VERTICAL SUPERCOOLED CLOUD TUNNEL STUDIES ON THE GROWTH OF DENDRITIC SNOW CRYSTALS

Tsuneya Takahashi, Norihiko Fukuta and Takayuki Hashimoto

1 Hokkaido Univ. of Education, Sapporo, 002-8501, Japan
2 Univ. of Utah, Salt Lake City, Utah 84112-0110, USA
3 New Peak Film Inc., Sapporo, 062-0901, Japan

1. INTRODUCTION

Snow crystals grow by vapor diffusion while falling in the atmosphere. This process is known to play important roles in various weather phenomena.

Laboratory studies of snow crystal habits have been carried out in a static cloud chamber, in which ice crystals have been grown on a hair or a fiber (Nakaya, 1954; Hallett and Mason, 1958; Kobayashi, 1961). These studies revealed that a crystal habit is determined mainly by temperature and that the complicated secondary features depend on the supersaturation of water vapor in air; however, information regarding the free-fall behavior of a snow crystal during its growth could not be obtained. On the other hand, simulation experiments of ice crystal growth under free-fall conditions have been carried out by many researchers (Fukuta 1969; Ryan et al. 1974, 1976; Michaeli and Gallily 1976; Song and Lamb 1994a). Unfortunately, these experiments were carried out for a time period of less than 4 min; experimental studies carried out over much longer growth periods are required to better understand the growth of snow crystals.

For simulating the growth of a snow crystal in the atmosphere, vertical supercooled cloud tunnels were developed with the second author as the central figure (Fukuta 1980; Fukuta et al. 1982, 1984; Takahashi and Fukuta 1988; Takahashi et al. 1991; Fukuta and Takahashi 1999). The tunnel was distinguished by the Lagrangian way; that is, a single snow crystal could be suspended continuously in front of an experimenter. In these tunnels, the growth of an isolated snow crystal under free-fall conditions was studied for up to 30 min of growth.

In this paper, we show the results of a 30-min dendritic snow crystal growth on a high-definition-television (HDTV) film. With respect to the growth of dendritic snow crystals, Takahashi and Endoh (2000) pointed out that growth enhancement by the cloud droplets that coexist with a snow crystal was essential in addition to the ventilation effect. In order to discuss the growth enhancement, research has been carried out to make up for the data deficiency by continuing and extending the work. In this study, we have also addressed the conditions of temperature and liquid water content necessary for the dendritic growth.

2. EXPERIMENTS

The present study was carried out in a
vertical wind tunnel at Sapporo, Japan, in which a snow crystal could be suspended freely and grown in a vertical stream of artificially generated supercooled cloud by applying aerodynamical mechanisms for horizontal stability. A convergent configuration of the working/observation section provides excellent horizontal stability for the crystal suspension; vertical stability is not suitable because the upward wind velocity increases from the bottom to the top. Therefore, the upward wind velocity at the holding position is ceaselessly adjusted to the terminal fall velocity of the floating snow crystal by constantly manipulating the velocity control valves. The snow crystal fluctuates vertically because of the repeated and slight overshooting of the holding position of the snow crystal. Here, a video of a dendritic snow crystal grown in the tunnel for 30 min was taken using a HDTV camera by the third author who is a professional TV cameraman.

Further, for investigating the characteristics of the dendritic crystal growth in a cloud, experiments were carried out for 10 min under isothermal and water-saturated conditions from -12°C to -16.5°C with constant liquid water contents between 0 and 1.2 g m⁻³. The concentration of fog was controlled by adjusting impressed voltage to an ultrasonic atomizer. The liquid water content was calculated from the air temperature, and the dew point of air was obtained by evaporating the cloud. The air temperature and the dew point were continuously monitored by a thermistor thermometer and a quartz dew point hygrometer, respectively. The vapor pressure corresponding to the dew point was calibrated at ice saturation. In this case, the acceleration of the falling crystal was zero: a condition was achieved by lowering the impressed voltage provided to the atomizer in the course of the experiment. The cloud droplet size distri-

Fig. 1. The growth of a dendritic snow crystal with time up to 30 min at -15.0°C. The crystal was suspended in a vertical stream of supercooled cloud. The growth time is shown for each stage. The stills were extracted from a video taken using a HDTV camera.
3. RESULTS AND DISCUSSION

The HDTV video of a snow crystal grown in the tunnel at −15.0°C for 30 min was analyzed. Figure 1 shows the growth of a dendritic snow crystal with time. The secondary branches started growing at 10 min and were well developed at 20 min. After about 20 min, a spatial branch also grew downward as shown in Fig. 2. Looking at the crystal from above, it was observed that the crystal rotated clockwise before 16 min of growth and anticlockwise after 18 min; from 16 min to 18 min, the rotation stopped. The rotation rate varied: for example, 1.9 times per minute at 15 min of growth and 23 times per minute at 30 min of growth. The rotation appeared to be caused by the asymmetry of the crystal-shaped pattern around the c-axis or around the vertical air streamline.

Figure 3 shows the variation in crystal dimension along the a-axis with the growth time. The dimension of the crystal was approximately proportional to time, and the crystal reached a diameter of 5 mm after 30 min of growth; this size is almost equal to the maximum size of natural dendritic snow crystals.

The variation in the crystal fall velocity with time is shown in Fig. 4. There were velocity fluctuations within 1.5 cm s⁻¹ because of the vertical instability, as mentioned in the previous section. The variation was expressed by a curve that was convex upward.
up to about 7 min of growth and thereafter a
straight line. This was probably because the
drag increased due to the change in the
shape of the crystal from a plate to a dendrite
in the first stage, and a dendrite continued to
grow in the second stage, as pointed out by
Takahashi et al. (1991). Contrary to the ob-
servations of Nakaya and Terada (1935), the
fall velocity did not become constant when
the dendrite grew large.

The variation in crystal shapes formed at
different temperatures between −12°C and −
16.5°C and the liquid water contents between
0 to 1.2 g m$^{-3}$ after 10 min of growth are
summarized in Fig. 5. The crystal shape de-
pended on the liquid water content in the
temperature range of −12.3°C and −13.8°C.
The crystal shape shifted from a sector to a
broad branch between −12.3°C and −13.2°C,
and a broad branch to a dendrite between −
13.2°C and −13.8°C with increasing liquid
water content: examples of snow crystals are
shown in Fig. 6. Further, sectors and plates
grew above the temperature of −12.3°C. The
lowest temperature limit for the growth of a
dendrite was observed to be −15.8°C. Broad
branches and sectors grew at temperatures
between −15.8°C and −16.2°C and at those
below −16.2°C, respectively. Around −16°C,
a shift in the shape of the snow crystal with
increasing liquid water content was not ob-
served.

Dendritic crystals (dendrites and broad
branches) were observed at temperatures
ranging from −12.3°C to −16.2°C; this range
coincides with the results obtained using a
static chamber (Hallett and Mason 1958; Ko-
pointed out that the dendritic crystal growth at
water saturation between −14°C and −16°C
was ascribed to the ventilation effect. It was
shown that dendritic crystals grew from −

Fig. 5. Shape of a snow crystal as a function
of temperature and liquid water content
for a growth time of 10 min.

12.3°C to −13.8°C owing to the effect of the
existence of supercooled cloud droplets
around the crystals in addition to the ventila-
tion effect.

Figure 7 shows the changes in crystal di-

Fig. 6. Snow crystals grown for 10 min at −
temperatures of −12.6°C and −13.4°C and
different liquid water contents.
Fig. 7. Changes in crystal dimension along the a-axis with changes in the liquid water content at various temperatures after 10 min of growth.

Fig. 8. Variation in crystal dimension along the a-axis with decreasing temperature at the growth of 10 min.

The dendritic snow crystal growth was studied by a vertical wind tunnel to simulate the growth of an isolated snow crystal under free fall conditions in a supercooled cloud environment.

A video of a snow crystal grown at −15.0°C for 30 min in the tunnel was taken using a HDTV camera. The dimension of the dendritic crystal grown was approximately proportional to time, and the crystal finally reached a diameter of 5 mm. The crystal rotated. Secondary branches were well developed, and a spatial branch was grown downward. The variation of the fall velocity with time was expressed by a curve that was convex upward up to about 7 min of growth and thereafter a straight line.

Moreover, for investigating the characteristics of the dendritic crystal growth in a cloud, experiments were carried out for 10 min under isothermal and constant water saturation conditions with liquid water contents between 0 and 1.2 g m⁻³ and temperatures between −12°C and −16.5°C. Dendritic crys-
crystals appeared between $-12.3^\circ C$ and $-16.2^\circ C$. With increases in the liquid water content, the crystal shapes changed from a sector to a broad branch between $-12.3^\circ C$ and $-13.2^\circ C$ and from a broad branch to a dendrite between $-13.2^\circ C$ and $-13.8^\circ C$. In response to the shape enhancements, the crystal dimensions increased as the liquid water content increased; however, the dimensions of the dendrite grown between $-14^\circ C$ and $-15.7^\circ C$ were almost constant regardless of the liquid water contents, i.e., 1.7 mm for a 10-min growth. Takahashi et al. (1991) pointed out that the dendrites grew at water saturation due to the ventilation effect. It was shown that dendritic crystals grew at temperatures ranging from $-12.5^\circ C$ to $-14^\circ C$ owing to the effect of the existence of supercooled cloud droplets around the crystals in addition to the ventilation effect.

REFERENCES


___, M. H. Kowa and N. H. Gong, 1982: Determination of ice crystal growth parameters in a new supercooled cloud tunnel. Preprints Conf. on Cloud Phys., Chicago, IL, 325-328.


