A Vertical Wind Tunnel for Small Droplet Studies

THOMAS E. HOFFER AND STEVEN C. MALLEN
Desert Research Institute, University of Nevada, Reno
(Manuscript received 18 December 1967)

ABSTRACT

A vertical wind tunnel which will support droplets in the size range of 50–200 μ is described. It consists of three sections, a diffuser, a profile forming section, and the observational section. The construction details of all three sections are provided with emphasis on velocity profile formation. Its materials are such that experiments requiring a clean atmosphere can be performed on droplets less than 200 μ in diameter.

1. Introduction

In order to investigate the freezing properties of droplets under conditions as close to atmospheric as possible, it is necessary to either 1) let the droplet free fall under conditions where the assumption that it is in equilibrium with its environment is acceptable, or 2) suspend the droplet in a wind tunnel. Other techniques for studying the droplets provide unrealistic conditions compared to those encountered in the atmosphere and hence the results are not directly applicable to atmospheric processes. Among these can be included droplet suspension in an electric or sonic field which provides energy sources not available to the droplet in the atmosphere. This paper deals with the construction details for a wind tunnel which will stably support droplets in the size range of 50–200 μ.

Other investigators (Blanchard, 1955; Cotton and Gokhale, 1967; Koenig, 1965; Kinzer and Gunn, 1951; Maybank and Briosi, 1961) have made wind tunnels to support and study drops. The turbulence and other factors in such tunnels precluded the support of droplets smaller than roughly 500 μ in diameter. In general, these investigators have taken similar approaches: a velocity profile is developed by the use of screens or other flow limiting devices. The screening also serves to damp out turbulence in the tunnel. It is probable that the turbulence level and the velocity profile are the determining factors in droplet suspension. In our tunnel it appears that the turbulence is low, and the velocity profile, as a function of height in the tunnel, is such that the small droplets are stable.

2. Design features

Many parameters needed to be considered during the design of the wind tunnel. Some of these were: maintenance of air purity, minimal turbulence, generation of a suitable velocity profile, constancy of air temperature and humidity, constancy of air flow through the system, visual tracking of the droplets, and the droplet size range to be investigated. After separately considering the ease of controlling each of these parameters, it was apparent that the wind tunnel should be as small as possible without permitting the droplets to be influenced by the walls. According to Landenburg (1907), when the tunnel diameter is greater than a hundred droplet diameters the flow around the droplet will be relatively undisturbed and its terminal velocity will be within 1% of that in the air. For a 200-μ diameter droplet (the maximum of interest to our future studies) the inlet to the working section should therefore be 2 cm in diameter.

![Cross-sectional view of profile forming section of the tunnel showing: A, observation section; B, 100-mesh screening; C, outer ring of large polyethylene tubing; D, inner core of smaller polyethylene tubing; E, 100-mesh screening at inlet to section.](image)
Visual tracking of the droplet as it enters the tunnel is necessary not only for positioning the droplet at the appropriate height within the tunnel but also for adjusting the height of the droplet as it evaporates. Therefore, it was desirable to have the entire upper section of the tunnel transparent.

Although the maintenance of air purity is not a factor in the actual operation of the wind tunnel it must be considered in the design. Air which has few particles in it is difficult to obtain through filtration. One of the best sources of clean air is bottled breathing gas, compressed over water. The Aitken count in such air is consistently zero. The use of bottled gas serves two purposes. It not only provides clean air but also a constant steady air flow from the cylinder if good flow regulators are placed in the system. The use of bottled gas dictates that the wind tunnel be relatively small. Maintenance of air purity is attained by using inert materials such as polyethylene and stainless steel.

Turbulence and the generation of a suitable droplet supporting profile are interrelated. Minimal turbulence can be obtained by using the appropriate screening, while a suitable droplet supporting velocity profile requires some type of blocking of the air flow in the center of the tunnel.

3. Description of the tunnel

Fig. 1 illustrates the tunnel and its construction details. The tunnel consists of three sections—1) the inlet diffuser, 2) the velocity profile former, and 3) the observational section.

The first section is a thermal setting plastic diffuser of sufficient length with stainless steel screening (100 mesh) at the indicated positions. The purpose of the diffuser is to expand slowly the air flow from the initial inlet to the inlet diameter of the tunnel. Its length, 14 cm, is sufficient to minimize turbulence and to insure that the air speed across the radius of the inlet is uniform.

The central section of the tunnel develops the velocity profile. This section has required a large amount of our experimental effort. At the present time, it consists of two concentric rings of different sized polyethylene tubing (5 cm in length) which develops the flat velocity “bucket-shaped profile” necessary to support a droplet stably in the observational section.

The observational section of the tunnel is an acrylic thermal setting plastic tube, tapering downwards on the inside at an included angle of 3°. (A taper of less than 5° results in stable laminar flow for the wind speeds in the tunnel.) An internal mandrel whose external dimensions are identical to the internal dimensions of the tunnel was constructed and the plastic poured into a mold. The resultant section is transparent with an extremely smooth inner surface. Although the plastic does acquire a static charge, it is not detrimental to the support of the droplet.

4. Profiles in the observational section

The profile of the vertical component of the velocity was determined by means of a heated thermistor probe. The thermistor probe was calibrated by monitoring the flow through a turbulence-damped tube and relating the velocity to the voltage output of the thermistor bead. Such a calibration scheme is feasible in this case where the flow rate is low. The radial component of velocity can be neglected in this calibration since the flow is laminar and with a total taper of 3°, the total velocity exceeds the vertical component by only about 0.04%.

The calibrated thermistor probes were used to measure the velocity profiles during the experimental program to determine the best combination of poly-
ethylene tubing sizes and configurations in the central section. The final selection was 0.11 cm on the outside and 0.08 cm inside. The two sizes of tubing are separated by a thin stainless steel cylinder. There is one ring of the larger tubing.

The turbulence within the tunnel is below the detection capability of our measuring techniques. At an air speed of 50 cm sec⁻¹, which is typical, the thermistor can detect speed fluctuations of 1 cm sec⁻¹, provided they last for a time comparable with 0.3 sec, the time constant of these uncoated thermistor beads. Thus, tunnel shear turbulence of the order of 2% could not have been detected, since eddies of this type would have characteristic lengths of the order of a radius, corresponding to 0.02 sec. On the other hand, any gross pulsing of the flow of this magnitude could have been observed. Figs. 2 and 3 show the velocity profiles at the heights of 2.5 and 5 cm above the screening at the base of the observational section. These profiles were obtained by slowly traversing the width of the tunnel with the thermistor probe mounted on an electric motor drive. The speed of traversing was 6×10⁻⁴ cm sec⁻¹, so that the lag of the bead corresponded to only 2×10⁻⁴ cm along a diameter.

These profiles show the well developed flat velocity bucket which decays as expected with increasing distance above the screening. They also show that the profile is maintained to relatively low flow rates (Fig. 2). At low flow rates, corresponding to small terminal velocities, the profile disappears. Under these conditions, droplets wander and drift to the wall.

When the flow in the tunnel is considerably in excess of 12 liters min⁻¹, the flow in the outer tubing becomes turbulent and it becomes impossible to support droplets in the tunnel. The maximum size of droplet using the present tubing inserts which can be supported is close to 200 μ diameter.

After a drop is introduced, it can be brought to a desired level by varying the flow rate. As they evaporate, they can be held there by reducing the flow, until their terminal velocity falls below 7 cm sec⁻¹. Naturally, the higher the relative humidity the longer the droplets can be observed. At 50% relative humidity, droplets have been supported in the tunnel for 4 min, the length of time necessary for the droplet to evaporate from 150 μ to 50 μ diameter. Pith balls about 2 mm diameter, having approximately the same mass as a 100-μ droplet have been stably suspended for hours. A water droplet in the tunnel during evaporation can be positioned to within ±2 mm in the vertical; it stays in the horizontal to within the same tolerance.

REFERENCES


