"USE OF A SNOW GUN FOR PRODUCTION OF A MODEL SNOW MATERIAL"

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ABSTRACT

Artificial snow can be generated as a model of natural snow whose properties have been evaluated on a limited basis. Grain size, density, and snow cover depth have been correlated with air/water ratio. Data indicate that grain size, density and accumulation increase in a rather linear fashion with increasing water rate of a snow gun, using compressed air at supersonic speed. Since the air and water are not mixed until after discharge from the gun, shock waves are minimized, and isentropic flow yields very cold process air temperatures, thereby realizing high efficiency. Ranges of test data of about 10 gpm of water and 120 scfm of air were limited by laboratory facilities. The ability to control the density of artificial snow demonstrates its potential for use as a model material.

INTRODUCTION

Snow and ice can be both a curse and a boon to a large number of people in this world. The detrimental effects are seen most prominently in the interruption of transportation. But on the other hand, snow and ice provide a construction material of extremely beneficial properties; a principal example is the use of compacted snow for winter roads. The purpose of this paper is to propose the use of artificial snow as a model material for predicting the effects of natural snow in engineering applications.

At the time of deposition, there is a distinct difference between artificial and natural snow, as pointed out in a personal communication from A. F. Wuori at USACRREL. Crystals of natural snow are often dendritic in shape while artificial snow crystals are approximately spherical. Evidently the artificial crystals are not exposed to the air long enough to grow into a dendritic shape. However, metamorphic processes occur that make artificial and natural snows almost indistinguishable in appearance a month or more after deposition.

The majority of reports reviewed by the authors have directed their attention to after-the-fact, on-site reporting of snow conditions and properties for a particular location over a limited time. Data must be correlated between sites to generate meaningful predictions relative to typical problems such as planning, protection of the environment, and management of resources.

It is fully realized that natural and artificial snow, even of the same density, might vary widely in their thermal and physical properties. The other properties considered to be significant are: hardness, grain size, grain shape, permeability, ultimate strength, temperature history, and stage of metamorphism. Such a list indicates that field testing of natural snow is difficult because of the specialized equipment needed. A need exists to correlate data of properties of natural snow and artificial snow. This paper correlates data for air-water ratio, rate of production, grain size, and density for man-made snow.

DESIGN AND TEST OF A SNOW GUN

Controlling the thermal and physical properties of artificial snow under field conditions is a major problem. The properties chosen for evaluation in this study are crystal size, snow accumulation, and density. The comments will be directed towards a single system: compressed air and water, brought together by a so-called "snow gun." The reason for specifying field conditions is that if tests of snowblower performance, roller effectiveness, etc. are required, they cannot be conducted properly in a closed laboratory situation.

Cursory analysis of the system considered identifies three major requirements:

1) the air must be as cold as possible,

2) the water must be in fine particles,

3) sufficient time must be allowed for thermal contact to permit freezing.

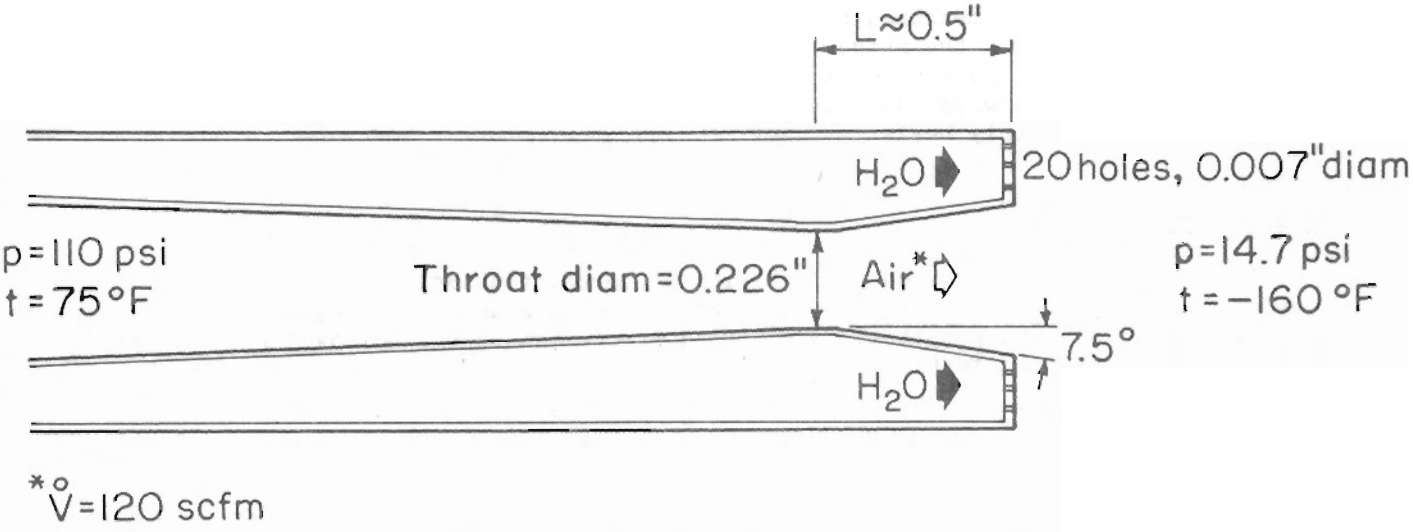
The principles of gas dynamics were introduced into the design of the air circuit by the creation of a convergent-divergent nozzle. Most artificial snow-making devices bring the air to a reduction cross section at the throat of a nozzle, but lessons in thermodynamics indicate that shock waves are established at the exit by an incorrect isentropic pressure ratio, with a resultant rise in static temperature almost to the upstream stagnation temperature. Thus, many nozzles reporting a static discharge temperature of -50°F have actually shocked back to a temperature of about +70°F.

An effort was made to alleviate this design difficulty by machining an appropriately designed supersonic nozzle, consistent with the mass choked flow rate and upstream pressure ratio of available laboratory equipment (Figure 1). Using a fixed half divergent angle of 7 1/2° for minimum turbulence, and a compressor capacity of 120 scfm at 110 psia, the first of three air nozzles was machined. A 1/2-in. throat diameter and 2-in. length gave the correct area ratio.

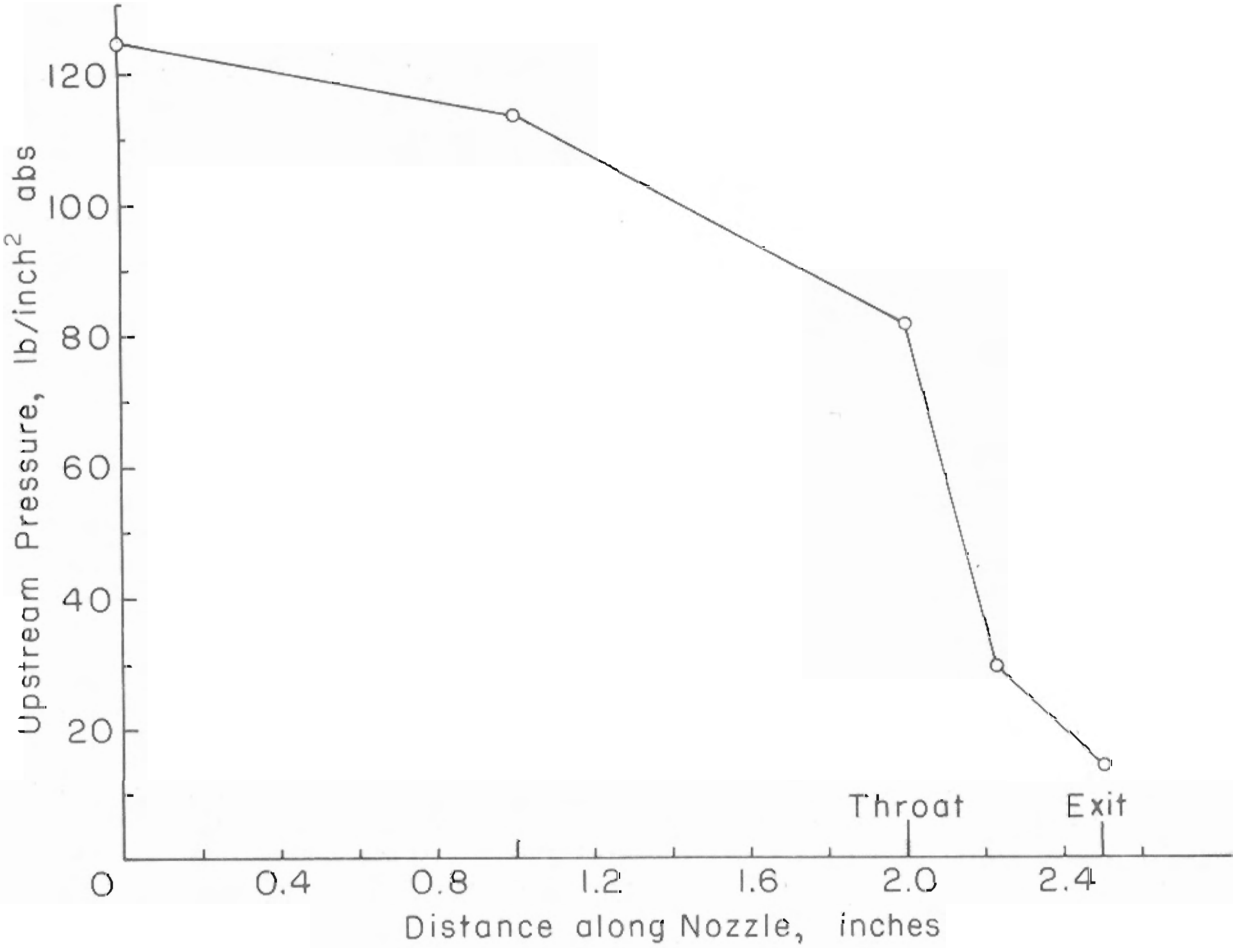
From gas tables, with the designed pressure P/P_o, discharge temperatures were -160°F, with exit Mach numbers of 1.4-1.6. An annulus of water was created on the outside of the air nozzle. About 20 holes, 0.007 in. in diameter, were drilled into the face plate which had been brazed to the air nozzle exit, and drops of water were pumped into the cold air. To show that essentially isentropic flow conditions were achieved without shock occurring, Figure 2 shows a plot of static pressure vs. nozzle length. The noise level of the gun was measured at 105 db.

Instrumentation

The air circuit cfm was measured by means of a sharp-edged orifice inserted in the line with appropriate fittings; the entire assembly had been calibrated in a variable capacity wind tunnel using a precision ASME nozzle. Air from the 80-scfm compressor was pumped into a large storage tank, allowed to stabilize to room temperature, then passed to the gun through 2-inch rubber fire hoses. Temperatures in the tank were monitored with copper-constantan thermocouples.



1. Schematic diagram of supersonic nozzle.



2. Static pressure vs. nozzle length.

The water rate was measured by two rotameters in parallel, each having the desired sensitivity depending on the range. These rotameters had been calibrated in a high capacity water tunnel. The rotameters became damaged during the season, and were replaced by a 2-position 3-way valve which diverted the water into a 55-gal. weigh tank. Times were extrapolated to an hourly basis.

Test Sequence

Preliminary testing showed the futility of correlating ambient air temperature, wind speed and direction with the results desired. In preliminary testing, gusting winds played havoc with the collection system. A Latin square technique was followed for varying the water rates in a random fashion.

Data Collection

Independent tests of this gun, along with others, were conducted by the Cold Regions Research and Engineering Laboratory. The results point out the need for standardization of test conditions. The snow density, as a function of location and time, was reported in "Degradation Effects Project, Winter, 1968-1969" as:

Near gun	Mean away from gun	3-5 days after test
0.3 g/cm^3	0.26 g/cm^3	0.41 g/cm^3

Even though the gun was obviously making snow, updrafts and cross winds sometimes left the measuring cans completely empty. Snow density was measured by collecting the snow in kerosene-filled cans, measuring the differential of weight (± 0.1 g on a chemical balance) and volume of fluid (± 0.05 ml), and averaging the results. Luckily, all data were recorded under calm wind conditions. The average ambient air temperature was +26°F, and the atmospheric pressure was 30.18 in. Hg. The time period was 1-5 a.m. local time and the ground elevation 120 feet.

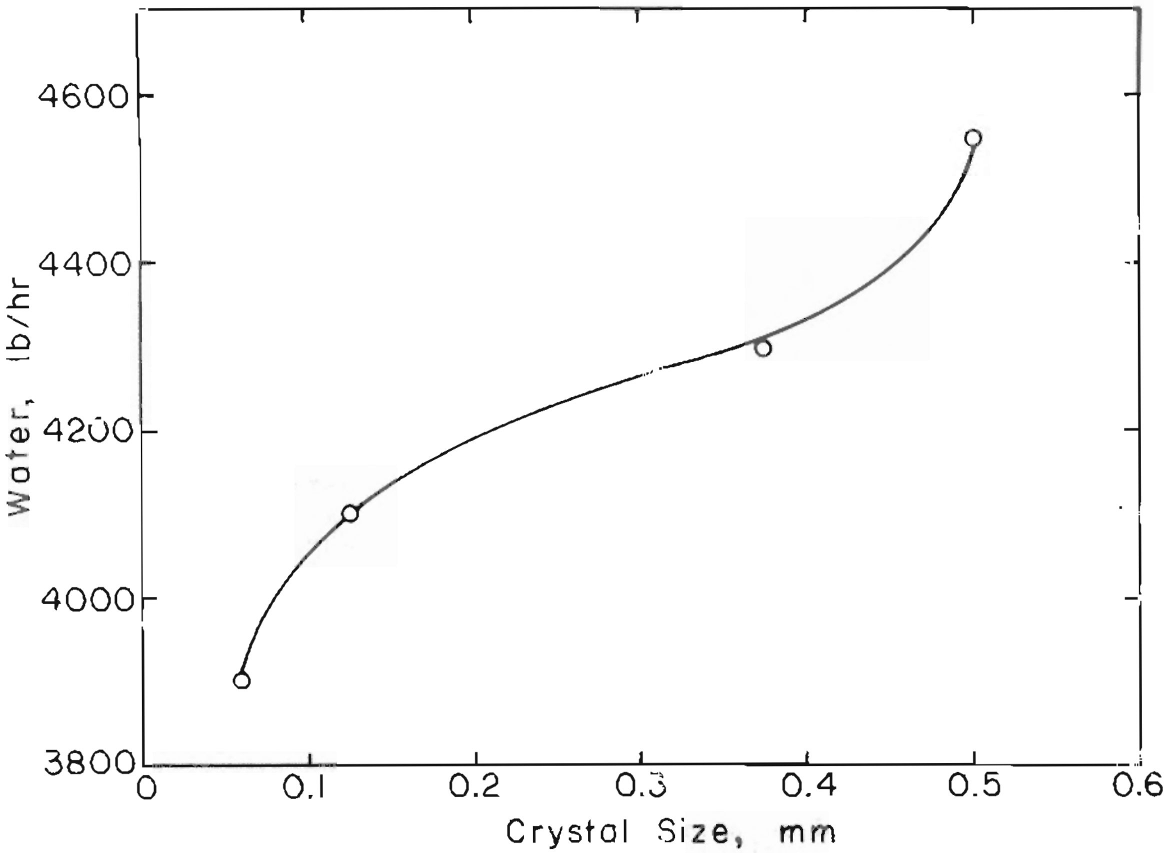
RESULTS AND CONCLUSIONS

A representative distribution of particle size was sampled to determine crystal size (Figure 3). Figure 4 shows the gun in full operation in the laboratory. Figure 5 shows snow depth and density as a function of water rate at a constant 120 scfm of air.

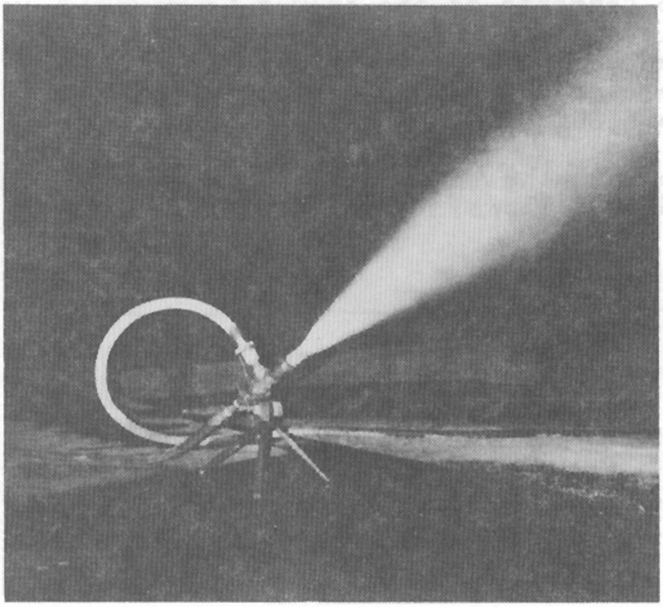
A 300-scfm air nozzle was also tested in late March, with the results reported only as clouds of snow.

A fringe benefit from this research program was when Winter Carnival snow sculpture contestants at the University of Massachusetts used the artificial snow generated from this gun, which was run continuously over a 54-hour period. About 6 ft of snow was produced over a 20- x 10-ft area.

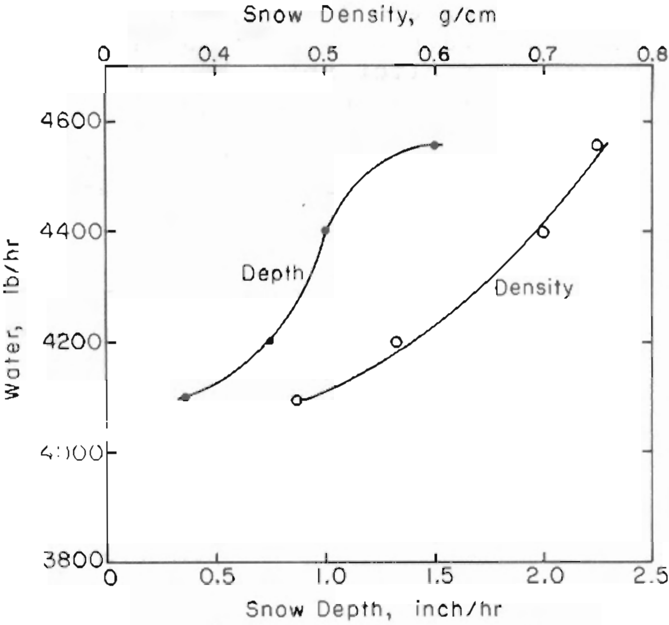
A snow gun which allows the air and water to mix after discharge was used to produce artificial snow. The advantages of this method are that shock waves are minimized and air temperatures of -140°F are realized because of isentropic flow. Flow rates of 5-10 gpm of water and 120 SCFM of air were used to determine their effect on grain size, density and snow cover depth. The test results showed a direct relationship of these variables with the air/water ratio. Of particular importance to the use of artificial snow as a model material is the ability to control its density.



3. Crystal size as a function of water rate.



4. Snow gun in operation.



5. Snow depth and density as a function of water rate.