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A DROP-SIZE STUDY IN THE ICING WIND TUNNEL

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Project M992-3

WRIGHT AIR DEVELOPMENT CENTER, U.S. AIR FORCE
CONTRACT AF 18(600)-51, E.O. NO. 462 BR-1

June, 1953

SUMMARY

Measurements of water concentrations and drop-size distributions in the University of Michigan icing wind tunnel show that when the drop size is large (mean drop size above 40 m) very poor water distribution occurs.

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INTRODUCTION

This study was instituted to determine the drop-size distribution in the Icing Wind Tunnel operated by Project M992 at Willow Run Airport. The construction and operation of the tunnel have been described at length elsewhere.

The drops were measured at the test section under several conditions of tunnel operation with a Drop Size Analyzer, an instrument recently developed at the University of Michigan for the DeVilbiss Company. This instrument has a charged electric conductor which is placed in the path of the water drops. When a drop impinges on the conductor it produces an electric pulse. Associated electrical apparatus measures and counts all such pulses. The size of a pulse depends on the size of the drop that made it, so that by an appropriate calibration the drop size can be determined from the size of the electric pulse.

Thus by a series of measurements the instrument will give the rate of impingement of drops greater than a certain diameter as a function of diameter, or as it is sometimes called, the cumulative distribution curve. From this curve any distribution information can be derived by appropriate mathematical manipulations.

Those parts of the Drop Size Analyzer which are placed in the tunnel are designed so that they do not appreciably disturb the air flow at the point where the drops are measured; thus, the drop distribution measured with the instrument is representative of tunnel conditions during operation when the instrument is not present. The instrument is capable of measuring all drops greater than 25 microns in diameter.*

The Drop Size Analyzer is designed for use with drops which carry no electric charge. If a drop having a large charge were to impinge on the sensing element of the instrument, the pulse produced would not correspond to the diameter given in the calibration. In view of this, a preliminary test was made in which it was established that the charges on the drops passing through this wind tunnel were insufficient to produce any effect on the readings of the instrument.

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*The DeVilbiss Company has proprietary rights to the Drop Size Analyzer, and further details of its design, therefore, cannot be revealed until patent applications have been completed.

PROCEDURE DURING MEASUREMENTS

In order to support the DeVilbiss Drop Analyzer in the test section of the tunnel, a jig was built which held the probe of the instrument securely and permitted the probe to be moved horizontally across the test section. It was not possible to move the instrument probe in a vertical direction; all measurements were made at points equally distant from the top and bottom of the tunnel. After the instrument had been placed in position, the tunnel and spraying system were put in operation, and sufficient measurements were made with the Drop Analyzer to determine the cumulative distribution of the drops passing through the tunnel at the point being measured.

Five operating conditions of the tunnel and spray system were selected for the testing.

Run	Air Temperature at Inlet	Air Velocity at Test Section	Position of Test	Number of Nozzles	Total Flow of Water	Total Flow of Air
1	45°F	140 ft/sec	Center	4	1.5 lb/min	1.6 lb/min
2	49	140	Center	4	2.2	1.6
3	49	225	Center	14	6.4	3.9
4	49	225	Side	14	6.4	3.9
5	51	240	Center	4	2.2	1.6

Nozzle air pressure for all runs: 20 psig.

The indicated number of NACA-type nozzles installed in the spray tower were used to produce the spray. The spray conditions chosen for the tests are not typical of the operation of the tunnel when it is used in icing runs because most of the spray formed during icing runs is in drops that are too small for our measuring instrument to detect. We therefore reduced the air-to-water ratio of the nozzles in order to make larger drops. Typical spray conditions for an icing run would use 1.5 lb/min of water and 3.86 lb/min of air at 30 psig. When the results of this test are evaluated it should be remembered that drop sizes were larger during the tests than during the icing runs.

It was necessary to stop Runs 3 and 4 part-way through the measurements to allow the air compressor to build up pressure in the supply tanks. The spray equipment was operated continuously for the other runs. At the beginning of a new run and after interruption of Run 3 or 4, a full minute was allowed for the spray tower to fill to equilibrium before measurements were started.

Soon after the measurements were started, considerable variation in the rate at which drops passed the test position was noticed. This variability may be illustrated by the times required for 1024 drops of all sizes to pass the test position as determined by successive measurements: 27.85 sec, 22.64 sec, 31.83 sec, and 42.87 sec. The data cited are taken from Run 2, but the variability shown is typical of all runs and sizes of drops. The variation in successive measurements is far greater than is to be expected if the drops pass at random with no relation to each other, which indicates that the drops pass in groups or gusts.

When these variations in measurements were noticed, we stepped inside the spray tower to see if irregularities were evident. There we saw that drops entering the tunnel were concentrated in streams or wisps which were not stationary but wandered about the cross section of the tunnel. In addition, there were small clouds of drops that floated down the tower and were sucked into the tunnel at irregular intervals. It was obvious that the drops throughout the tower were distributed nonuniformly, which seems to account adequately for the variations in instrument readings.

CALCULATIONS AND TREATMENT OF THE DATA

When the drop rates as measured by the instrument are plotted against drop diameter, the cumulative distribution curve of the drops is obtained. This is done for each of the five runs in Figs. 1-5. The circled points represent average values of all similar measurements of drop rate. The scale appropriate to the cumulative curve is given at the left of the plot. The points are somewhat scattered because of the irregularity of the dispersion of drops, but smooth curves have been drawn which form the basis of further mathematical manipulations.

Differentiating the cumulative distribution curve yields the frequency distribution curve of the drops,* which is also plotted in Figs. 1-5 with the appropriate scale at the right of the plot. The differentiation was made graphically from the cumulative curve except for the large diameters, where it was done arithmetically. If these frequency curves have maxima, they occur at diameters less than 25 microns.

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*Defined as $\lim_{\Delta x \to 0} (n/\Delta x)$, where n is the number of drops having diameters between x and x + Δx.

More informative curves than those discussed above are the mass-distribution curves which show how the mass of the drops is distributed. The mass curve is obtained by multiplying the frequency curve at each diameter by the mass of a drop of that diameter. The mass curves for each run are shown in Fig. 6, while Fig. 7 shows those for Runs 1 and 2 on a larger scale.

The distribution curves shown in Figs. 1-5 are slightly distorted, giving somewhat higher than true values for the large diameters. The distortion arises from the geometry of the measuring instrument. The curves in Figs. 6 and 7 incorporate a correction for the geometric distortion, and truly represent the mass distribution of the drops. The area under each curve represents the total water rate.

INTERPRETATION

The curves of Figs. 6 and 7 should be accepted with some reservations about the correctness of minor details, since the smoothing of the original data was somewhat arbitrary. The true values should differ from those shown by not more than 25 per cent, and the areas under the curves by less than that.

The frequency distribution curves show that in all runs most of the drops have diameters less than 25 microns and are thus too small for the Drop Analyzer to detect. When, however, the mass of the drops is considered, the range of the instrument extends well below the greatest mass concentration in Runs 1, 3 and 4, and it is likely that in the other runs the range of the instrument covers substantially more than half the mass of water that passes the test point.

Runs 2 and 5 afford an interesting comparison because the spray conditions are the same but the air velocity is greater in Run 5. The curves of Fig. 6 show that at the higher air velocity about 10 times as much water is going through the center of the tunnel. This large difference may in part be caused by shifts within the tunnel in the positions of concentrated streams of drops, but the most important cause is that only a fraction of the drops formed in the spray tower are sucked into the tunnel, the rest falling to the floor or attaching themselves to the walls of the tower. This conclusion is confirmed by the collection of water on the floor of the tower while the tunnel and spray system are operating.

When the air velocity in the tunnel is changed, the fraction of drops generated in the tower that enter the tunnel is radically changed, and at the same time the selective action of the air flow in drawing a larger proportion of small drops in comparison to large drops changes, so that both the number and the size distribution of the drops in the tunnel change. It is clear that any measurements of water content or drop-size distribution made in the spray tower do not even approximately indicate conditions in the test section of the tunnel. Again, the reader is reminded that when the tunnel is operated as an icing tunnel, with smaller drops present, these effects are much less important.

A comparison of Runs 1 and 2 in Fig. 7 shows the influence of changing spray conditions, since the air velocity in the tunnel was the same for both runs. There is a considerable shift in the drop size, but the effect of changing spray conditions is far less than that produced by changing air velocity.

Runs 3 and 4 were made with identical conditions of spray and tunnel operation to give a comparison of the drop distributions at the center (Run 3) and at the side about 2 inches from the wall (Run 4). The distribution curves at the test points differ considerably, although the total water rate is about the same. The streams of high drop concentration that can be seen passing into the tunnel give strong evidence of nonuniformity in the cross section of the tunnel, and the equality of water rates is probably fortuitous.

Perhaps the most important information revealed by this study is that there are a number of spacial and temporal irregularities in the flow of drops through the test section. The variations in drop flow are such that average values taken over periods as great as several minutes and perhaps longer will not be reproducible and cannot be predicted. Under these circumstances, the interpretation of experiments in which ice accretion or related data are obtained for periods of less than several minutes is very difficult. The flow irregularities arise principally because the drops generated in the spray tower are not well mixed with incoming air before being sucked into the tunnel. It appears that it would be highly desirable to increase the mixing in the tower as much as possible without affecting other design conditions of the system, and it might be worthwhile to increase the mixing even if it were necessary to compromise other design desiderata.

These conclusions do not necessarily apply to the tunnel when operated at its design point, but they are important when an effort is made to duplicate, for example, freezing rain or similar conditions.

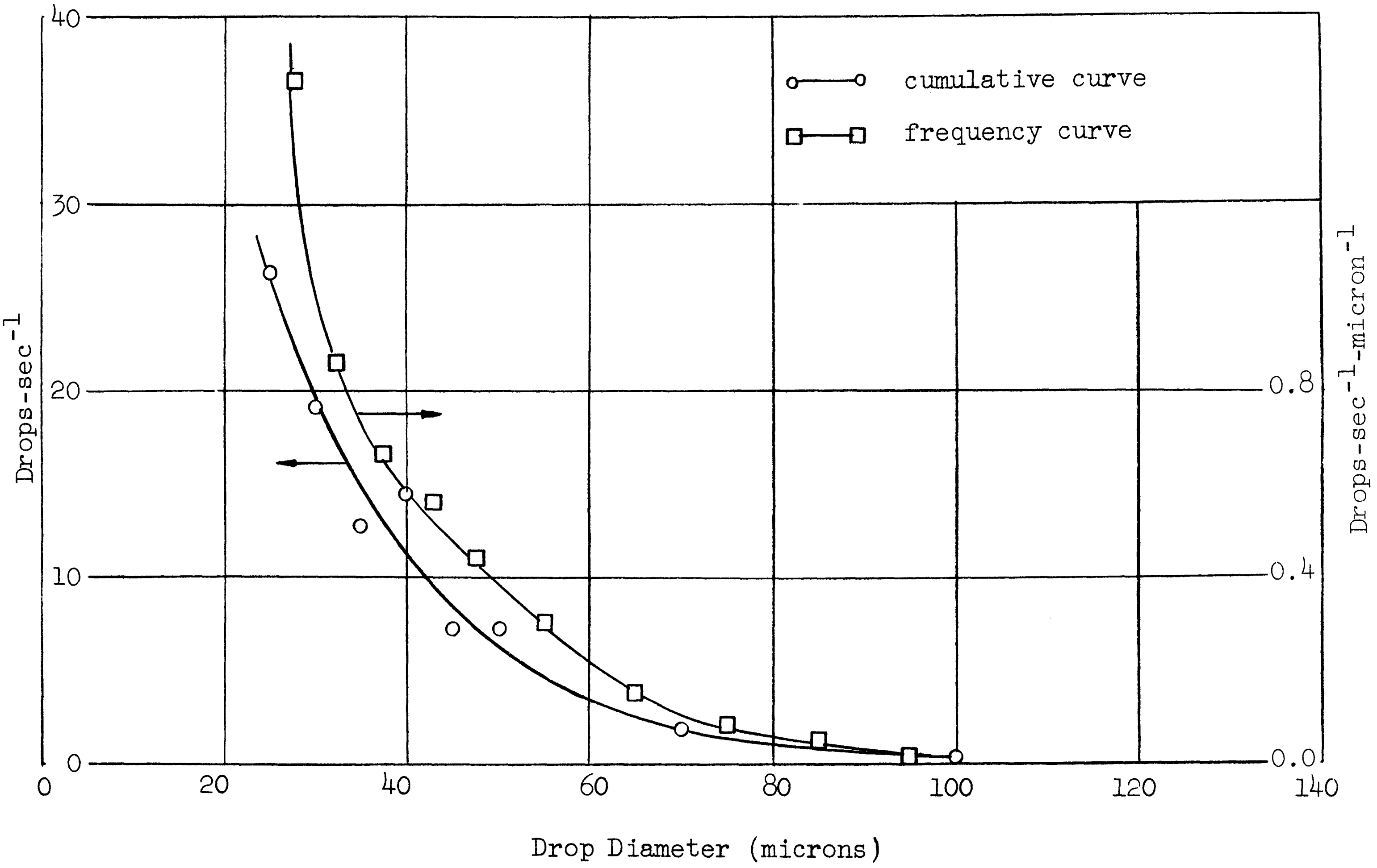

Fig. 1

Frequency Distribution of Drops in
the University of Michigan
Icing Wind Tunnel

Run 1

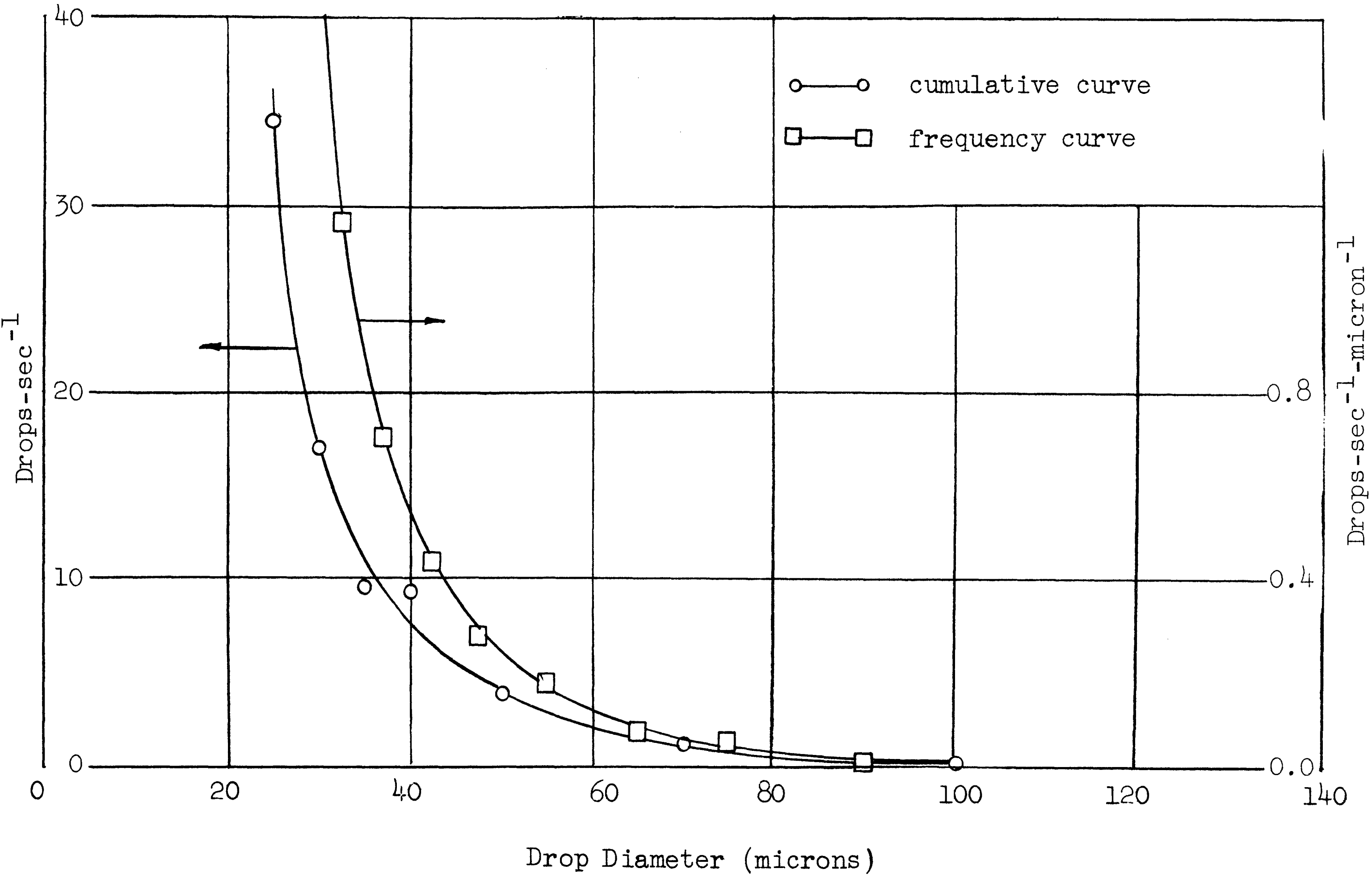

Fig. 2

Frequency Distribution of Drops in
the University of Michigan
Icing Wind Tunnel

Run 2

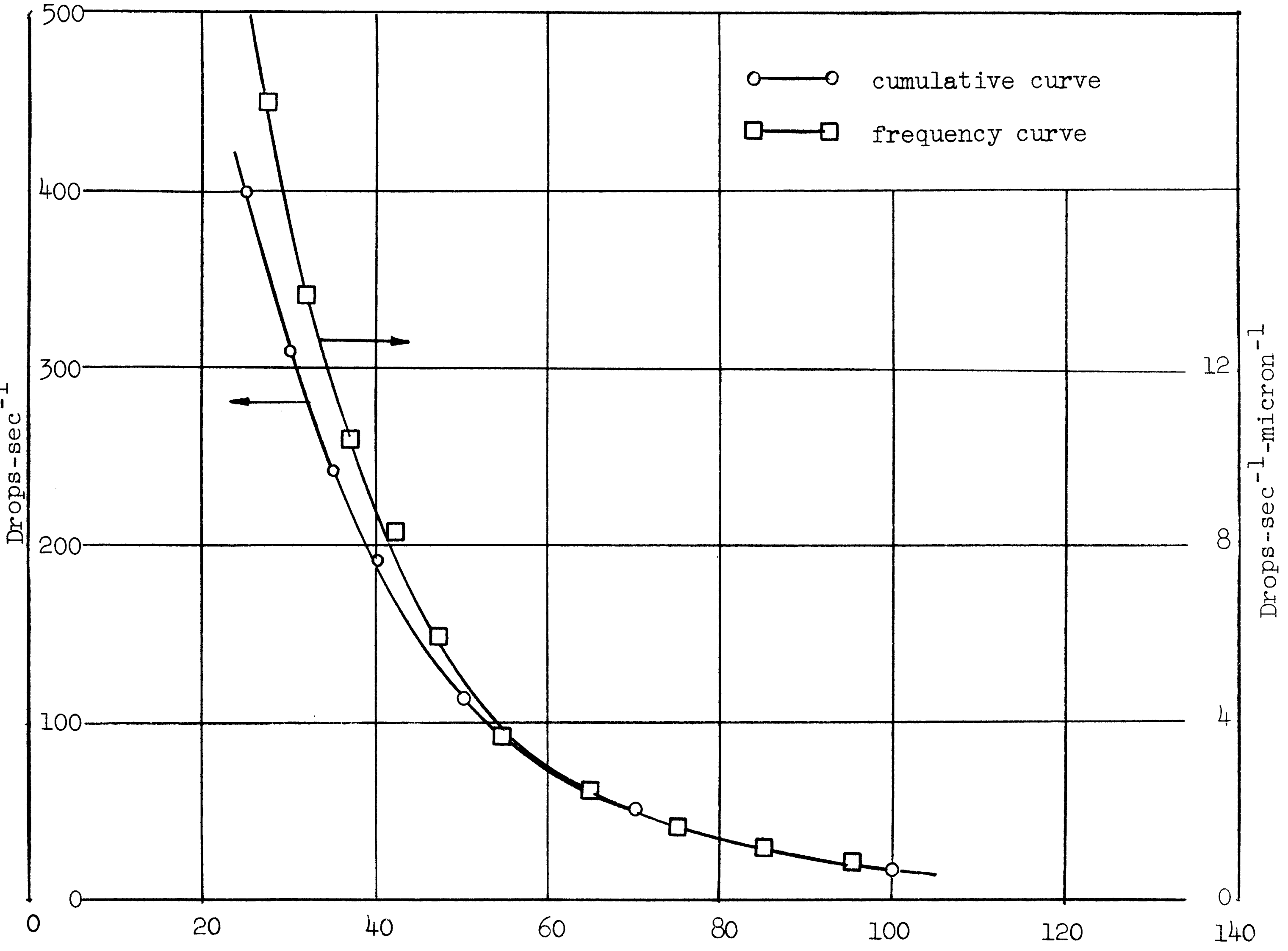

Fig. 3

Frequency Distribution of Drops in
the University of Michigan
Icing Wind Tunnel

Run 3

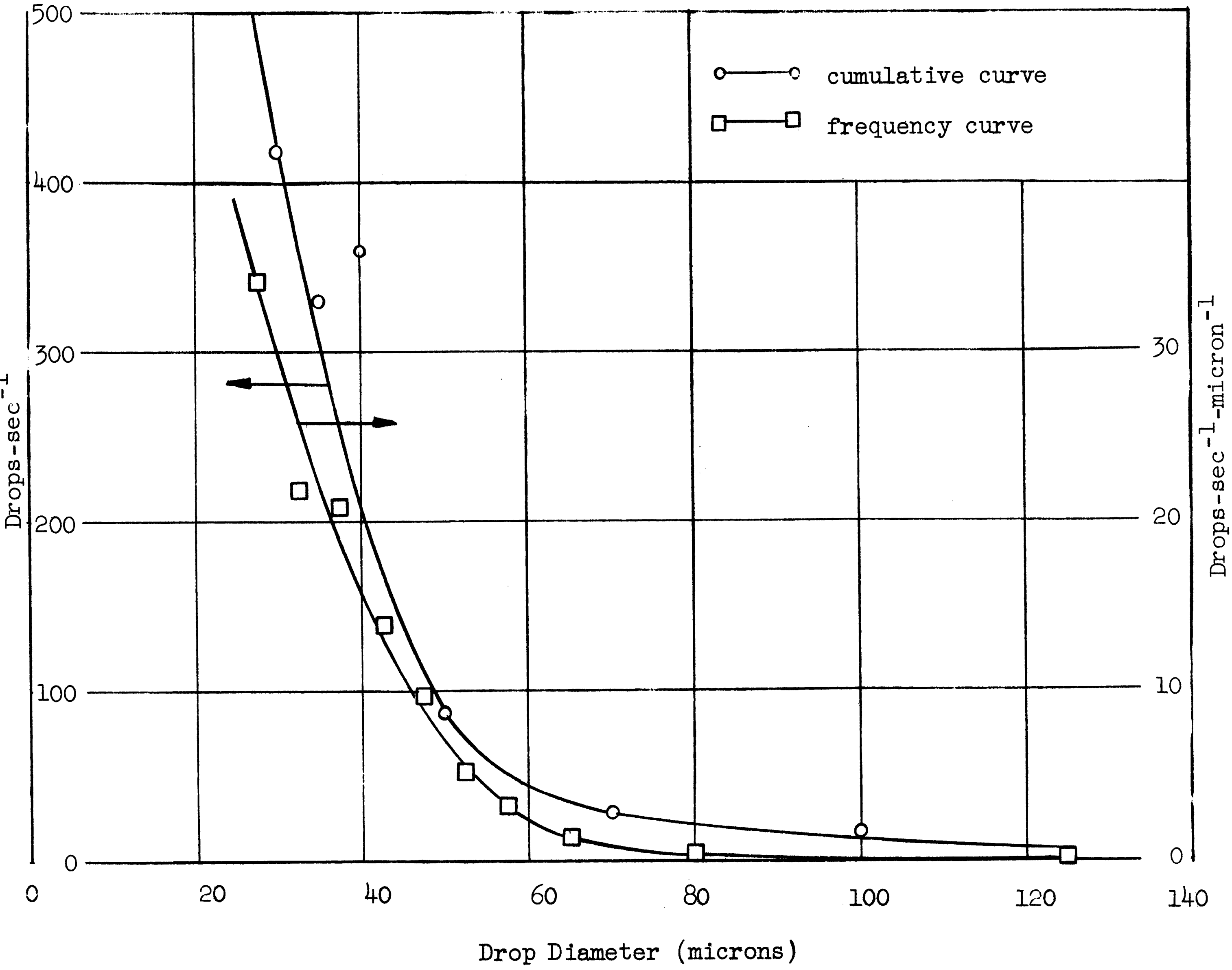

Fig. 4

Frequency Distribution of Drops in
the University of Michigan
Icing Wind Tunnel

Run 4

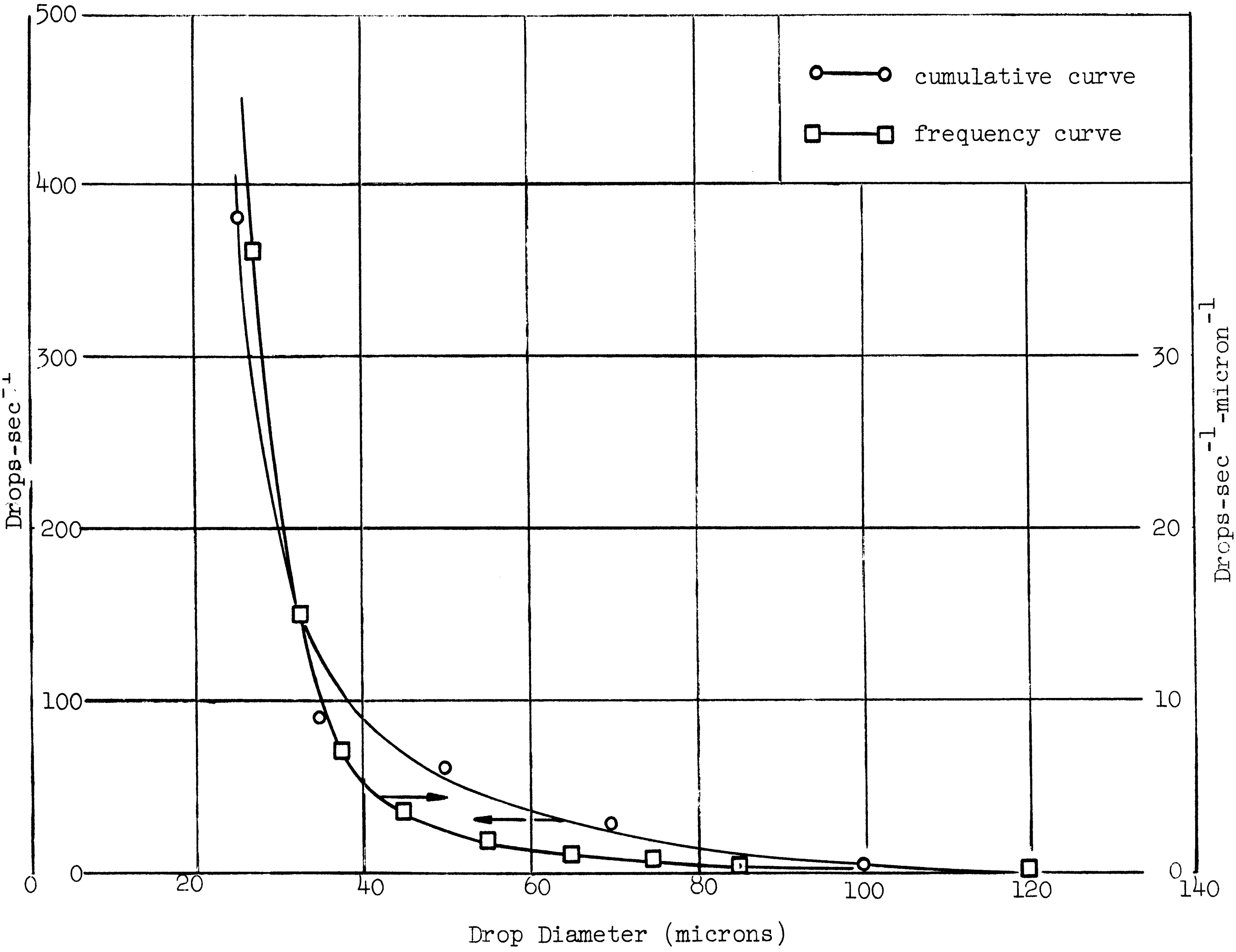

Fig. 5

Frequency Distribution of Drops
in
University of Michigan Icing Wind Tunnel

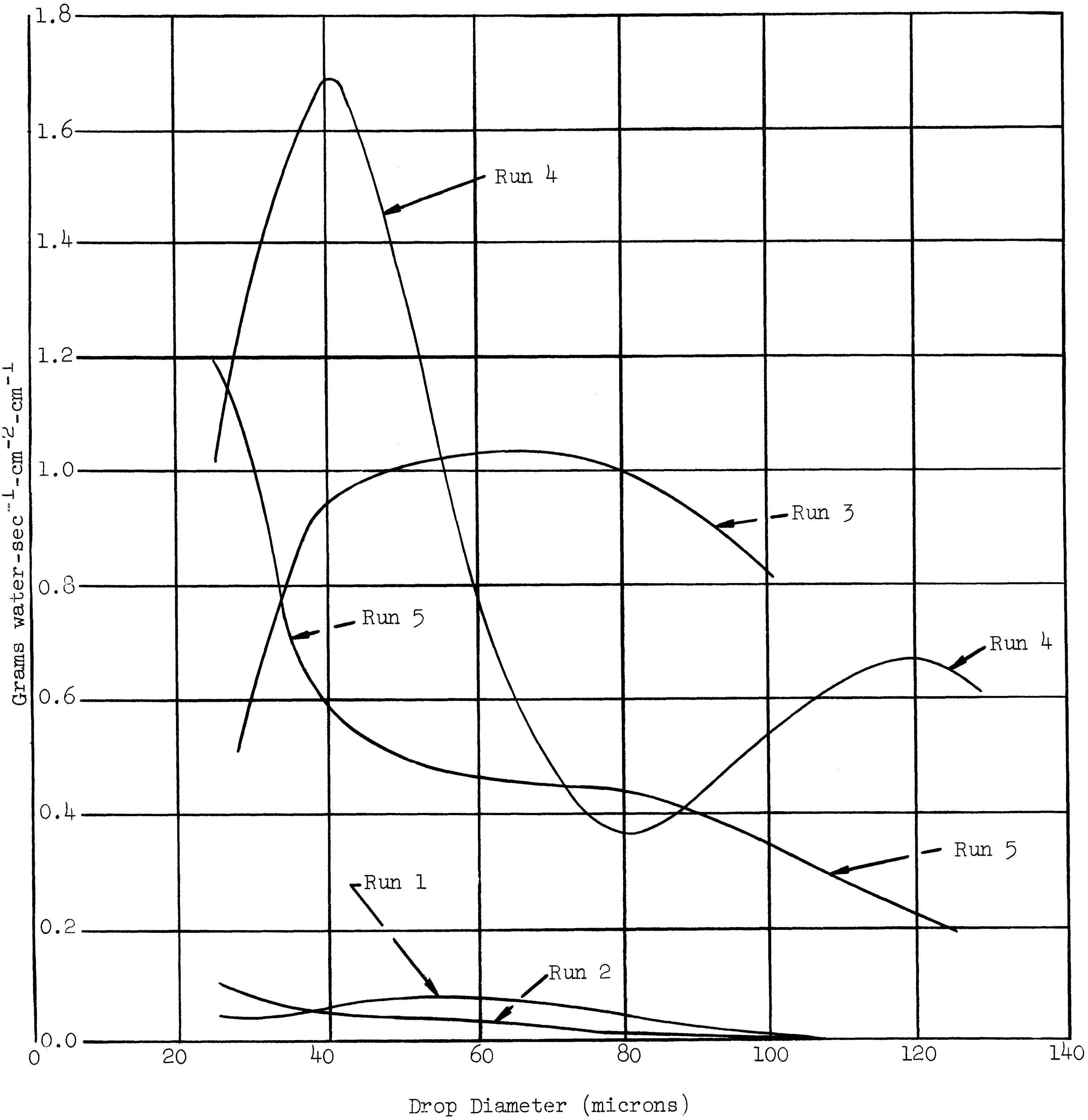

Fig. 6

Volume Distribution of Drops
in
University of Michigan Icing Wind Tunnel

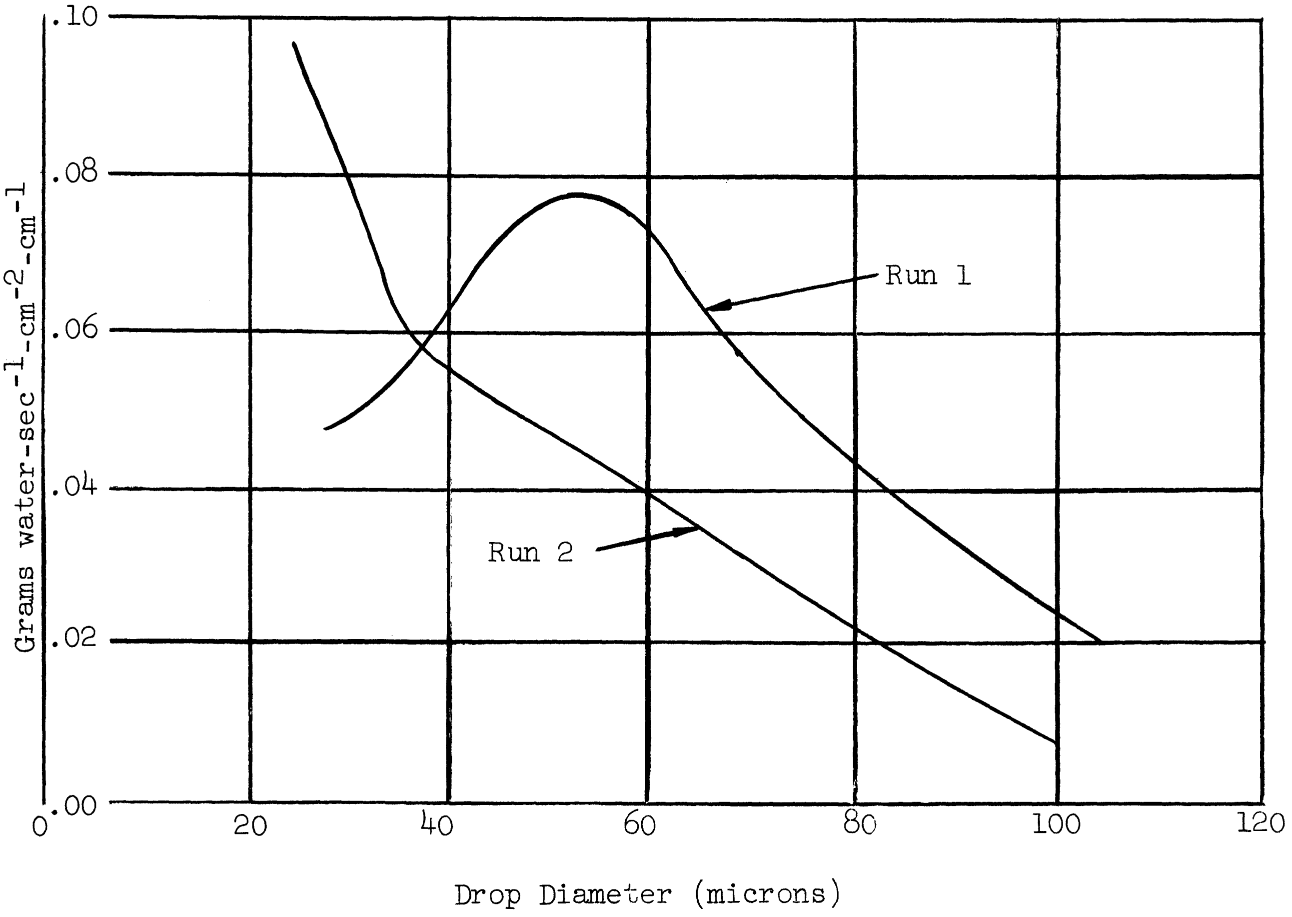

Fig. 7

Volume Distribution of Drops
in
University of Michigan Icing Wind Tunnel

(Magnification of Runs 1 and 2 Shown on Fig. 6)