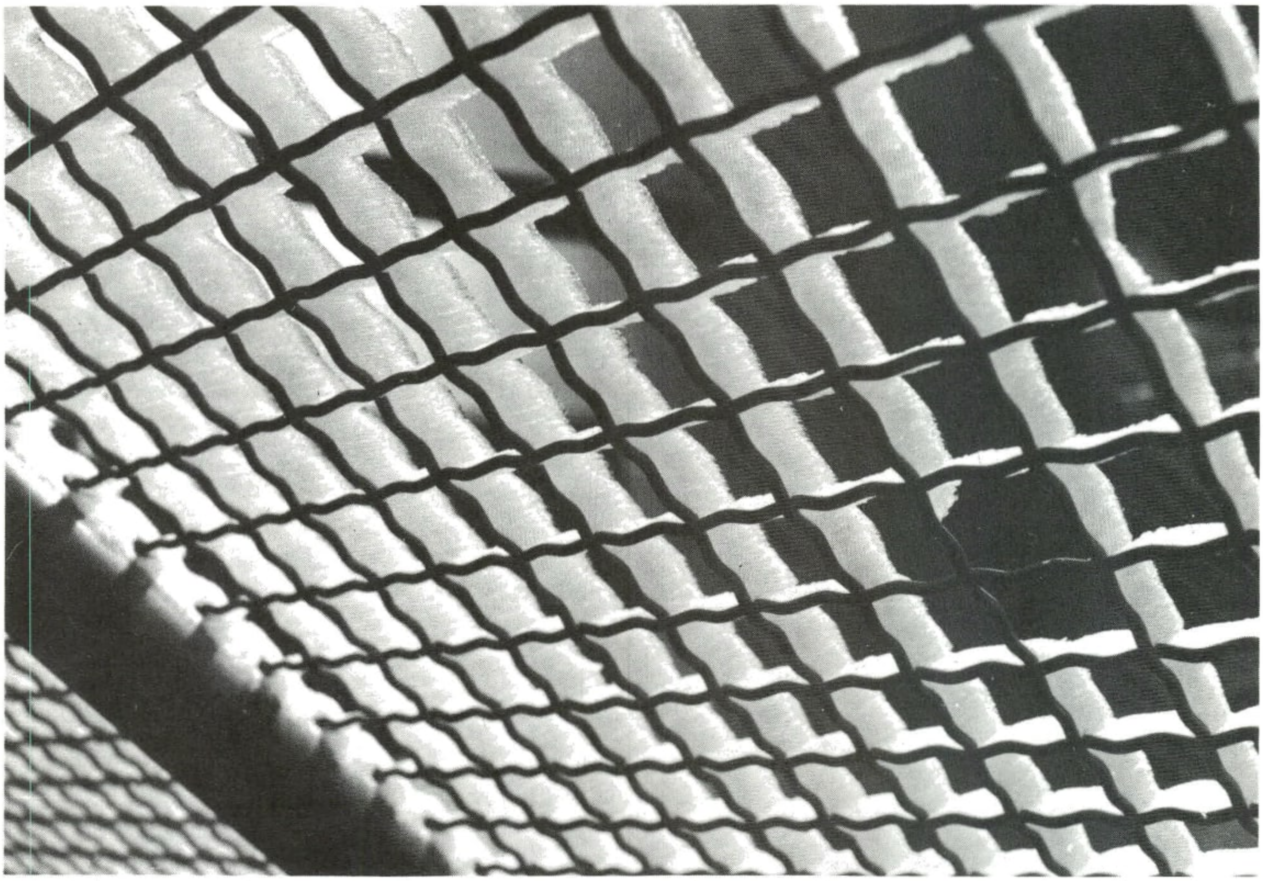


FIG. 6: CLEAR DOWNSTREAM SIDE OF HEAVILY ICED SCREEN

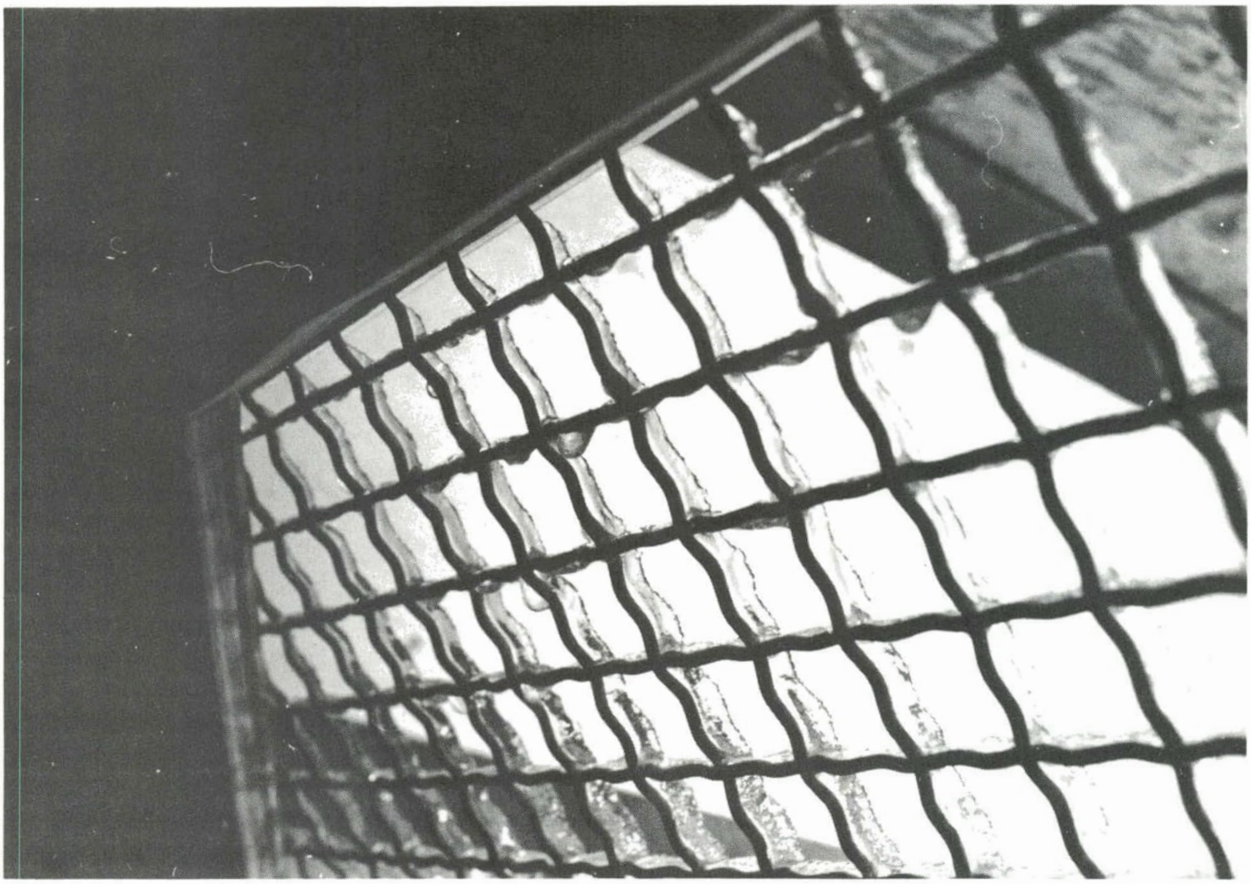


FIG. 7: ICE GLOBULES SUSPENDED FROM WIRES AT NEAR-FREEZING AIR TEMPERATURE

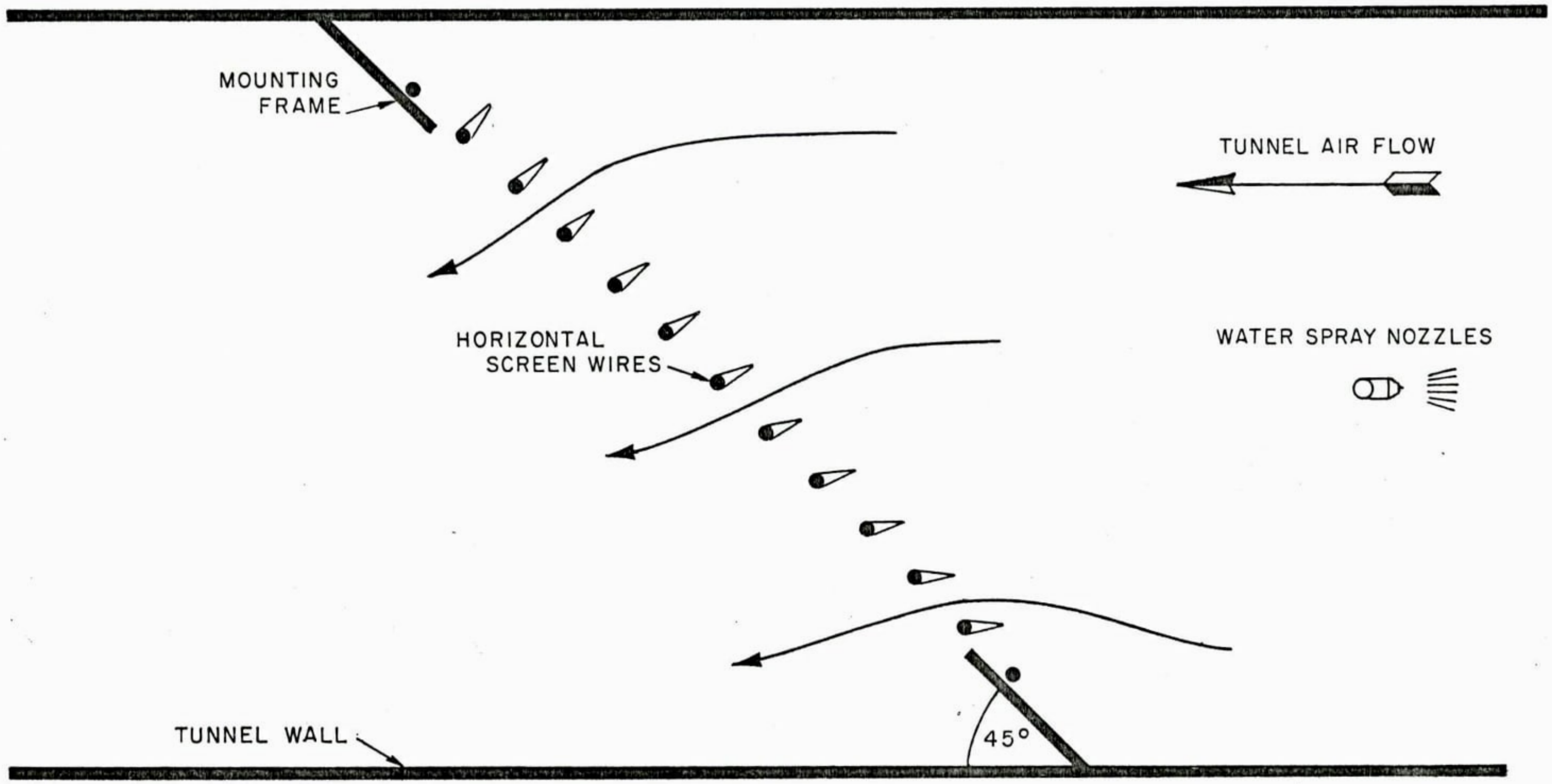


FIG.8: SCHEMATIC OF ICE FORMATION ON INCLINED SCREEN

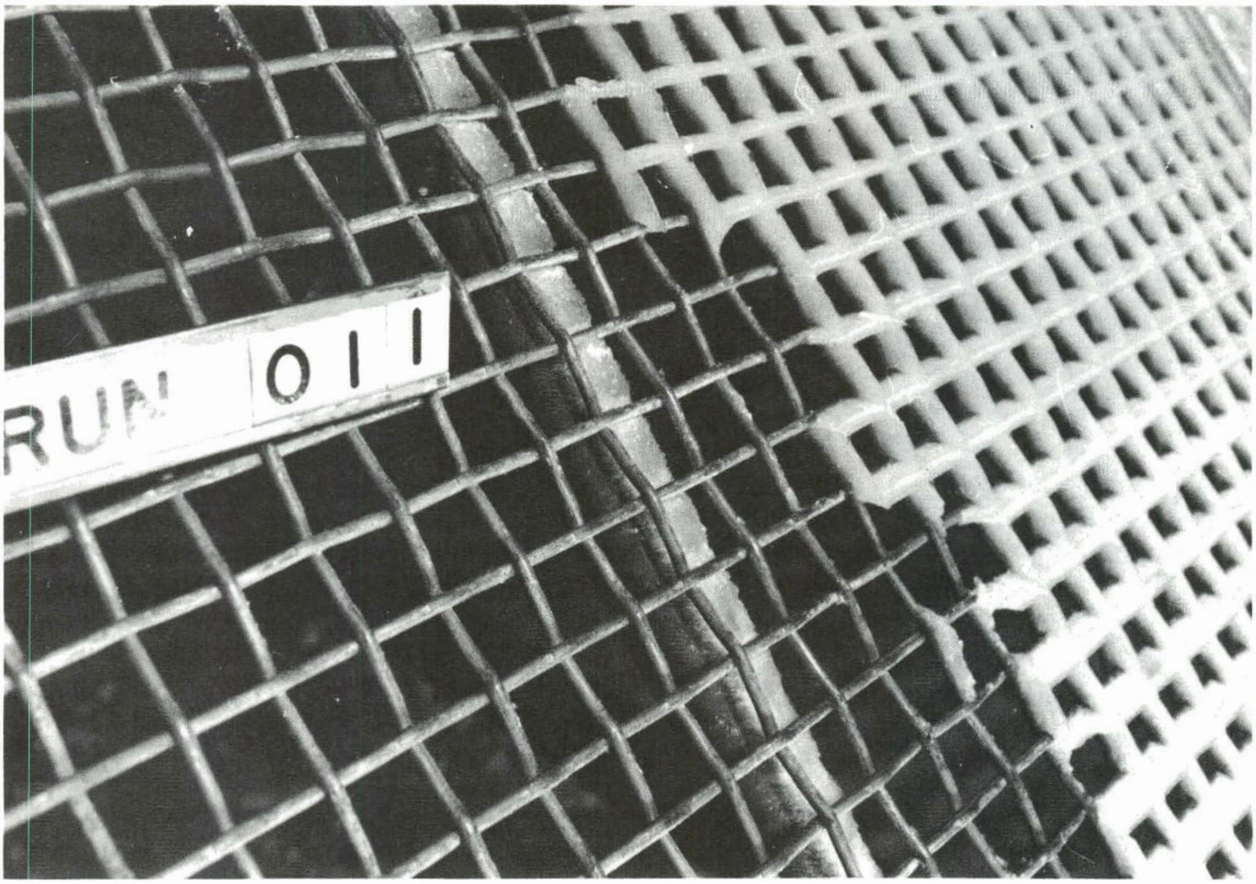


FIG. 9: GLAZE ICE FORMATION ON UPSTREAM SIDE OF PIPE BEHIND SCREEN

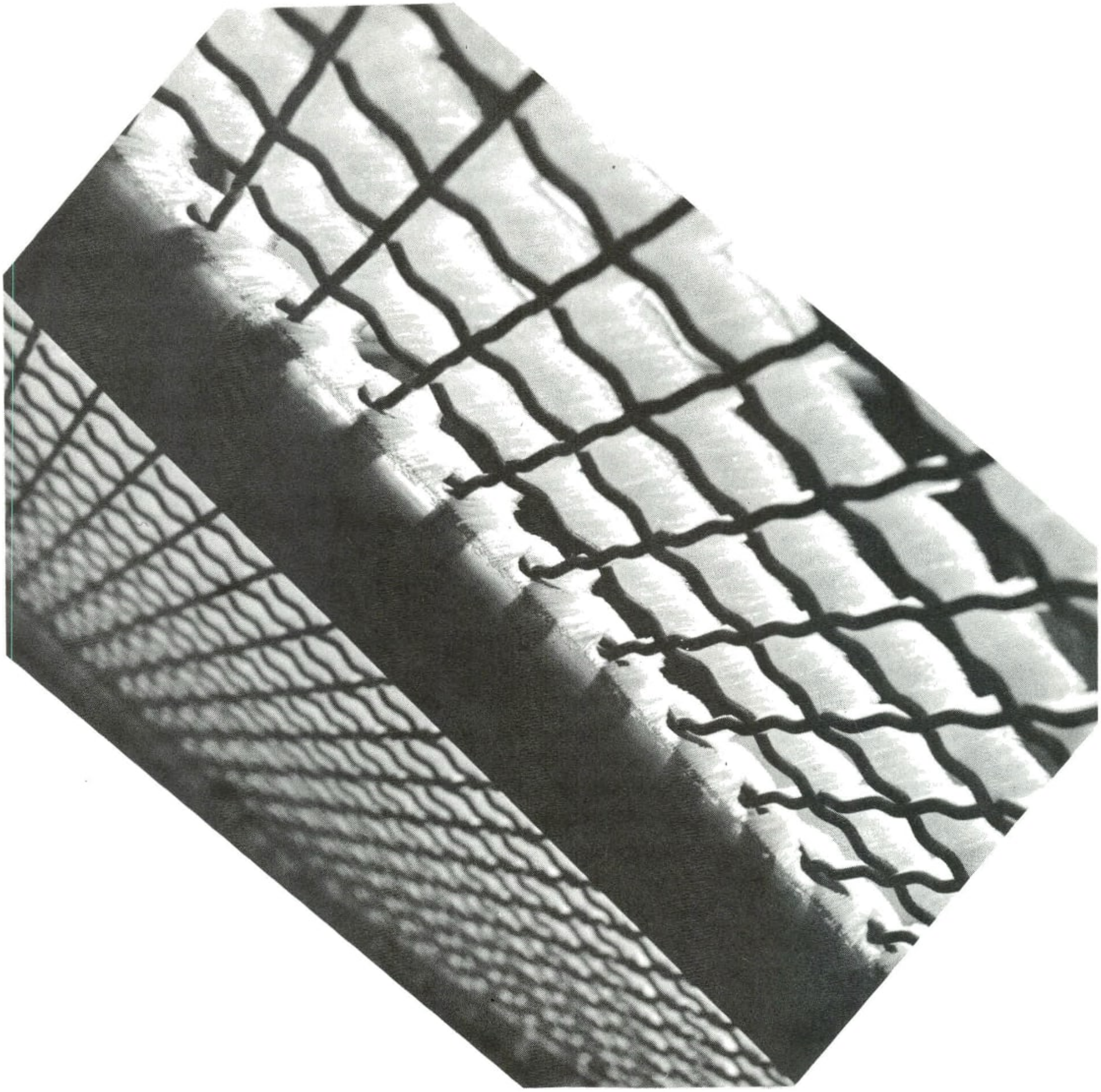
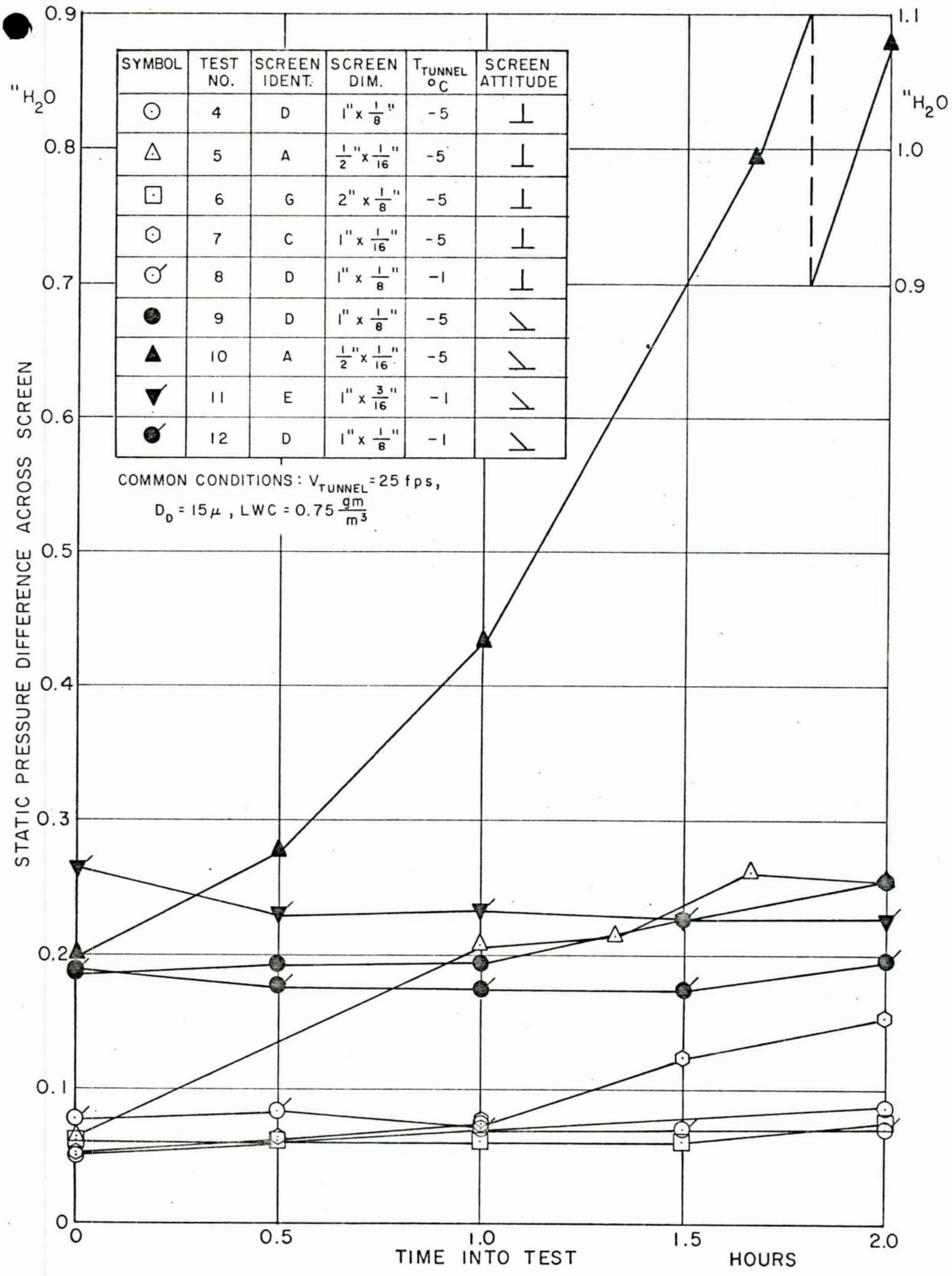


FIG. 10: GLAZE ICE FORMED BETWEEN SCREEN AND PIPE



SYMBOL	TEST NO.	SCREEN IDENT.	SCREEN DIM.	T_{TUNNEL} °C	SCREEN ATTITUDE
⊙	4	D	$1'' \times \frac{1}{8}''$	-5	⊥
△	5	A	$\frac{1}{2}'' \times \frac{1}{16}''$	-5	⊥
⊡	6	G	$2'' \times \frac{1}{8}''$	-5	⊥
⬡	7	C	$1'' \times \frac{1}{16}''$	-5	⊥
⊙✓	8	D	$1'' \times \frac{1}{8}''$	-1	⊥
●	9	D	$1'' \times \frac{1}{8}''$	-5	∠
▲	10	A	$\frac{1}{2}'' \times \frac{1}{16}''$	-5	∠
▼	11	E	$1'' \times \frac{3}{16}''$	-1	∠
●✓	12	D	$1'' \times \frac{1}{8}''$	-1	∠

COMMON CONDITIONS: $V_{TUNNEL} = 25$ fps, $D_D = 15\mu$, LWC $= 0.75 \frac{gm}{m^3}$

FIG.11: STATIC PRESSURE DIFFERENCE ACROSS SCREEN vs TIME INTO TEST

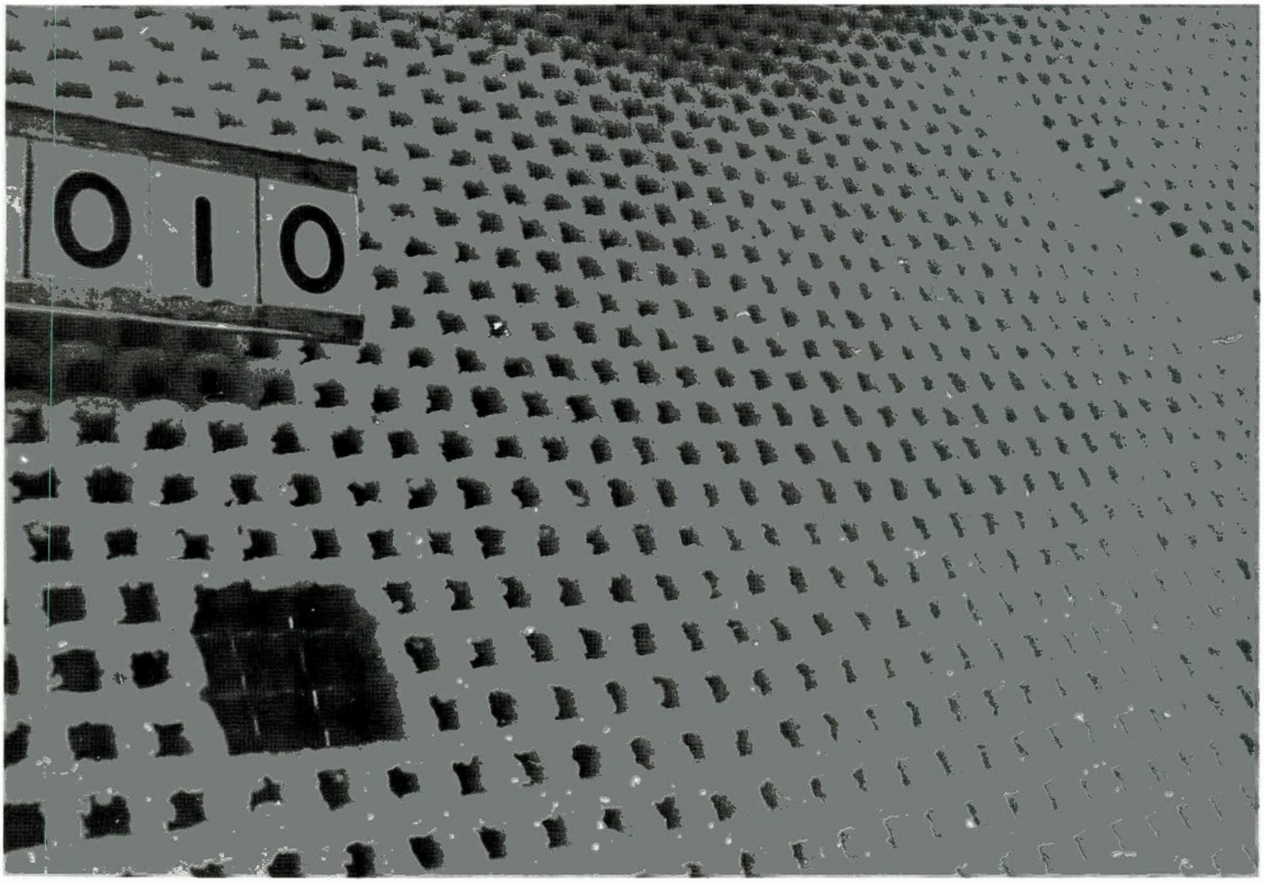


FIG. 12: HEAVY RIME ICE BUILD-UP ON INCLINED 1/2-INCH SCREEN AFTER 2 HOURS OF TESTING