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CHAPTER 8. BALLOON TECHNIQUES

8.1 BALLOONS

8.1.1 Main types of balloons

Two main categories of balloons are used in meteorology, as follows:

(a) Pilot balloons, which are used for the visual measurement of upper wind, and ceiling balloons for the measurement of cloud-base height. Usually they do not carry an appreciable load and are therefore considerably smaller than radiosonde balloons. They are almost invariably of the spherical extensible type and their chief requirement, apart from the ability to reach satisfactory heights, is that they should keep a good spherical shape while rising;

(b) Balloons which are used for carrying recording or transmitting instruments for routine upper-air observations are usually of the extensible type and spherical in shape. They are usually known as radiosonde or sounding balloons. They should be of sufficient size and quality to enable the required load (usually 200 g to 1 kg) to be carried up to heights as great as 35 km at a rate of ascent sufficiently rapid to enable reasonable ventilation of the measuring elements. For the measurement of upper winds by radar methods, large pilot balloons (100 g) or radiosonde balloons are used depending on the weight and drag of the airborne equipment.

Other types of balloons used for special purposes are not described in this chapter. Constant-level balloons that rise to, and float at, a pre-determined level are made of inextensible material. Large constant-level balloons are partly filled at release. Super-pressure constant-level balloons are filled to extend fully the balloon at release. Tetroons are small super-pressure constant-level balloons, tetrahedral in shape, used for trajectory studies. The use of tethered balloons for profiling is discussed in Part II, Chapter 5.

8.1.2 Balloon materials and properties

The best basic materials for extensible balloons are high-quality natural rubber latex and a synthetic latex based upon polychloroprene. Natural latex holds its shape better than polychloroprene – which is stronger and can be made with a thicker film for a given performance. It is less affected by temperature, but more affected by the ozone and ultraviolet radiation at high altitudes, and has a shorter storage life. Both materials may be compounded with various additives to improve their storage life, strength and performance at low temperatures both during storage and during flight, and to resist ozone and ultraviolet radiation. As one of the precautions against explosion, an antistatic agent may also be added during the manufacture of balloons intended to be filled with hydrogen.

There are two main processes for the production of extensible balloons. A balloon may be made by dipping a form into latex emulsion, or by forming it on the inner surface of a hollow mould. Moulded balloons can be made with more uniform thickness, which is desirable for achieving high altitudes as the balloon expands, and the neck can be made in one piece with the body, which avoids the formation of a possible weak point.

Polyethylene is the inextensible material used for constant-level balloons.

8.1.3 Balloon specifications

The finished balloons should be free from foreign matter, pinholes or other defects and must be homogeneous and of uniform thickness. They should be provided with necks of between 1 and 5 cm in diameter and 10 to 20 cm long, depending on the size of the balloon. In the case of sounding balloons, the necks should be capable of withstanding a force of 200 N without damage. In order to reduce the possibility of the neck being pulled off, it is important that the thickness of the envelope should increase gradually towards the neck; a sudden discontinuity of thickness forms a weak spot.

Balloons are distinguished in size by their nominal weights in grams. The actual weight of individual balloons should not differ from the specified nominal weight by more than 10%, or preferably 5%. They should be capable of expanding to at least four times, and preferably five or six times, their unstretched diameter and of maintaining this expansion for at least 1 h. When inflated, balloons should be spherical or pear-shaped.

The question of specified shelf life of balloons is important, especially in tropical conditions. Artificial ageing tests exist but they are not reliable guides. One such test is to keep sample balloons in an oven at a temperature of 80 °C for four days, this being reckoned as roughly equivalent to four years in the tropics, after which the samples should still be capable of meeting the minimum expansion requirement. Careful packing of the balloons so that they are not exposed to light (especially sunlight), fresh air or extremes of temperature is essential if rapid deterioration is to be prevented.

Balloons manufactured from synthetic latex incorporate a plasticizer to resist the stiffening or freezing of the film at the low temperatures encountered near and above the tropopause. Some manufacturers offer alternative balloons for daytime and night-time use, the amount of plasticizer being different.

8.2 BALLOON BEHAVIOUR

8.2.1 Rate of ascent

From the principle of buoyancy, the total lift of a balloon is given by the buoyancy of the volume of gas in it, as follows:

$$T = V\left(\rho - \rho_g\right) = 0.523\,D^3\left(\rho - \rho_g\right) \tag{8.1}$$

where T is the total lift; V is the volume of the balloon; ρ is the density of the air; ρ_g is the density of the gas; and D is the diameter of the balloon, which is assumed to be spherical.

All units are in the International System of Units. For hydrogen at ground level, the buoyancy ($\rho - \rho_g$) is about 1.2 kg m^{-3}. All the quantities in equation 8.1 change with height.

The free lift L of a balloon is the amount by which the total lift exceeds the combined weight W of the balloon and its load (if any):

$$L = T - W \tag{8.2}$$

namely, it is the net buoyancy or the additional weight which the balloon, with its attachments, will just support without rising or falling.

It can be shown by the principle of dynamic similarity that the rate of ascent V of a balloon in still air can be expressed by a general formula:

$$V = \frac{qL^n}{\left(L+W\right)^{1/3}} \tag{8.3}$$

in which q and n depend on the drag coefficient, and therefore on the Reynolds number, $v\rho D/\mu$ (μ being the viscosity of the air). Unfortunately, a large number of meteorological balloons, at some stages of flight, have Reynolds numbers within the critical region of $1 \cdot 10^5$ to $3 \cdot 10^5$, where a rapid change of drag coefficient occurs, and they may not be perfectly spherical. Therefore, it is impracticable to use a simple formula which is valid for balloons of different sizes and different free lifts. The values of q and n in the above equation must, therefore, be derived by experiment; they are typically, very approximately, about 150 and about 0.5, respectively, if the ascent rate is expressed in m min^{-1}. Other factors, such as the change of air density and gas leakage, can also affect the rate of ascent and can cause appreciable variation with height.

In conducting soundings during precipitation or in icing conditions, a free lift increase of up to about 75%, depending on the severity of the conditions, may be required. An assumed rate of ascent should not be used in any conditions other than light precipitation. A precise knowledge of the rate of ascent is not usually necessary except in the case of pilot- and ceiling-balloon observations, where there is no other means of determining the height. The rate of ascent depends largely on the free lift and air resistance acting on the balloon and train. Drag can be more important, especially in the case of non-spherical balloons. Maximum height depends mainly on the total lift and on the size and quality of the balloon.

8.2.2 Balloon performance

The table in this section lists typical figures for the performance of various sizes of balloons. They are very approximate. If precise knowledge of the performance of a particular balloon and train is necessary, it must be obtained by analysing actual flights. Balloons can carry payloads greater than those listed in the table if the total lift is increased. This is achieved by using more gas and by increasing the volume of the balloon, which will affect the rate of ascent and the maximum height.

Typical balloon performance

Weight (g)	10	30	100	200	350	600	1 000	1 500	3 000
Diameter at release (cm)	30	50	90	120	130	140	160	180	210
Payload (g)	0	0	0	250	250	250	250	1 000	1 000
Free lift (g)	5	60	300	500	600	900	1 100	1 300	1 700
Rate of ascent (m min^{-1})	60	150	250	300	300	300	300	300	300
Maximum height (km)	12	13	20	21	26	31	34	34	38

The choice of a balloon for meteorological purposes is dictated by the load, if any, to be carried, the rate of ascent, the altitude required, whether the balloon is to be used for visual tracking, and by the cloud cover with regard to its colour. Usually, a rate of ascent between 300 and 400 m min^{-1} is desirable in order to minimize the time required for observation; it may also be necessary in order to provide sufficient ventilation for the radiosonde sensors. In choosing a balloon, it is also necessary to bear in mind that the altitude attained is usually less when the temperature at release is very low.

For balloons used in regular operations, it is beneficial to determine the free lift that produces optimum burst heights. For instance, it has been found that a reduction in the average rate of ascent from 390 to 310 m min^{-1} with some mid-size balloons by reducing the amount of gas for inflation may give an increase of 2 km, on average, in the burst height. Burst height records should be kept and reviewed to ensure that optimum practice is sustained.

Daytime visual observations are facilitated by using uncoloured balloons on clear sunny days, and dark-coloured ones on cloudy days.

The performance of a balloon is best gauged by the maximum linear extension it will withstand before bursting and is conveniently expressed as the ratio of the diameter (or circumference) at burst to that of the unstretched balloon. The performance of a balloon in flight, however, is not necessarily the same as that indicated by a bursting test on the ground. Performance can be affected by rough handling when the balloon is filled and by stresses induced during launches in gale conditions. In flight, the extension of the balloon may be affected by the loss of elasticity at low temperatures, by the chemical action of oxygen, ozone and ultraviolet radiation, and by manufacture faults such as pinholes or weak spots. A balloon of satisfactory quality should, however, give at least a fourfold extension in an actual sounding. The thickness of the film at release is usually in the range of 0.1 to 0.2 mm.

There is always a small excess of pressure p_1 within the balloon during ascent, amounting to a few hPa, owing to the tension of the rubber. This sets a limit to the external pressure that can be reached. It can be shown that, if the temperature is the same inside and outside the balloon, this limiting pressure p is given by:

$$p = \left(\frac{1.07W}{L_0} + 0.075 \right) p_1 \cong \frac{W p_1}{L_0} \tag{8.4}$$

where W is the weight of the balloon and apparatus; and L_0 is the free lift at the ground, both expressed in grams. If the balloon is capable of reaching the height corresponding with p, it will float at this height.

8.3 HANDLING BALLOONS

8.3.1 Storage

It is very important that radiosonde balloons should be correctly stored if their best performance is still to be obtained after several months. It is advisable to restrict balloon stocks to the safe minimum allowed by operational needs. Frequent deliveries, wherever possible, are preferable to purchasing in large quantities with consequent long periods of storage. To avoid the possibility of using balloons that have been in storage for a long period, balloons should always be used in the order of their date of manufacture.

It is generally possible to obtain the optimum performance up to about 18 months after manufacture, provided that the storage conditions are carefully chosen. Instructions are issued by many manufacturers for their own balloons and these should be observed meticulously. The following general instructions are applicable to most types of radiosondes balloons.

Balloons should be stored away from direct sunlight and, if possible, in the dark. At no time should they be stored adjacent to any source of heat or ozone. Balloons made of either polychloroprene or a mixture, or polychloroprene and natural rubber may deteriorate if exposed to the ozone emitted by large electric generators or motors. All balloons should be kept in their original packing until required for preflight preparations. Care should be taken to see that they do not come into contact with oil or any other substance that may penetrate the wrapping and damage the balloons.

Wherever possible, balloons should be stored in a room at temperatures of 15 to 25 °C; some manufacturers give specific guidance on this point and such instructions should always be followed.

8.3.2 Conditioning

Balloons made from natural rubber do not require special heat treatment before use, as natural rubber does not freeze at the temperatures normally experienced in buildings used for human occupation. It is, however, preferable for balloons that have been stored for a long period at temperatures below 10 °C to be brought to room temperature for some weeks before use.

Polychloroprene balloons suffer a partial loss of elasticity during prolonged storage at temperatures below 10 °C. For the best results, this loss should be restored prior to inflation by conditioning the balloon. The manufacturer’s recommendations should be followed.

It is common practice to place the balloon in a thermally insulated chamber with forced air circulation, maintained at suitable temperature and humidity for some days before inflation, or alternatively to use a warm water bath.

At polar stations during periods of extremely low temperatures, the balloons to be used should have special characteristics that enable them to maintain strength and elasticity in such conditions.

8.3.3 Inflation

If a balloon launcher is not used, a special room, preferably isolated from other buildings, should be provided for filling balloons. It should be well ventilated (e.g. NFPA, 1999). If hydrogen gas is to be used, special safety precautions are essential (see section 8.6). The building should be free from any source of sparks, and all electric switches and fittings should be spark-proof; other necessary details are given in section 8.6.2. If helium gas is to be used, provision may be made for heating the building during cold weather. The walls, doors and floor should have a smooth finish and should be kept free from dust and grit. Heating hydrogen-inflation areas can be accomplished by steam, hot water or any other indirect means; however, electric heating, if any, shall be in compliance with national electrical codes (e.g. NFPA 50A for Class I, Division 2, locations).

Protective clothing (see section 8.6.4) should be worn during inflation. The operator should not stay in a closed room with a balloon containing hydrogen. The hydrogen supply should be controlled and the filling operation observed, from outside the filling room if the doors are shut, and the doors should be open when the operator is in the room with the balloon.

Balloons should be inflated slowly because sudden expansion may cause weak spots in the balloon film. It is desirable to provide a fine adjustment valve for regulating the gas flow. The desired amount of inflation (free lift) can be determined by using either a filling nozzle of the required weight or one which forms one arm of a balance on which the balloon lift can be weighed. The latter is less convenient, unless it is desirable to allow for variations in the weights of balloons, which is hardly necessary for routine work. It is useful to have a valve fitted to the weight type of the filler, and a further refinement, used in some services, is to have a valve that can be adjusted to close automatically at the required lift.

8.3.4 Launching

The balloon should be kept under a shelter until everything is ready for its launch. Prolonged exposure to bright sunshine should be avoided as this may cause a rapid deterioration of the balloon fabric and may even result in its bursting before leaving the ground. Protective clothing should be worn during manual launches.

No special difficulties arise when launching radiosonde balloons in light winds. Care should always be taken to see that there is no risk of the balloon and instruments striking obstructions before they rise clear of trees and buildings in the vicinity of the station. Release problems can be avoided to a large extent by carefully planning the release area. It should be selected to have a minimum of obstructions that may interfere with launching; the station buildings should be designed and sited considering the prevailing wind, likely gust effects on the release area and, in cold climates, drifting snow.

It is also advisable in high winds to keep the suspension of the instrument below the balloon as short as possible during launching, by using some form of suspension release or unwinder. A convenient device consists of a reel on which the suspension cord is wound and a spindle to which is attached an air brake or escapement mechanism that allows the suspension cord to unwind slowly after the balloon is released.

Mechanical balloon launchers have the great advantage that they can be designed to offer almost fool-proof safety, by separating the operator from the balloon during filling and launching. They can be automated to various degrees, even to the point where the whole radiosonde operation requires no operator to be present. They might not be effective at wind speeds above 20 m s^{-1}. Provision should be made for adequate ventilation of the radiosonde sensors before release, and the construction should desirably be such that the structure will not be damaged by fire or explosion.

8.4 ACCESSORIES FOR BALLOON ASCENTS

8.4.1 Illumination for night ascents

The light source in general use for night-time pilot-balloon ascents is a lamp powered by a small electric battery. A battery of two 1.5 V cells, or a water-activated type used with a 2.5 V 0.3 A bulb, is usually suitable. Alternatively, a device providing light by means of chemical fluorescence may be used. For high-altitude soundings, however, a more powerful system of 2 to 3 W, together with a simple reflector, is necessary.

If the rate of ascent is to remain unchanged when a lighting unit is to be used, a small increase in free lift is theoretically required; that is to say, the total lift must be increased by more than the extra weight carried (see equation 8.3). In practice, however, the increase required is probably less than that calculated since the load improves the aerodynamic shape and the stability of the balloon.

At one time, night ascents were carried with a small candle in a translucent paper lantern suspended some 2 m or so below the balloon. However, there is a risk of flash or explosion if the candle is brought near the balloon or the source of hydrogen, and there is a risk of starting a forest fire or other serious fires upon return to the Earth. Thus, the use of candles is strongly discouraged.

8.4.2 Parachutes

In order to reduce the risk of damage caused by a falling sounding instrument, it is usual practice to attach a simple type of parachute. The main requirements are that it should be reliable when opening and should reduce the speed of descent to a rate not exceeding about 5 m s^{-1} near the ground. It should also be water-resistant. For instruments weighing up to 2 kg, a parachute made from waterproof paper or plastic film of about 2 m diameter and with strings about 3 m long is satisfactory. In order to reduce the tendency for the strings to twist together in flight it is advisable to attach them to a light hoop of wood, plastic or metal of about 40 cm in diameter just above the point where they are joined together.

When a radar reflector for wind-finding is part of the train it can be incorporated into the parachute and can serve to keep the strings apart. The strings and attachments must be able to withstand the opening of the parachute. If light-weight radiosondes are used (less than about 250 g), the radar reflector alone may provide sufficient drag during descent.

8.5 GASES FOR INFLATION

8.5.1 General

The two gases most suitable for meteorological balloons are helium and hydrogen. The former is much to be preferred on account of the fact that it is free from risk of explosion and fire. However, since the use of helium is limited mainly to the few countries which have an abundant natural supply, hydrogen is more generally used (see WMO, 1982). The buoyancy (total lift) of helium is 1.115 kg m^{-3}, at a pressure of 1 013 hPa and a temperature of 15 °C. The corresponding figure for pure hydrogen is 1.203 kg m^{-3} and for commercial hydrogen the figure is slightly lower than this.

It should be noted that the use of hydrogen aboard ships is no longer permitted under the general conditions imposed for marine insurance. The extra cost of using helium has to be reckoned against the life-threatening hazards to and the extra cost of insurance, if such insurance can be arranged.

Apart from the cost and trouble of transportation, the supply of compressed gas in cylinders affords the most convenient way of providing gas at meteorological stations. However, at places where the cost or difficulty of supplying cylinders is prohibitive, the use of an on-station hydrogen generator (see section 8.5.3) should present no great difficulties.

8.5.2 **Gas cylinders**

For general use, steel gas cylinders, capable of holding 6 m^3 of gas compressed to a pressure of 18 MPa (10 MPa in the tropics), are probably the most convenient size. However, where the consumption of gas is large, as at radiosonde stations, larger capacity cylinders or banks of standard cylinders all linked to the same outlet valve can be useful. Such arrangements will minimize handling by staff. In order to avoid the risk of confusion with other gases, hydrogen cylinders should be painted a distinctive colour (red is used in many countries) and otherwise marked according to national regulations. Their outlet valves should have left-handed threads to distinguish them from cylinders of non-combustible gases. Cylinders should be provided with a cap to protect the valves in transit.

Gas cylinders should be tested at regular intervals ranging from two to five years, depending on the national regulations in force. This should be performed by subjecting them to an internal pressure of at least 50% greater than their normal working pressure. Hydrogen cylinders should not be exposed to heat and, in tropical climates, they should be protected from direct sunshine. Preferably, they should be stored in a well-ventilated shed which allows any hydrogen leaks to escape to the open air.

8.5.3 **Hydrogen generators**

Hydrogen can be produced on site using various kinds of hydrogen generators. All generator plants and hydrogen storage facilities shall be legibly marked and with adequate warnings according to national regulations (e.g. “This unit contains hydrogen”; “Hydrogen – Flammable gas – No smoking – No open flames”). The following have proven to be the most suitable processes for generating hydrogen for meteorological purposes:

(a) Ferro-silicon and caustic soda with water;

(b) Aluminium and caustic soda with water;

(c) Calcium hydride and water;

(d) Magnesium-iron pellets and water;

(e) Liquid ammonia with hot platinum catalyst;

(f) Methanol and water with a hot catalyst;

(g) Electrolysis of water.

Most of the chemicals used in these methods are hazardous, and the relevant national standards and codes of practice should be scrupulously followed, including correct markings and warnings. They require special transportation, storage, handling and disposal. Many of them are corrosive, as is the residue after use. If the reactions are not carefully controlled, they may produce excess heat and pressure. Methanol, being a poisonous alcohol, can be deadly if ingested, as it may be by substance abusers.

In particular, caustic soda, which is widely used, requires considerable care on the part of the operator, who should have adequate protection, especially for the eyes, from contact not only with the solution, but also with the fine dust which is liable to arise when the solid material is being put into the generator. An eye-wash bottle and a neutralizing agent, such as vinegar, should be kept at hand in case of an accident.

Some of the chemical methods operate at high pressure, with a consequential greater risk of an accident. High-pressure generators should be tested every two years to a pressure at least twice that of the working pressure. They should be provided with a safety device to relieve excess pressure. This is usually a bursting disc, and it is very important that the operational instructions should be strictly followed with regard to the material, size and form of the discs, and the frequency of their replacement. Even if a safety device is efficient, its operation is very liable to be accompanied by the ejection of hot solution. High-pressure generators must be carefully cleaned out before recharging since remains of the previous charge may considerably reduce the available volume of the generator and, thus, increase the working pressure beyond the design limit.

Unfortunately, calcium hydride and magnesium-iron, which have the advantage of avoiding the use of caustic soda, are expensive to produce and are, therefore, likely to be acceptable only for special purposes. Since these two materials produce hydrogen from water, it is essential that they be stored in containers which are completely damp-proof. In the processes using catalysts, care must be taken to avoid catalyst contamination.

All systems produce gas at sufficient pressure for filling balloons. However, the production rates of some systems (electrolysis in particular) are too low, and the gas must be produced and stored before it is needed, either in compressed form or in a gasholder.

The processes using the electrolysis of water or the catalytic cracking of methanol are attractive because of their relative safety and moderate recurrent cost, and because of the non-corrosive nature of the materials used. These two processes, as well as the liquid ammonia process, require electric power. The equipment is rather complex and must be carefully maintained and subjected to detailed daily check procedures to ensure that the safety control systems are effective. Water for electrolysis must have low mineral content.

8.6 USE OF HYDROGEN AND SAFETY PRECAUTIONS

8.6.1 General

Hydrogen can easily be ignited by a small spark and burns with a nearly invisible flame. It can burn when mixed with air over a wide range of concentrations, from 4% to 74% by volume (NFPA, 1999), and can explode in concentrations between 18% and 59%. In either case, a nearby operator can receive severe burns over the entire surface of any exposed skin, and an explosion can throw the operator against a wall or the ground, causing serious injury.

It is possible to eliminate the risk of an accident by using very carefully designed procedures and equipment, provided that they are diligently observed and maintained (Gremia, 1977; Ludtke and Saraduke, 1992; NASA, 1968). The provision of adequate safety features for the buildings in which hydrogen is generated and stored, or for the areas in which balloons are filled or released, does not always receive adequate attention (see the following section). In particular, there must be comprehensive training and continual meticulous monitoring and inspection to ensure that operators follow the procedures.

The advantages of automatic balloon launchers (see section 8.3.4) are that they can be made practically fool-proof and operator injuries can be prevented by completely separating the operator from the hydrogen.

An essential starting point for the consideration of safety precautions is to follow the various national standards and codes of practice concerned with the risks presented by explosive atmospheres in general. Additional information on the precautions that should be followed will be found in publications dealing with explosion hazards, such as in hospitals and other industrial situations where similar problems exist. The operator should never be in a closed room with an inflated balloon. Other advice on safety matters can be found throughout the chapter.

8.6.2 **Building design**

Provisions should be made to avoid the accumulation of free hydrogen and of static charges as well as the occurrence of sparks in any room where hydrogen is generated, stored or used. The accumulation of hydrogen must be avoided even when a balloon bursts within the shelter during the course of inflation (WMO, 1982).

Safety provisions must be part of the structural design of hydrogen buildings (NFPA, 1999; SAA, 1985). Climatic conditions and national standards and codes are constraints within which it is possible to adopt many designs and materials suitable for safe hydrogen buildings. Codes are advisory and are used as a basis of good practice. Standards are published in the form of specifications for materials, products and safe practices. They should deal with topics such as flame-proof electric-light fittings, electrical apparatus in explosive atmospheres, the ventilation of rooms with explosive atmospheres, and the use of plastic windows, bursting discs, and so on (WMO, 1982).

Both codes and standards should contain information that is helpful and relevant to the design of hydrogen buildings. Furthermore, it should be consistent with recommended national practice. Guidance should be sought from national standards authorities when hydrogen buildings are designed or when the safety of existing buildings is reviewed, in particular for aspects such as the following:

(a) The preferred location for hydrogen systems;

(b) The fire resistance of proposed materials, as related to the fire-resistance ratings that must be respected;

(c) Ventilation requirements, including a roof of light construction to ensure that hydrogen and products of an explosion are vented from the highest point of the building;

(d) Suitable electrical equipment and wiring;

(e) Fire protection (extinguishers and alarms);

(f) Provision for the operator to control the inflation of the balloon from outside the filling room.

Measures should be taken to minimize the possibility of sparks being produced in rooms where hydrogen is handled. Thus, any electrical system (switches, fittings, wiring) should be kept outside these rooms; otherwise, special spark-proof switches, pressurized to prevent the ingress of hydrogen, and similarly suitable wiring, should be provided. It is also advisable to illuminate the rooms using exterior lights which shine in through windows. For the same reasons, any tools used should not produce sparks. The observer’s shoes should not be capable of emitting sparks, and adequate lightning protection should be provided.

If sprinkler systems are used in any part of the building, consideration should be given to the possible hazard of hydrogen escaping after the fire has been extinguished. Hydrogen detection systems exist and may be used, for instance, to switch off power to the hydrogen generator at 20% of the lower explosive limit and should activate an alarm, and then activate another alarm at 40% of the lower explosive limit.

A hazard zone should be designated around the generator, storage and balloon area into which entry is permitted only when protective clothing is worn (see section 8.6.4).

Balloon launchers (see section 8.3.4) typically avoid the need for a special balloon-filling room, and greatly simplify the design of hydrogen facilities.

8.6.3 **Static charges**

The hazards of balloon inflation and balloon release can be considerably reduced by preventing static charges in the balloon-filling room, on the observer’s clothing, and on the balloon itself. Loeb (1958) provides information on the static electrification process. Static charge control is effected by good earthing provisions for hydrogen equipment and filling-room fittings. Static discharge grips for observers can remove charges generated on clothing (WMO, 1982).

Charges on balloons are more difficult to deal with. Balloon fabrics, especially pure latex, are very good insulators. Static charges are generated when two insulating materials in contact with each are separated. A single brief contact with the observer’s clothing or hair can generate a 20 kV charge, which is more than sufficient to ignite a mixture of air and hydrogen if it is discharged through an efficient spark. Charges on a balloon may take many hours to dissipate through the fabric to earth or naturally into the surrounding air. Also, it has been established that, when a balloon bursts, the separation of the film along a split in the fabric can generate sparks energetic enough to cause ignition.

Electrostatic charges can be prevented or removed by spraying water onto the balloon during inflation, by dipping balloons into antistatic solution (with or without drying them off before use), by using balloons with an antistatic additive in the latex, or by blowing ionized air over the balloon. Merely earthing the neck of the balloon is not sufficient.

The maximum electrostatic potential that can be generated or held on a balloon surface decreases with increasing humidity, but the magnitude of the effect is not well established. Some tests carried out on inflated 20 g balloons indicated that spark energies sufficient to ignite hydrogen-oxygen mixtures are unlikely to be reached when the relative humidity of the air is greater than 60%. Other studies have suggested relative humidities from 50% to 76% as safe limits, yet others indicate that energetic sparks may occur at even higher relative humidity. It may be said that static discharge is unlikely when the relative humidity exceeds 70%, but this should not be relied upon (see Cleves et al., 1971).

It is strongly recommended that fine water sprays be used on the balloon because the wetting and earthing of the balloon will remove most of the static charges from the wetted portions. The sprays should be designed to wet as large an area of the balloon as possible and to cause continuous streams of water to run from the balloon to the floor. If the doors are kept shut, the relative humidity inside the filling room can rise to 75% or higher, thus reducing the probability of sparks energetic enough to cause ignition. Balloon release should proceed promptly once the sprays are turned off and the filling-shed doors opened.

Other measures for reducing the build-up of static charge include the following (WMO, 1982):

(a) The building should be provided with a complete earthing (grounding) system, with all fittings, hydrogen equipment and the lightning conductor separately connected to a single earth, which itself must comply with national specifications for earth electrodes. Provision should be made to drain electrical charges from the floor;

(b) Static discharge points should be provided for the observers;

(c) The windows should be regularly coated with an antistatic solution;

(d) Operators should be encouraged not to wear synthetic clothing or insulating shoes. It is good practice to provide operators with partially conducting footwear;

(e) Any contact between the observer and the balloon should be minimized; this can be facilitated by locating the balloon filler at a height of 1 m or more above the floor.

8.6.4 **Protective clothing and first-aid facilities**

Proper protective clothing should be worn whenever hydrogen is being used, during all parts of the operations, including generation procedures, when handling cylinders, and during balloon inflation and release. The clothing should include a light-weight flame-proof coat with a hood made of non-synthetic, antistatic material and a covering for the lower face, glasses or goggles, cotton gloves, and any locally recommended anti-flash clothing (see Hoschke et al., 1979).

First-aid facilities appropriate to the installation should be provided. These should include initial remedies for flash burns and broken limbs. When chemicals are used, suitable neutralizing solutions should be on hand, for example, citric acid for caustic soda burns. An eye-wash apparatus ready for instant use should be available (WMO, 1982).

REFERENCES AND FURTHER READING

Atmospheric Environment Service (Canada), 1978: *The Use of Hydrogen for Meteorological Purposes in the Canadian Atmospheric Environment Service*, Toronto.

Cleves, A.C., J.F. Sumner and R.M.H. Wyatt, 1971: The Effect of Temperature and Relative Humidity on the Accumulation of Electrostatic Charges on Fabrics and Primary Explosives. *Proceedings of the Third Conference on Static Electrification*, (London).

Gremia, J.O., 1977: *A Safety Study of Hydrogen Balloon Inflation Operations and Facilities of the National Weather Service*. Trident Engineering Associates, Annapolis, Maryland.

Hoschke, B.N. et al., 1979: *Report to the Bureau of Meteorology on Protection Against the Burn Hazard from Exploding Hydrogen-filled Meteorological Balloons*. CSIRO Division of Textile Physics and the Department of Housing and Construction, Australia.

Loeb, L.B., 1958: *Static Electrification*, Springer-Verlag, Berlin.

Ludtke, P. and G. Saraduke, 1992: *Hydrogen Gas Safety Study Conducted at the National Weather Service Forecast Office*. Norman, Oklahoma.

National Aeronautics and Space Administration, 1968: *Hydrogen Safety Manual*. NASA Technical Memorandum TM-X-52454, NASA Lewis Research Center, United States.

National Fire Protection Association, 1999: *NFPA 50A: Standard for Gaseous Hydrogen Systems at Consumer Sites*. National Fire Protection Association, Quincy, Maryland.

———, 2002: *NFPA 68: Guide for Venting of Deflagrations*. National Fire Protection Association, Batterymarch Park, Quincy, Maryland.

———, 2005: *NFPA 70, National Electrical Code*. National Fire Protection Association, Quincy, Maryland.

———, 2006: *NFPA 220, Standard on Types of Building Construction*. National Fire Protection Association, Quincy, Maryland.

Rosen, B., V.H. Dayan and R.L. Proffit, 1970: *Hydrogen Leak and Fire Detection: A Survey*. NASA SP-5092.

Standards Association of Australia, 1970: AS C99: *Electrical equipment for explosive atmospheres – Flameproof electric lightning fittings*.

———, 1980: AS 1829: *Intrinsically safe electrical apparatus for explosive atmospheres*.

———, 1985: AS 1482: *Electrical equipment for explosive atmospheres – Protection by ventilation – Type of protection V*.

———, 1995: ASNZS 1020: *The control of undesirable static electricity*.

———, 2004: AS 1358: *Bursting discs and bursting disc devices – Application selection and installation*.

World Meteorological Organization, 1982: *Meteorological Balloons: The Use of Hydrogen for Inflation of Meteorological Balloons*. Instruments and Observing Methods Report No. 13. Geneva.