Controlling Crystal Habit in a Small Scale Snowmaker

Josephine Bones, E.E. Adams
Department of Civil Engineering, Montana State University, Bozeman, MT USA

ABSTRACT: The crystal habit, plates or columns, in snow crystals is dependent on atmospheric temperature. The secondary feature of the crystal, plates versus dendrites and columns versus needles, depends on the degree of supersaturation of the air. In the Montana State University's Subzero Science and Engineering Research Facility specific snow crystals were grown by varying the temperature and supersaturation of the air in a controlled environment. A humidifier was engineered to generate a water vapor source. Air at the controlled temperature was directed across the humidifier at a low velocity using cross flow fans. The water vapor was transported into a chimney where hemp strings served as nuclei for crystal growth. Dendrites, plates, columns and needles were successfully created along with a byproduct of rime. The occurrence of rime appeared to be dependent on the transport wind velocity and rate of humidification. Addressing the occurrence of rime and purifying the crystal habits should be further researched. The significance of this project's success in growing distinct crystal habits provides a potential avenue for a low-cost, small scale snowmaking system providing opportunities for other research.

KEYWORDS: Controlling crystal habit, growing snow crystals

1 INTRODUCTION

According to Libbrecht (2003), crystal habit is a function of temperature and supersaturation. In addition, a nucleus is required to initiate growth. Based on research conducted by Nakaya (1978), a snow morphology diagram was created (Libbrecht 2003), and reproduced in Figure 1. This diagram shows the type of crystal that forms in nature based on air temperature and humidity. Nakaya found that while the humidity is important to developing crystal complexity, the main factor for the crystal habit is the ambient air temperature (Libbrecht, 2003).

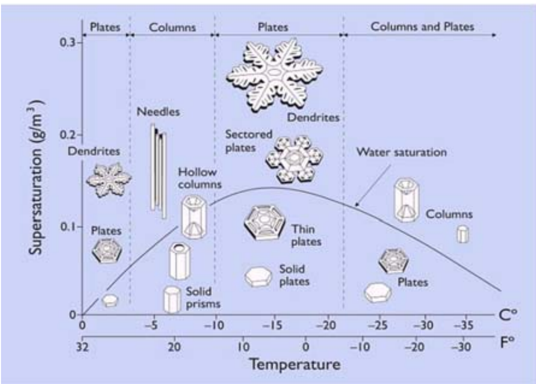

Figure 1 – *Snow Morphology Diagram*

Snow forms when saturation or supersaturation conditions are reached and water vapor deposits into ice particles. Convective currents in the atmosphere force the nucleus, microscopic dust or bacteria, to collide with water molecules causing crystallization. Deposition occurs when the vapor pressure in the air is greater than the vapor pressure on the surface of the ice crystal. Once crystals are too heavy to remain suspended in the atmosphere the snow crystals fall. Libbrecht (2003) determined that snow crystals generally do not form when the temperature drops below -20°C because clouds will have already precipitated out most of the moisture and the remaining particulate is too light to fall.

In addition to typical crystal columns, plate and needles, snow rime or grauple can also occur. In clouds consisting of both liquid water and ice crystals, the water droplets collide with the frozen ice crystals freezing on contact. The resulting formation is a snowflake with frozen droplets also known as a rimed snowflake. Since the crystal formed in the absence of water vapor (liquid to solid) it is classified as rime (Betker, 2006). Not only does rime occur in clouds, but it also commonly forms on the windward side of solid surfaces (Eden, 2009). Heavily rimed crystals still in the atmosphere typically fall as graupel. Graupel has a characteristic appearance similar to styrofoam balls unlike crystal columns and plates (Avalanche.org, 2009).

Currently, the Swiss at the WSL Institute for Snow and Avalanche Research SLF (Schneebeli 2006) and Nakamura (1978) in Japan have developed devices to grow specific types of snow crystals in a laboratory. At SLF dendrites, needles, and ice pellets have been created in sufficient amounts for detailed study (Schneebeli, 2006). Thus, the purpose of this project is to engineer, build and test a low cost, small scale apparatus to grow specific crystals in a controlled environment. By regulating crystal growth, the opportunities for new research are endless. This technology could be used to create an artificial snowpacks with any number of specific crystal types in each layer. The snowpack

Josephine Bones
Montana State University, Bozeman MT USA
Tel: +1 406 212 4520
Email: jodiebones@gmail.com

could be subjected to various conditions and stresses allowing advanced studies of crystal metamorphism, strength and shear testing.

2 METHODS

2.1 Snowmaking Apparatus

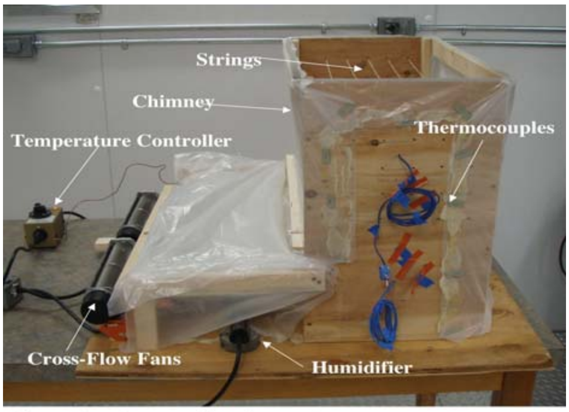

Figure 2 – *Snowmaking Apparatus*

The “Crystal Creator,” shown above in Figure 2, was engineered and built for Montana Sate University’s Subzero Science and Engineering Research Facility (SSERF) following the methodology established by Nakamura (1978). The “Crystal Creator” is a mixture of wood and 2 mm plastic film. Housed in the lower portion is a water pan and cross-flow fans. To heat the water a heating coil was inserted through one end of an aluminum foil grilling pan. High heat silicone sealant created a water tight seal. The heater receives power through a bulb and capillary sensor. The water vapor produced is transported by the cross-flow fans. Mixing cold room air with the warm moist air lowers the air saturation point. The fans were modified by adding a power converter that provided control of the current, which allows the fan speed to be adjusted. In the chimney portion of the box, hemp strings were strung horizontally to serve as nuclei for crystal growth. The air temperature within the chimney and the cold air passing over the humidifier is controlled by the room thermostat. Room set temperatures chosen reflect the temperature ranges of the snow morphology diagram.

2.2 Experiments Conducted

Two different rooms were used for trials; CC2, the Experiment Preparation Room, and CC5, the Cold Climate Simulation Room. Experiments were conducted in CC2 unless specifically noted. This room has two sets of cooling fans that regulate temperature based on a temperature set point. CC5 houses a “cold sky”, which is a large metal plate mounted on the ceiling that can be cooled to maintain temperatures down to -50°C. CC5 is smaller with a lower ceiling causing the room cooling fans to be closer to the experiment. For the following experimental trials the cold sky was not utilized. Temperatures were recorded for the water, air above the humidifier, the ambient room temperature, and five elevations in the chimney. Multiple readings were recorded because temperature is the main controlling factor for the crystal habit. The level of humidity was directly controlled by the heat of the water and was shown by the complexity of the crystals. Complex crystals occur when humidity levels are above the saturation curve on the morphology diagram. Table 1 summarizes the laboratory conditions for the experimental trials. Trials 1-3 were conditions for plate to dendrite habit in the 0°C to -4°C range, Trials 4-6 were conditions for column to needle habit within the -4°C to -10°C range, Trials 7-9 were conditions for plate to dendrite habit in the -10°C to -21°C, and Trial 10 was for columns or plates formed below -21°C.

Table 1	Trials									
	1	2	3	4	5	6	7	8	9	10
Set Room Temp (°C)	-10.0	-10.0	-7.6	-15.0	-10.0	-10.0	-25.0	-20.0	-20.0	-35.0
Actual Room Temp (°C)	-8.1	-8.5	-2.6	-9.4	-7.6	-7.6	-21.8	-16.2	-16.5	-31.8
Set Water Temp (°C)	37.8	37.8	15.6	15.6	15.6	15.6	15.6	15.6	15.6	37.8
Actual Room Temp (°C)	43.9	44.1	30.3	25.6	27.4	27.8	26.2	30.3	32.6	42.3
Time Elapse (hours)	4.4	5.8	9.3	6.4	8.0	9.0	7.1	5.5	5.0	1.1
Fan Control (Volts)	12.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	12.0
Avg. Chimney Temp (°C)	-4.5	-3.6	-2.0	-6.3	-5.0	-5.6	-15.3	-11.6	-15.2	-27.0

3 RESULTS

Successful trials are included in Table 1. Trials were excluded if no crystal growth was observed, growth melted during laboratory defrost cycles, or rime developed. Rime was considered an undesired byproduct. However, in some trials, the conditions favoring rime formation were utilized to make adjustments to further optimize crystal growth.

3.1 Plate to dendrite habit between 0°C to -4°C (Figure 3)

Early in Trial 1, small moisture accumulations were observed only on the thinnest threads of the hemp. Once growth was present throughout, the crystal habit appeared to be rime in the form of stellar crystals. The crystals had a classical stellar appearance, but when viewed under magnification, the individual ice crystals were rime. The backbone of the stellars ranged from approximately 0.50 mm to 2 mm with smaller individual rime particles.

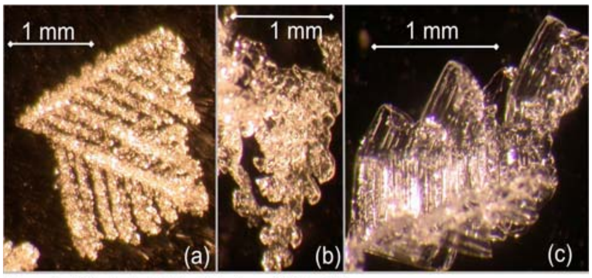

Figure 3 - *Plate to dendrite habit between 0°C to -4°C*
(a) Trial 1 dendritic rime *(b)* Trial 2 mixed dendrites and plates *(c)* Trial 3 crisp plates

During Trial 2 miniscule, less than 0.50 mm, growth was noted. When viewed later the growth on the bottom set of strings had begun to melt in the center section. The growth on the top strings appeared to be long ribs with dendritic arms that resembled rounded plates, along with intermittent rime.

Trial 3 resulted in tiny crystal growth. The crystals were approximately 0.50 mm to 2 mm. The most growth occurred on the upper most strings. Samples taken from the lower strings were round tipped plate growth about 0.50 mm in size. Crystals from the upper strings were much more distinctly plates. These crystals were much larger, ranging up to 2 mm. Typical plate crystal striations were vividly evident.

3.2 Column to needle habit between -4°C to -10°C (Figure 4)

Trial 4 samples were taken from all strings at the same time. The growth was slightly rounded columns up to about 1 mm. The crystals had a long columnar habit with rounded ends. Along with the columns was some rime.

Trial 5 showed needle growth ranging from 2 mm to 7 mm. The crystals were relatively clear and individual. Some crystals had bonded ice crystals along one edge of the needle. Upper string growth was more developed than lower strings.

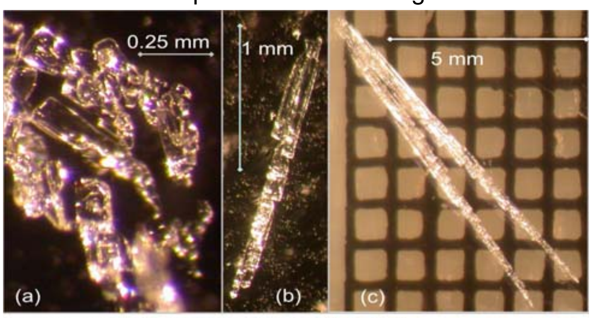

Figure 4 - *Column to needle habit between-4°C to -10°C*
(a) Trial 4 tiny columns *(b)* Trial 5 small needles *(c)* Trial 6 very long needles

Trial 6 resulted in very long distinct individual needles. The needles ranged in length from 2 mm to 8 mm. Needles had begun to break and fall. These needles had jagged crisp edges and none of the frozen droplets of previous trials. In this trial there was no rime. Light was refracted by the crystals extremely well, resulting in pictures being difficult to capture.

3.3 Plate to dendrite habit between -10°C to -21°C (Figure 5)

For Trial 7 the fans were set to a low speed in an attempt to avoid rime. Growth not only occurred on the hemp strings, but on the fan housing and blades. The growth on the strings was dendritic arms of plates while the fans were rime growth.

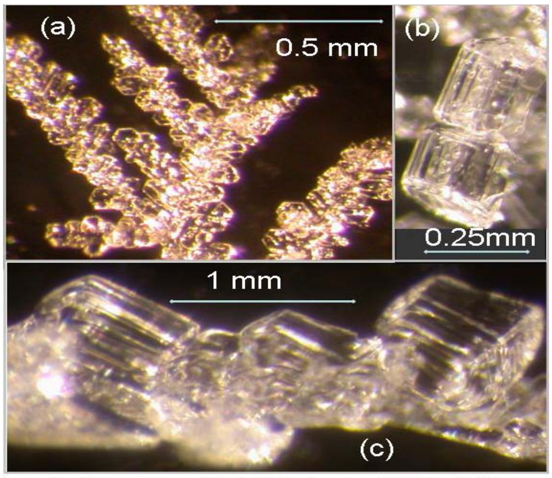

Figure 5 - *Plate to dendrite habit between -10°C to -21°C*
(a) Trial 7 tiny plates *(b)* Trial 8 slightly larger plates *(c)* Trial 9 largest plates

Trial 8 yielded plates. The crystals showed very distinct plate edges ranging from 1 mm to 2 mm. Crystals from the upper strings were much crisper than the lower strings. The lower string crystal corners were more rounded.

Trial 9 growth was distinctly grouped plates. Plates from this trial ranged from 1 mm to 3 mm. There was also rime growth on the fan housings and blades.

3.4 Column or plate habit between -21°C to -35°C

Trial 16 took place in CC5. The growth was completely rime. The growth was expected to be plates or columns depending on the level of super saturation. Growth appeared localized to the fan rather than the strings. The wind speeds were much higher than for other trials. The first few thermocouple readings appeared to be accurate, but then the readings became very erratic, hence not all of the temperature data was collected.

4 DISCUSSION

The Kelvin Equation can be used to explain why crystallization occurred. In cold environments the critical radius becomes quite small allowing for nucleation on microscopic particles. This is a reason why nucleation first started on the thinnest filaments of the hemp and then grew larger. Also from Kelvin's Equation, when the saturated vapor pressure is less than the actual vapor pressure ice particles begin to sublimate and loose mass. When the saturation vapor pressure is greater than the actual vapor pressure, liquid vapor is deposited onto the crystal increasing the size (Watkins). Conditions for the second relationship were realized when the water pan was heated and crystallization was occurring.

4.1 Plate to dendrite habit between 0°C to -4°C

The occurrence of rime in Trial 1 was disappointing. The overall shape was stellar, but created of rime particles. Rime being ice, the particles should demonstrate bonding following the stellar shape at these temperatures. The fan velocity set at 12V, and the resulting wind speed, was most likely too high, causing the rime growth.

In Trial 2 the rounded plates at the end of the dendritic arms were caused by too high of fan velocities and high water temperatures. The middle of the bottom string was melting. The melting most likely was due to the room fans recently cycling off to regulate the ambient room temperature or to defrost the lab. Without the fans running, the room warmed up and heat from the water pan was enough to cause melting. The middle would be the first location to melt due to proximity to the humidifier.

Trial 3 resulted in minimal plate growth due to the water temperature being low, 30.3°C. Room temperatures close to freezing require more moisture to reach saturation levels and create the necessary vapor pressure gradient required for crystal growth. When the vapor pressure gradient is from the air to the strings, moisture will deposit as ice crystals on the strings. This relationship is shown in Figure 6, a water phase diagram (Microsoft 2009).

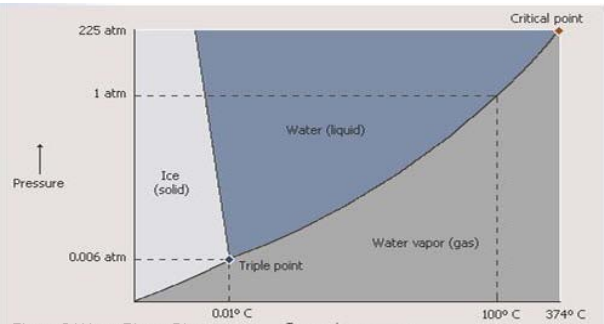

Figure 6 Water Phase Diagram

4.2 Column to needle habit between -4°C to -10°C

The rounded crystal tips on the columns formed in Trial 4 meant the crystals formed near rime conditions. Having a slightly higher level of saturation should have resulted in needles forming rather than columns. Sampling from different string levels may have shown if rime crystals grew next to columns or on a different level of strings.

Growing needles in Trial 5 indicates the humidity was higher than in the trials resulting in columnar growth. The extraneous molecules bonded to one edge indicated conditions near the end of the trial were resulting in rime. Having more developed growth on the top strings indicates the height of the box and location of strings may not have been ideal.

In Trial 6 no rime, only long distinct needles, demonstrated the conditions for needles were correct. The shorter needles appeared to have broken off from the longer needles. To grow shorter needles less growth time would be appropriate. The water temperature was 2.2°C warmer than Trial 4. Warmer water resulted in more humidity placing the trial above the saturation curve, causing needles.

4.3 Plate to dendrite habit between -10°C to -21°C

Dendtritic arms of columns observed in Trial 7 indicate growth occurred near the saturation curve. Having rime on the fans indicates water vapor had been escaping from the front of the apparatus. With this flow direction, deposition on the fans would be expected; the metal was supercooled.

The crystals from Trial 8 were the first to have the distinct plate habit for this temperature range. A combination of the right water temperature, which in turn means the right saturation, and a low wind speed, was necessary to create clean crystals. These crystals nucleated below the saturation vapor pressure for this room temperature.

Plates from Trial 9 were well formed and distinct. Rime on the fans meant moist air was being pulled through the fans and then into the box. This might have resulted from not having the plastic film around the fans tacked down tightly. Pinning the plastic down better would decrease the likelihood of moist air circulating and precipitating on the fans. This would result in more growth in the box. A warmer water temperature would have raised the level of saturation which should yield dendrites.

4.4 Column or plate habit between -21°C to -35°C

Since the fan paddlewheels in Trial 10 had growth this means that again moist air was being pulled and cycled through the fans. The higher wind speed readings could mean the room cooling fans had been either pushing or pulling air through the chimney; rather than air movement only being influenced by the cross flow fans. This would have been likely in CC5 because the cooling fans were much closer to the experiment. Since the thermocouple reader was stressed by the extreme cold and not performing correctly and in Montana it is rare for snow to form below -20^{o}C testing was stopped. It was decided to create snow crystal growth in temperature ranges more applicable for the area and hold trials in CC2 to reduce the number of variables influencing the growth.

4.5 Future Modifications

The results have demonstrated possible future modifications. The apparatus was created using a mixture of wood and plastic film to decrease weight; however this may have allowed moisture to escape or conditions to vary for reasons other than the transport wind speed, set room temperature and water temperatures. Using wood throughout would keep conditions more uniform. Having the room cooled by the fans meant that the ambient air temperature varied depending on if the fans were on or off. In the future, running trials in CC5 utilizing the room cooling fans to initially cool the room, then using the cold sky to retain the temperature while growth takes place would remove a possible element of variability. Rather than reading the thermocouples only at the end of a trial, utilizing a data collector would illustrate the different temperature fluctuations within the time period. This might explain why sometimes rime appeared to be intermixed with other crystal forms.

Since humidity is a deciding factor in the crystal complexity, modifications with respect to vaporization could be made. Recording the humidity within the chimney would be very beneficial. Measuring the level of saturation would determine more precisely where in relation to the saturation curve trials were occurring. Having more consistent control over the water temperature would reduce variance in moisture levels. When the heater was on, more moisture was being created than when the heater cycled off.

Once modifications have occurred, trials could be done at temperature intervals from 0^{o}C to -20^{o}C. This would allow for calibration of the box to SSERF. The results could be utilized to create a “Crystal Creator” specific snow morphology diagram with information pertaining to laboratory conditions for optimal crystal growth.

5 CONCLUSION:

Wind speed appeared to be the determining factor for rime growth or crystal habit following the snow morphology diagram. Crystals formed at different levels within the chimney show that those formed on higher strings were more distinct. This means that when designing the box, the height should have been taller. The design was patterned after the Japanese “Frost Box”. For this experiment the fans utilized were shorter so the entire apparatus was scaled. In hindsight only the width should have changed, the height should have remained the same

Overall it is possible to create snow crystals following those produced in nature rather quickly and in large quantities. With future modifications the process could become even more efficient. By utilizing the “Crystal Creator,” new snow and snow packs emulating those found in nature can be created and studied in the laboratory setting.

ACKNOWLEDGEMENTS

Special thanks to Ladean McKittrick, Dan Miller, Andrew Slaughter, Jared Nelson, Patrick Staron, Rich Shertzer, and Jonathan Binger for their assistance.

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