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A vertical wind tunnel for water drop studies

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सार — मिलीमीटर आकार के जल बिन्दुओं के उन्मुक्त निलम्बन के लिए एक उर्ध्वाधर पवन सुरंग का प्रारूप तैयार करके उसका निर्माण किया गया । इसमें एक टंकी, प्रवाह को सीधा करने वाला उपकरण वितरक भाग और परीक्षण भाग होता है । निलंबित बिन्दुओं के क्षेत्र में वेग वाह्य रूप दिए हुए होते हैं । यहां सुरंग के उर्ध्वाधर वायु प्रवाह से उत्पन्न हुए वेग कूपों में रखे बिंदुओं की स्थिरता पर विचार-विमर्श किया गया है । निलंबित बिंदुओं के फोटो लेने और विद्युत क्षेत्रों के अनुप्रयोग के लिए प्रबंध किए गए । इस सुरंग के कुछ संभावित प्रयोगों के बारे में भी विचार-विमर्श किया गया ।

ABSTRACT. A vertical wind tunnel for free suspension of millimetre size water drops has been designed and constructed. It consists of a reservoir, flow straightning devices, a diffusor section and a test section. The velocity profiles in the region of suspended drops are given. Stability of the drops placed in velocity wells generated in the vertical air flow of the tunnel, is discussed. Arrangements to apply electric fields and to take photographs of the suspended drops are described. Some possible uses of this tunnel are discussed.

1. Introduction

Investigations on behaviour of millimetre size water drops freely falling in the atmosphere are difficult because of their large velocities under gravity. Therefore, these drops are usually suspended in an air stream in vertical wind tunnels (*e.g.*, Blanchard 1955; Cotton and Gokhale 1967; Koenig 1965; Kinzer and Gunn 1951; Pruppacher and Neiburger 1968) to study their dynamic behaviour and interaction characteristics with other drops. Here we describe the design and details of the construction of a vertical wind tunnel in which drops can be suspended and subjected to different aerodynamic and electrical stresses similar to those prevailing inside clouds. These drops and their interactions with others can be photographed. Velocity profiles measured near the place of suspension of the drop are also given. Design of a screen with which more than one drop can be simultaneously suspended in the tunnel is also discussed.

2. Basic features of a tunnel

Basic consideration in designing a vertical wind tunnel is to create a velocity profile wherein a drop could be suspended in the air. It is necessary, therefore, that the air flow in the tunnel has minimum of turbulence and has a velocity well, *i.e.*, a dip in the horizontal profile of the vertical air velocity where the drop could be suspended. Different types of devices are used to create this velocity well. One such device is a screen which utilizes wires crossing each other at the centre of the screen so that the air experiences greater resistance at the centre of the screen. However, the velocity well so created collapses as the air diverges a few centimetres downstream of the screen. Blanchard (1950) observed that the maintenance of the desired air flow pattern required that a back pressure plate (cap) be kept 1 to 3 tunnel diameters above the screen. Shape, dimensions and material of this cap were observed to be not very critical.

Another way of maintaining the flow pattern downstream of the crossed wire screen is to use a working section whose cross-section gradually increases upwards over its length.

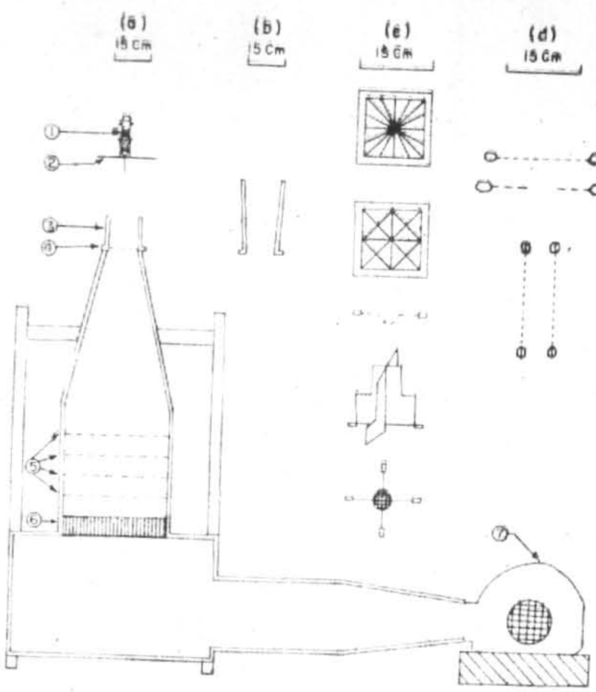
Shape and dynamics of a drop and its interaction characteristics with other drops are also influenced by the electrical stresses acting on it. It is well known that drops inside thunderstorms are electrically charged and move under electric fields. Occasionally these electrical charges on the drops and the electrical fields is which they move are very large. Under such conditions the electrical stresses on the drop may become comparable to other stresses acting on it. To simulate these electrical stresses acting on drop suspended in the tunnel, some electrodes are required to be introduced near to the place of suspension of drops. These electrodes should not produce turbulence in the air flow large enough to make the drops unstable. At the same time shape of these electrodes should be such that they do not produce corona currents at the potentials to which they are raised.

3. Description of the tunnel

Fig. 1 illustrates the design of the tunnel. Air is sucked by a centrifugal blower driven by a ¼ H.P. motor. An air vent with three different settings to control the air intake, is fixed at the inlet of the blower. The air slowly expands and enters into a 336 litre (84 cm × 80 cm × 50 cm) reservoir (plenum) which smoothes out the fluctuations entered in the air flow by the fan of the blower. From this reservoir the air moves vertically up into a straight section of cross-section 40 cm × 40 cm and length 50 cm having a honeycomb and 4 wire screens fitted in it. Honeycomb consists of 7.5 cm long cells of cross-section 0.6 cm × o.6 cm made out of a 8.0 mm thick tin plate. Screens are made out of a wire mesh of size 21 meshes per inch. Honeycomb and screens minimize the turbulence in the flow. Above the straight section there is a diffusor section which reduces the tunnel cross-section from (40 × 40) cm to (12 ×12) cm at its top over a vertical length of 66 cm. Diffusor section compreses and smoothens the air flow. Above the diffusor section is placed a test-section with a rubber gasket in between them. Two types of test sections have been used by us. First one is rectangular and consists of parallel sides of length 15 cm and has a cross-section of 12 cm × 12 cm. Other one is tapering downwards [Fig. 1(b)] with an angle of 3° and of vertical length 30 cm. Its cross-sections are 15 cm ×15 cm at the top and 12 cm ×12 cm at the bottom. The whole tunnel is made of plywood coated with white enamel paint except that the test sections are made of perspex.

In beween the diffusor and test section is placed a crossed wired screen [Fig. 1(c)] made from a brass frame and wired with a 40 SWG copper wire. It provides greater resistance to the air flow at the centre and thus creats a velocity well where a drop could be suspended. For maintenance of the well upto some distance above the crossed wired screen, however, it is necessary to put a back pressure plate above the test section as shown in Fig. 1. This plate is not required while using the tapered test section. The plate is 20 cm × 20 cm in cross-section and made out of a brass plate. It has a hollow brass tube of internal diameter 2 cm attached at its centre. A syringe with hypodermic needle facing downwards can be fixed in this tube for releasing water drops.

In place of crossed wire screen, another screen wired with 30 SWG of wire and shown in Fig. 1(c) (second from top) can be fitted in the tunnel. With this screen fitted in the tunnel, as many as five drops of approximately the same size can be suspended simultaneously (Kamra and Ahire 1985).



Figs. 1. (a-d). (a) Vertical wind tunnel : (1) Hypodermic syringe, (2) Back pressure plate, (3) Test section, (4) Radial screen, (5) Screens, (6) Honeycomb, (7) Blower, (b) Tapered test section, (c) Devices to generate a velocity well, (d) High voltage electrodes (Vertical and horizontal field arrangement)

4. Arrangements to apply electric field

As mentioned earlier, water drops inside thunderclouds may be located in large electric fields. To simulate the effect of these electric fields on the dynamic behaviour of the drops and their collision characteristics with other drops, we apply such electric fields on the drops suspended above the test section of wind tunnel. Three special electrodes [Fig. 1(d)] have been constructed for this purpose. Two electrodes, 22 cm × 22 cm in size are made of copper wire mesh of size 21 meshes per inch. These are used for applying horizontal electric field. One of these electrodes can be used as upper electrode for vertical electric field arrangement while the lower electrode used is of 25 cm × 25 cm in size and made of iron wire mesh of size 8 meshes per inch. Lower electrode has a hole of diameter 5 cm at its centre in order to reduce the turbulence. Ends of wire mesh are enclosed between two thick copped strips which are soldered together and whose corners are smoothened to increase the corona threshold of the electrodes. These electrodes are placed horizontally or vertically above the test section of the tunnel and connected to a high voltage d.c. power supply of ± 50 kV. Thus, high electric fields, horizontal or vertical in direction, can be applied in the region where drops are suspended.

Water drops released from the syringe can be charged with either polarity by inserting a wire in the water in syringe and raising it to the desired voltage.

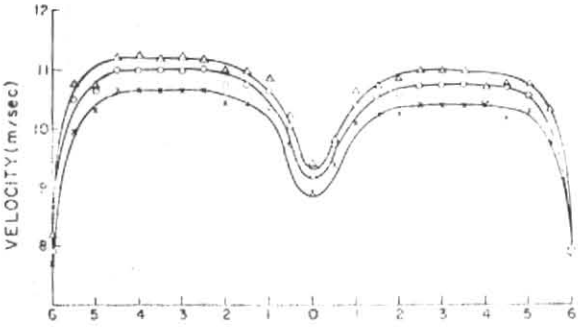


Fig. 2. Velocity profile across horizontal cross-section of the tunnel at a height of 8 cm above the rectangular test section, ——x——, ——o——, ——△—— are three different fixed settings of air vent at the blower's intake

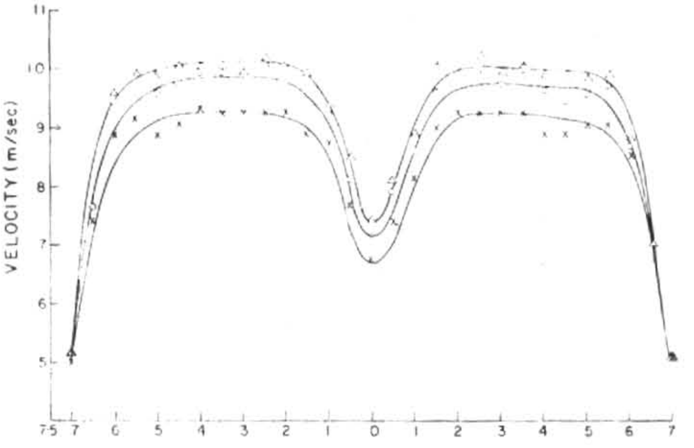
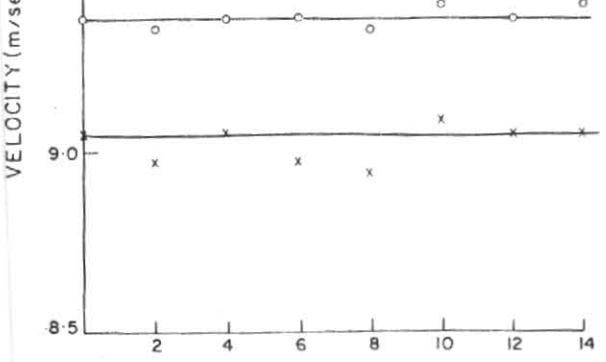
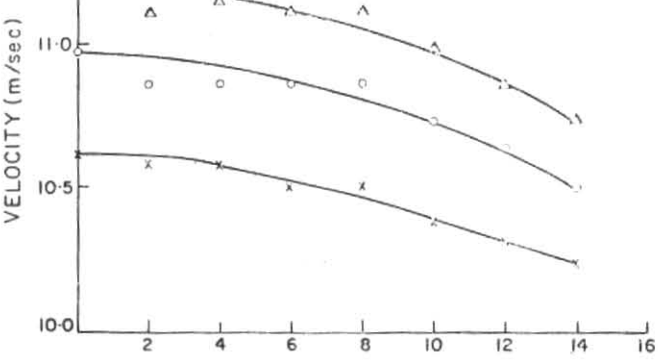


Fig. 3. Velocity profile across horizontal cross-section of the tunnel at a depth of 4 cm below the top of a tapered test section, ——x——, ——o——, ——△—— are for three different fixed settings of air vent at the blower's intake





Figs. 4. (a & b). Variation of velocity upwards from the top end of the rectangular test section along (a) The central axis of the tunnel & (b) The line at 2.5 cm from the central axis of the tunnel

Fig. 5 (a). Photographs of the suspended drops of diameters 3.5, 5.3 and 6.6 mm respectively

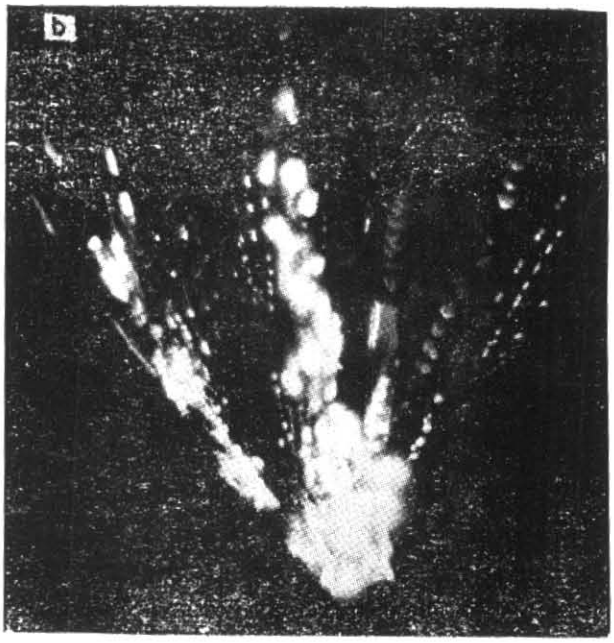


Fig. 5. (b). Breakup of two drops on their collision

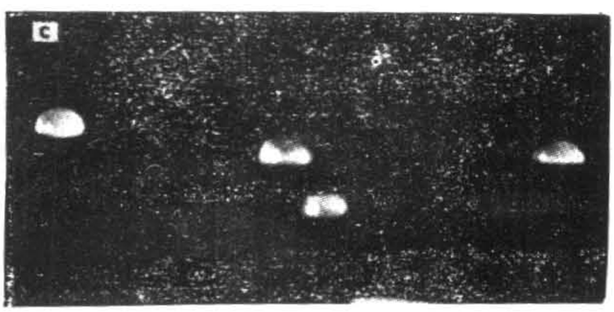


Fig. 5. (c). Four drops suspended simultaneously

5. Velocity profiles

Vertical velocity of the air in tunnel is measured with a small pitot static tube. Fig. 2 shows the velocity profile across horizontal cross-sectional area of the tunnel for three different blower settings and at a height of 8 cm above the test section. Test section with parallel sides alongwith the back pressure plate is used in these measurements. Back pressure plate is placed at height of 23 cm above the top of test section. Measurements are also taken by using the tapered test section. Fig. 3 shows velocity profiles across horizonal cross-sectional area of the tunnel for three different blower settings and at a depth of 4 cm inside from the top of a tapered test section. It clearly depicts how a velocity well is created in the air flow. The suspended water drops stay in this velocity well. Fig. 4(a) shows the variation of velocity upwards from the top end of the rectangular test section along the central axis of the tunnel. Fig. 4(b) shows the variation of velocity upwards from the top end of the same test section along a line at a distance of 2.5 cm from central axis of the tunnel.

6. Tunnel operation

Air vents fixed at the blower's inlet are adjusted to any of the three different position to control the velocity of the air in wind tunnel. Fine adjustment of velocity is done with a variac used for applying voltage to the blower. With full vents open and the blower operating at 220 V it is possible to achieve air velocities upto 12 m/s in the test section.

Different types of devices have been tried to create velocity well in the horizontal velocity profile of the tunnel. Positioning a 21 mesh wire screen of 4 cm diameter at the centre of the tunnel, two metallic plates arranged perpendicular to each other and special shaped screens (Blanchard 1951) of wire mesh have been tried. These are shown in Fig. 1(c). However, finally the crossed wire screen is selected and fitted in view of the greater stability of the drop achieved with it. With this screen fitted in the tunnel, the drop could be suspended in the air flow for 15-20 minutes. Fig. 5(a) shows some photographs of the suspended drops. However, a sudden change in the air flow or drop shape caused the drop to move up or down along vertical axis. Once the drop moves up by a few centimetre, it generally falls down to its original position within a second or two Occasionally, drops are thrown out of the velocity well and out of the tunnel. This occurs, perhaps, due to some turbulent eddy in the flow. Even the movement of the air in the room affected the stability of the drop. In case of tapering test section, drops move up and down within the test section itself. Fig. 5(b) shows the breakup of two drops when they collide with each other.

Drops are released either by the hypodermic syringe fitted in the back-pressure plate or by an ordinary water dropper held in operators hand. In the former case drops can be charged with either polarity by applying the required potential to the water in the syringe. Once the drop is suspended, it can be subjected to electric field by applying potentials to the electrodes with a power supply of $\pm$ 50 kV. These wire mesh electrodes can be placed horizontally or vertically above the test section. Electric fields upto 3 or 4 kV/cm can be applied with no significant corona occurring from the electrodes. Velocity of the air is somewhat reduced when an electrode is placed horizontally over the cross-section of the tunnel. Inspite of some turbulence produced by these electrodes, drops can still be suspended for many minutes. Size and charge of the drop can be measured by mechanically collecting it in some container. Size of the drop can also be measured from its photographs.

Drops are illuminated with a 150 W projector or a stroboscope. They are photographed with a 35 mm camera placed perpendicular to the projector and against a dark background. A solution of 1 part of sodium chloride and silver nitrate in 10^5 parts of distilled water is generally used for photographs (Blanchard 1948). Fig. 5(b) shows a photograph of four drops suspended simultaneously with the help of screen designed by us [Fig. 1 (c)].

7. Some uses of the vertical wind tunnel

Drops suspended in air stream experience maximum pressure at their bottom surfaces and minimum at the top. As a result of the balance of these and other forces acting on the drop, its bottom surface becomes flat. Ratio of the major and minor axis for a suspended drop depends upon its size. However, if an electric field is applied or the drop is charged, electrical forces acting on the drop will interfere with the equilibrium of forces acting on the drop. For example, a vertical field will tend to increase the minor axis of the drop while a horizontal field will tend to increase its major axis. Similarly an electric charge on the drop will increase the force acting outward on it. Since drops located in thunderclouds are charged and move in high electric fields it is worth studying as to what extent the electrical forces modify the shape of the drop.

As the drops fall they impart drag to the surrounding air. The drag force is proportional to the cross-sectional area of the drop and square of its terminal velocity. Since the electrical forces acting on the drop are likely to change the shape and velocity of the drop, it is possible that the drag they impart to the atmosphere also gets modified (Kamra 1982). Furthermore, electrical stresses are also likely to influence the oscillations and internal circulations of the drop. Photographs taken with stroboscopic illumination can be used to study the oscillations of the drop and its change of shape.

Stability of the drop is governed not only by its size but also by the kind of instability set in the drop. Therefore, the maximum size of the drop that exists in thunderstorms should be determined by its electrical characteristics also. Further, the number, and sizes of fragments into which a large drop breaks should also be influenced by the electrical stresses acting on it.

Drops in warm cloud are known to grow by their collision and coalescence with other drops as they fall down with their terminal velocities. Their collision and coalescence characteristics are largely governed by their sizes, velocities and the angles at which they collide with each other. In wind tunnel studies one drop is suspended and other smaller droplets can be injected from one side and made to collide with the larger drop. Electrical forces can also be applied on colliding drops to see their influence on the collision and coalescence characteristics. With the screen devised by Kamra and Ahire (1985) it is possible to study collisions of two drops of identical size colliding each other near to their horizontal periphery. Because of differences in pressures at the peripheries compared to the top or bottom of the drops, their coalescence properties are expected to be much different than in case of normal collisions. Some of these studies are under investigation at this laboratory.

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