M.3.3 Compliance criteria

These tests shall not result in any of the following:

– chemical leakage caused by cracking, rupturing or bursting of the BATTERY jacket, if such leakage could adversely affect a SAFEGUARD; or

- spillage of liquid from any pressure relief device in the BATTERY, unless such spillage is contained by the equipment without risk of damage to a SAFEGUARD or harm to an ORDINARY PERSON or an INSTRUCTED PERSON; or

- EXPLOSION of the BATTERY, if such EXPLOSION could result in injury to an ORDINARY PERSON or an INSTRUCTED PERSON; or

- emission of flame or expulsion of molten metal to the outside of the equipment ENCLOSURE.

Throughout the tests:

- the BATTERY temperature shall not exceed the allowable temperature of the BATTERY as specified by the BATTERY manufacturer; and

- the maximum current drawn from the BATTERY shall be within the range of the specification of the BATTERY.

M.4 Additional safeguards for equipment containing a portable secondary lithium battery

M.4.1 General

Equipment designed to be operated while incorporating one or more portable sealed SECONDARY LITHIUM BATTERIES are subject to the requirements in this clause.

M.4.2 Charging safeguards

M.4.2.1 Requirements

Under NORMAL OPERATING CONDITIONS, ABNORMAL OPERATING CONDITIONS or SINGLE FAULT CONDITIONS the charging voltage per SECONDARY LITHIUM BATTERY and the charging current per SECONDARY LITHIUM BATTERY shall not exceed the MAXIMUM SPECIFIED CHARGING VOLTAGE and MAXIMUM SPECIFIED CHARGING CURRENT.

Under ABNORMAL OPERATING CONDITIONS, the BATTERY charging circuit shall:

- stop charging when the temperature of the BATTERY exceeds the HIGHEST SPECIFIED CHARGING TEMPERATURE; and

– limit the current to the value specified by the BATTERY manufacturer when the BATTERY temperature is lower than the LOWEST SPECIFIED CHARGING TEMPERATURE.

M.4.2.2 Compliance criteria

Compliance is checked by measuring the charging voltage, the charging current and the temperature of each individual CELL of the SECONDARY LITHIUM BATTERY under NORMAL OPERATING CONDITIONS, ABNORMAL OPERATING CONDITIONS and SINGLE FAULT CONDITIONS. The CELL temperature shall be measured at the points specified by the BATTERY manufacturer. SINGLE FAULT CONDITIONS that may affect the charging voltage or charging current or the temperature shall be applied in accordance with Clause <u>B.4</u>.

NOTE 1 For potted assemblies, thermocouples could be attached to the CELL surface before potting.

A higher charging voltage than the MAXIMUM SPECIFIED CHARGING VOLTAGE or a higher charging current than the MAXIMUM SPECIFIED CHARGING CURRENT, that occurs just after the introduction of an ABNORMAL OPERATING CONDITION or a SINGLE FAULT CONDITION, may be ignored if the operation of a protective device or circuitry, provided in addition to the normal regulating circuitry, prevents an unsafe condition of the BATTERY.

Where appropriate, for the purpose of the measurement, the BATTERY may be replaced by a circuit simulating the BATTERY load.

The charging voltage shall be measured when the SECONDARY LITHIUM BATTERY becomes fully charged. The charging current shall be measured during the entire charging cycle up to the MAXIMUM SPECIFIED CHARGING VOLTAGE.

During and after the test, the following applies:

- The charging voltage shall not exceed the MAXIMUM SPECIFIED CHARGING VOLTAGE.

- The charging current shall not exceed the MAXIMUM SPECIFIED CHARGING CURRENT.

– The charging of the BATTERY shall stop when the temperature of the BATTERY exceeds the HIGHEST SPECIFIED CHARGING TEMPERATURE.

- The BATTERY charging circuit shall limit the current to the value specified by the BATTERY manufacturer when the battery temperature is lower than the LOWEST SPECIFIED CHARGING TEMPERATURE.

In addition, for equipment where the BATTERY can be removed from the equipment by an ORDINARY PERSON, compliance is checked by measuring the charging voltage and the charging current, and by evaluating the temperature control function of the equipment under NORMAL OPERATING CONDITIONS, ABNORMAL OPERATING CONDITIONS and SINGLE FAULT CONDITIONS.

All parameters controlled by the protection circuit for the BATTERY shall be within those specified in the relevant IEC BATTERY standard, and shall cover the following:

- the maximum current drawn from the BATTERY shall be within the range of the specification of the BATTERY; and

- throughout the tests, the BATTERY temperature shall not exceed the allowable temperature of the BATTERY as specified by the BATTERY manufacturer.

NOTE 2 The controlling elements are voltage, current, and temperature.

M.4.3 Fire enclosure

SECONDARY LITHIUM BATTERIES shall be provided with a FIRE ENCLOSURE according to <u>6.4.8</u>. The FIRE ENCLOSURE may be that of the SECONDARY LITHIUM BATTERY itself, of the CELL or of a combination of CELLS or that of the equipment containing the SECONDARY LITHIUM BATTERY.

Equipment with BATTERIES are exempt from the above requirement if the equipment uses a CELL that complies with PS1.

Compliance is checked by inspection of the relevant material or by evaluation of the SECONDARY LITHIUM BATTERY data sheet.

M.4.4 Drop test of equipment containing a secondary lithium battery

M.4.4.1 General

The tests for DIRECT PLUG-IN EQUIPMENT, HAND-HELD EQUIPMENT and TRANSPORTABLE EQUIPMENT that contain a SECONDARY LITHIUM BATTERY are specified below. These tests are specified to verify that mechanical shock will not compromise a SAFEGUARD within the BATTERY or the equipment.

M.4.4.2 Preparation and procedure for the drop test

The drop test is conducted in the following order:

- Step 1: drop of the equipment containing a BATTERY as specified in <u>M.4.4.3</u>.

- Step 2: check the charge and discharge function of the dropped equipment as specified in M.4.4.4.

- Step 3: conduct a charge and discharge cycle test of the dropped battery as specified in M.4.4.5.

As a preparation of the drop test, two BATTERIES are fully charged at the same time under the same charging conditions. The open circuit voltages of both BATTERIES are measured to confirm the initial voltages are the same. One BATTERY is used for the drop test and the other is used as a reference.

M.4.4.3 Drop

The equipment with a fully charged BATTERY installed shall be subjected to the drop test of Clause T.7.

After the drop test, the BATTERY is removed from the equipment. The open circuit voltages of the dropped BATTERY and the reference (undropped) BATTERY are periodically monitored during the following 24 hour period. The voltage difference shall not exceed 5 %.

M.4.4.4 Check of the charge / discharge function

The charging/discharging circuit functions (charging- control voltage, charging control current, and temperature control) are checked to determine that they continue to operate and that all SAFEGUARDS are effective. A dummy BATTERY or appropriate measurement tool that represents the BATTERY characteristics may be used for this examination in order to differentiate between BATTERY damage and equipment malfunctions.

If the charge/discharge function does not operate, the test is terminated, continuation with step 3 is not necessary and compliance is determined by $\underline{M.4.4.6}$.

M.4.4.5 Charge / discharge cycle test

If the dropped equipment is still functioning, the dropped equipment with the dropped BATTERY installed is subject to three complete discharge and charge cycles under NORMAL OPERATING CONDITIONS.

M.4.4.6 Compliance criteria

During the tests, fire or EXPLOSION of the BATTERY shall not occur unless an appropriate SAFEGUARD is provided that contains the EXPLOSION or fire. If venting occurs, any electrolyte leakage shall not defeat a SAFEGUARD.

When a protection circuitry for charging or discharging in the equipment or the battery detects an abnormality in the BATTERY and stops charging or discharging, the result is considered to be acceptable.

M.5 Risk of burn due to short-circuit during carrying

M.5.1 Requirements

BATTERY terminals shall be protected from the possible burn that may occur to an ORDINARY PERSON or an INSTRUCTED PERSON during the carrying of a BATTERY with exposed bare conductive terminals (such as in the user's carrying bag) due to a short-circuit caused by metal objects, such as clips, keys and necklaces.

Test method and compliance criteria

If the BATTERY is designed to be carried with bare conductive terminals, the BATTERY shall comply with the test of <u>P.2.3</u>.

The compliance criteria of <u>M.3.3</u> apply.

M.6 Safeguards against short-circuits

M.6.1 Requirements

The electric energy stored in CELLS or BATTERIES may be released in an inadvertent and uncontrolled manner due to external short-circuiting of the terminals or an internal SAFEGUARD failure, such as a metal contaminant bridging the insulation. As a result, the considerable amount of energy, heat and pressure generated by the high current can produce molten metal, sparks, EXPLOSION and vaporisation of electrolyte.

To address external faults, the main connections from the BATTERY terminals shall either:

- be provided with a sufficient overcurrent protective device to prevent any accidental short-circuit inducing conditions as mentioned above; or

- the BATTERY connections up to the first overcurrent protective device shall be constructed so that a shortcircuit is not likely to occur and connections shall be designed to withstand the electromagnetic forces experienced during a short-circuit.

NOTE 1 Where terminals and conductors are not insulated, by design or for maintenance purposes, only insulated tools are to be used in that area.

Unless internal fault testing has been conducted on the CELL as part of compliance with an IEC BATTERY standard in M.2.1, the internal fault testing as described below is required.

NOTE 2 Not all BATTERY standards in <u>M.2.1</u> contain a similar internal fault test.

Each CELL in a BATTERY shall be faulted to ensure that each CELL vents safely without introducing an EXPLOSION or fire. Where a CELL is incorporated into a BATTERY or the equipment, sufficient spacing shall be allowed for the proper vent operation of each CELL.

M.6.2 Compliance criteria

For external faults, compliance may be checked by inspection.

The sample shall not explode or emit molten material at any time during any of the tests.

M.7 Risk of explosion from lead acid and NiCd batteries

M.7.1 Ventilation preventing an explosive gas concentration

Where BATTERIES are provided within an equipment such that emitted gases may concentrate in a confined equipment space, the BATTERY construction, air flow or ventilation shall be such that the atmosphere within the equipment does not reach an EXPLOSIVE concentration.

In a compartment containing both a BATTERY and electrical components, the risk of ignition of local concentrations of hydrogen and oxygen by adjacent operational arcing parts, such as contactors and switches close to BATTERY vents or valves, shall be controlled. This shall be achieved, for example, by the use of fully enclosed components, separation of BATTERY compartments or adequate ventilation.

The ventilation system shall be so constructed that any potential fault, including distortion of the BATTERY cases due to overheating or thermal runaway, does not result in the ventilation system failing to vent EXPLOSIVE gasses.

If ventilation tubes are used for conducting EXPLOSIVE gas from the BATTERY cases to the outside air, they shall not be the only means of eliminating the build-up of gas from the cabinet. An independent means of natural ventilation that adequately ventilates the enclosure containing the BATTERIES shall be provided.

If mechanical or forced-air ventilation is used, adequate ventilation shall continue to be provided under SINGLE FAULT CONDITIONS.

ENCLOSURES with mechanical or electromechanical dampers shall continue to provide adequate ventilation when the damper is in the closed position.

Clause M.7 is applied for open type BATTERIES and valve regulated type BATTERIES. Sealed type BATTERIES with a mechanism of reducing gas are considered to comply with this requirement.

If it can be shown that the ventilation capability of the ENCLOSURE is compliant with the calculated required ventilation air flow (Q) according to M.7.2, the equipment is in compliance with Clause M.7. Unless it can be demonstrated under a SINGLE FAULT CONDITION in the charging circuitry that the charge voltage cannot exceed the values for float charging in <u>Table M.1</u>, or if the BATTERY ENCLOSURE contains no internal charging capability, calculations shall be conducted for boost charge condition for the BATTERY types and maximum capacity specified and approved by the manufacturer. If the ventilation cannot be adequately shown, one of the ventilation tests in M.7.3 shall be conducted in order to ensure adequate ventilation.

The hydrogen generation (flow rate for testing) for the maximum supported BATTERY capacity and supported BATTERY types shall be calculated using data from the BATTERY manufacturer, or the values for I_{float} and I_{boost} with supporting data as given in <u>Table M.1</u> or by the following:

$$q_{\text{Batt}} = 0.45 \times 10^{-3} \frac{m^3}{Ah} \times I_{\text{gas}} \times C_{\text{rt}} \times n$$

with I_{qas} , C_{rt} , and *n* as described in M.7.2.

M.7.2 Test method and compliance criteria

The purpose of ventilating a BATTERY location or ENCLOSURE is to maintain the hydrogen concentration below the EXPLOSIVE 4 $%_{vol}$ hydrogen LEL threshold. The hydrogen gas concentration shall not exceed 1 % by volume if the mixture is in proximity to an ignition source, and not exceed 2 % by volume if the mixture is not in proximity to an ignition source.

NOTE 1 When a CELL reaches its fully charged state, water electrolysis occurs according to the Faraday's law.

Under standard conditions of normal temperature and pressure where T = 273 K, P = 1 013 hPa:

- 1 Ah decomposes H₂O into 0,42 I H₂ + 0,21 I O₂,
- decomposition of 1 cm³ (1 g) H_2O requires 3 Ah,
- -26,8 Ah decomposes H₂O into 1 g H₂ + 8 g O₂.

When the charging operation is stopped, the emission of gas from the CELLS can be regarded as having come to an end 1 h after having switched off the charging current.

The minimum air flow rate for ventilation of a BATTERY location or compartment shall be calculated by the following formula:

$$Q = v \times q \times s \times n \times I_{\text{gas}} \times C_{\text{rt}} \times 10^{-3} \qquad [m^3/h]$$

where:

- *Q* is the ventilation air flow in m3/h;
- v is the necessary dilution of hydrogen:

$$\frac{(100-4)\%}{4\%} = 24;$$

 $q = 0.45 \times 10^{-3}$ [m³/Ah] generated hydrogen at 20 °C;

s = 5, general safety factor;

n is the number of CELLS;

 I_{gas} is the current producing gas in mA / Ah rated capacity for the float charge current I_{float} or the boost charge current I_{boost} ;

 C_{rt} is the capacity C_{10} for lead acid CELLS (Ah) or capacity C_5 for NiCd CELLS (Ah)

NOTE 2 C_{10} is the 10 h rate with current I_{10} for lead acid CELLS: (Ah) to $U_{\text{final}} = 1,80 \text{ V/CELL}$ at 20 °C.

 C_5 is the 5 h rate with current I_5 for NiCd CELLS: (Ah) to $U_{\text{final}} = 1,00 \text{ V/CELL}$ at 20 °C.

with $v \times q \times s = 0.05$ [m³/Ah] the ventilation air flow calculation formula is:

$$Q = 0.05 \times n \times I_{\text{gas}} \times C_{\text{rt}} \times 10^{-3} \qquad [\text{m}^3/\text{h}]$$

The current I_{aas} in mA producing gas is determined by one of the following formulas:

$$I_{\text{gas}} = I_{\text{float}} \times f_{\text{g}} \times f_{\text{s}} \quad [\text{mA/Ah}] \quad or$$

 $I_{\text{gas}} = I_{\text{boost}} \times f_{\text{g}} \times f_{\text{s}} \quad [\text{mA/Ah}]$

where:

 I_{gas} is the current producing gas in mA / Ah rated capacity for the float charge current I_{float} or the boost charge current I_{boost} ;

I_{float} is the float charge current under fully charged condition at a defined float charge voltage at 20 °C;

Iboost is the boost charge current under fully charged condition at a defined boost charge voltage at 20 °C;

 f_{g} is the gas emission factor, proportion of current at fully charged state producing hydrogen (see <u>Table</u> <u>M.1</u>);

 f_s is the safety factor, to accommodate faulty CELLS in a BATTERY and an aged BATTERY (see <u>Table M.1</u>).

Parameter	Lead-acid batteries vented cells Sb < 3 % ^a	Lead-acid batteries VRLA cells	NiCd batteries vented cells ^b
gas emission factor $f_{\rm g}$	1	0,2	1
Gas emission safety factor $f_{\rm s}$ (incl. 10 % faulty CELLS and ageing)	5	5	5
Float charge voltage <i>U</i> _{float} ^c V/CELL	2,23	2,27	1,40
Typical float charge current I _{float} A/Ah	1	1	1
Current (float) <i>I</i> _{gas} mA/Ah (under float charge conditions relevant for air flow calculation)	5	1	5
Boost charge voltage U _{boost} ^c V/CELL	2,40	2,40	1,55
Typical boost charge current I _{boost} mA/Ah	4	8	10
Current (boost) <i>I</i> _{gas} mA/Ah (under boost charge conditions relevant for air flow calculation)	20	8	50
^a For an antimony (Sb) content higher than 3 %, the current used for calculations shall be doubled.			
^b For recombination type NiCd CELLS consult the manufacturer.			
^c Float and boost charge voltage can vary with the specific gravity of electrolyte in lead-acid CELLS.			
The values of float and boost charge current increase with temperature. The consequences of an increase in temperature, up to a maximum of 40 °C, have been accommodated in the values in <u>Table M.1</u> .			

Table M.1 Values for current I_{float} and I_{boost} , factors f_g and f_s , and voltages U_{float} and U_{boost}

In case of use of gas recombination vent plugs, the gas producing current l_{gas} the values for vented cells can be reduced to 50 % of the values for vented cells.

The ventilation air volume requirements, for example, for two 48 V strings of VRLA CELLS in the same BATTERY cabinet and each with 120 Ah rated C_{10} capacity amount, under float and under boost charge service conditions are:

- service with float charge condition only: $Q = 0.05 \times 24 \times 1 \times 120 \times 0.001 = 0.144 \text{ m}^3/\text{h}$ per string or 288 l/h total;

- service with boost charge condition: $Q = 0.05 \times 24 \times 8 \times 120 \times 0.001 = 1.15 \text{ m}^3/\text{h}$ per string or 2 300 l/h total.

For recombinant NiCd cells, or for lead-acid BATTERY types where the gassing rate in volts per cell per hour (per ampere-hour) is published by the manufacturer, it is permitted to determine the minimum air flow rate Q using the measure gas emissions at boost-charge volts per cell charging, unless it can be verified that the output voltage of the charging circuit cannot exceed the float voltage under any conditions required by this document. The equation for Q becomes:

350

$$Q = v \times s \times n \times r (\times C_{\rm rt}) \times 10^{-3} (m^3/h)$$

where:

v = 24, the necessary dilution of hydrogen:

s = 5, general safety factor;

n is the number of CELLS;

r is the outgassing rate at a given voltage per cell per hour (may be per ampere-hour rating);

 C_{t} is the capacity C_{10} for lead acid CELLS (Ah) or capacity C_{5} for NiCd CELLS (Ah).

NOTE C_{rt} is not required for determining Q if the gassing rate r is provided in ml/(h-CELL) or the equivalent.

For the purpose of calculating the area of ventilation openings required for natural ventilation, the air velocity is assumed to be 0,1 m/s.

Alternately, the following equation can be used:

$$A = 28 \times Q$$

where:

Q is the ventilation rate of fresh air (m^3/h) ;

A is the free area of openings in air inlet and outlet (cm^2) .

M.7.3 Ventilation tests

M.7.3.1 General

The test shall be performed with the EUT stabilized at 25 °C. If forced air ventilation is used, it shall be run under SINGLE FAULT CONDITIONS. Movable mechanical or electro-mechanical dampers shall be closed or in the unpowered position. The air movement around the cabinet shall be minimized, or the EUT shall be placed in a cabinet to prevent air movement around the EUT during testing.

M.7.3.2 Ventilation test – alternative 1

Samples of the atmosphere within the BATTERY compartment are to be taken after 7 h of operation. The samples are to be taken at locations where the greatest concentration of hydrogen gas is likely. The hydrogen gas concentration shall not exceed 1 % by volume if the mixture is in proximity to an ignition source, and not exceed 2 % by volume if the mixture is not in proximity to an ignition source. See <u>M.3.2</u> for evaluating the overcharging of a rechargeable battery.

M.7.3.3 Ventilation test – alternative 2

The performance of the EUT BATTERY ventilation system shall be verified by conducting a test utilizing hydrogen, or helium to represent hydrogen.

The test will determine if the EUT is capable of ventilating the calculated hydrogen generation rate.

Step 1 Helium or hydrogen sensors (depending on the chosen gas) shall be placed in all cabinet compartments that are subjected to hydrogen evolution from the BATTERY compartment.

Step 2 Helium or hydrogen shall be injected into the BATTERY compartment until a concentration of 1 % or 2 % as required below is reached. The rate of helium or hydrogen injection required to maintain the concentration under steady state conditions shall be reported. Steady state shall be defined as a maximum variation of \pm 0,25 % over a period of 1 h.

Step 3 Compare the rate of helium or hydrogen obtained in Step 2 with the calculated hydrogen generation rate in M.7.1.

If the calculated hydrogen generation rate for the maximum BATTERY capacity as specified by the manufacturer exceeds the amount of helium or hydrogen that was being injected by more than 1 % by volume if the mixture is in proximity to an ignition source, or exceeds 2 % by volume if the mixture is not in proximity to an ignition source, the EUT compartment ventilation system is not in compliance with this requirement.

If the calculated hydrogen generation rate, for the maximum BATTERY capacity as specified by the manufacturer, is less than or equal to the rate of helium or hydrogen that was being injected, the EUT compartment ventilation system is in compliance with this requirement.

M.7.3.4 Ventilation test – alternative 3

The test shall be performed as described in <u>M.7.3.1</u> with a hydrogen or helium source used to inject a flow rate described in <u>M.7.1</u>. Samples of the atmosphere within the BATTERY compartment or other area where hydrogen may accumulate is continuously monitored for 7 h or until the levels are stable. Steady state shall be defined as a maximum variation of $\pm 0,25$ % over a period of 1 h. The gas monitored in this manner is to be returned to the EUT under test. The hydrogen gas concentration shall not exceed 1 % by volume if the mixture is in proximity to an ignition source, and not exceed 2 % by volume if the mixture is not in proximity to an ignition source. The sampling method in the original test may also be used, however, if hydrogen is used, care should be taken to establish that safe levels exist in the EUT prior to injecting for 7 h.

NOTE This method is particularly suited to evaluating mixed or complex systems or ventilation patterns.

M.7.4 Marking requirement

Unless the BATTERIES are provided with the equipment, the compartment shall be marked either with the supported BATTERY types and the maximum capacities or "Use only batteries approved by the manufacturer", provided that this information is specified in the installation/service instructions.

M.8 Protection against internal ignition from external spark sources of batteries with aqueous electrolyte

M.8.1 General

The requirements specified below apply to rechargeable BATTERIES providing a venting system.

NOTE For example, a BATTERY used in a UPS.

The level of air ventilation rate shall ensure that a risk of EXPLOSION does not exist by keeping the hydrogen content in air below 1 $%_{vol}$ at the PIS.

The use of an effective flame arrester in the BATTERY venting system will prevent an external EXPLOSION propagating into the BATTERY.

Clause M.8 is applied for open type BATTERIES and valve regulated type BATTERIES. Sealed type batteries with a mechanism of reducing gas are considered to comply with this requirement.

M.8.2 Test method

M.8.2.1 General

The test shall be carried out according to IEC 60896-21:2004, 6.4.

NOTE 1 This test is designed to reveal the protection afforded by the valve unit against the ignition of the gases within a CELL by an external ignition source. During this test, use proper precautions to SAFEGUARD persons and equipment from EXPLOSION and burns.

A minimum distance d extending through air shall be maintained within which a maximum surface temperature of 300 °C shall not be exceeded (no flames, sparks, arcs or glowing devices).

NOTE 2 When calculating the minimum distance *d* to protect against EXPLOSION in close proximity to the source of release of a CELL or BATTERY, the dilution of EXPLOSIVE gases is not always ensured. The dispersion of EXPLOSIVE gas depends on the gas release rate and the ventilation characteristics close to the source of release.

The minimum distance d can be estimated by calculating the dimensions of a hypothetical volume V_z of potentially EXPLOSIVE gas around the source of release, outside of which the concentration of hydrogen is below the safe concentration of the LEL.

$$d = 28.8 \times \sqrt[3]{I_{\text{gas}}} \times \sqrt[3]{C_{\text{rt}}} \qquad [\text{mm}]$$

where:

*I*_{gas} is the current producing gas [mA / Ah];

C_{rt} is the rated capacity [Ah].

NOTE 3 The required distance d can be achieved by the use of a partition wall between the BATTERY and sparking device.

Where BATTERIES form an integral part of a power supply system (for example, in a UPS system), the distance d, where d is the minimum distance (CLEARANCE) between the ventile of the BATTERY and the electronic equipment that may exhibit flames, sparks, arcs or glowing devices (maximum surface temperature 300 °C), may be reduced according to the equipment manufacturer's calculations or measurements. The level of air ventilation rate should ensure that a risk of EXPLOSION does not exist by keeping the hydrogen content in air below 1 $%_{vol}$ plus a margin at the PIS.

M.8.2.2 Estimation of hypothetical volume V_z

The theoretical minimum ventilation flow rate to dilute the flammable gas (hydrogen) to a concentration below the LEL can be calculated by means of the formula:

$$\left(\frac{dV}{dt}\right)_{\min} = \frac{\left(dG / dt\right)_{\max}}{k \times \text{LEL}} \times \frac{T}{293}$$

where:

 dV/dt_{min} is the minimum volumetric flow rate of fresh air required to dilute the gas (m³/s);

 dG/dt_{max} is the maximum gas release rate (kg/s);

LEL is 4 $\%_{vol}$ for hydrogen (kg/m³);

k is the factor applied to the LEL; k = 0.25 is chosen for dilution of hydrogen gas;

T is the ambient temperature in kelvin (293 K = 20 $^{\circ}$ C).

The volume V_z represents the volume over which the mean concentration of flammable gas will be 0,25 times the LEL. This means that at the extremities of the hypothetical volume, the concentration of gas will be significantly below the LEL (for example, the hypothetical volume where the concentration is above LEL would be less than V_z).

NOTE See B.4.2.2 in IEC 60079-10:2002 for the calculation of LEL.

M.8.2.3 Correction factors

With a given number of air changes per unit time, c, related to the general ventilation the hypothetical volume V_z of potentially EXPLOSIVE atmosphere around the source of release can be estimated as follows:

$$V_{\rm z} = \left(\frac{dV}{dt}\right)_{\rm min} / c$$

where c is the number of fresh air changes per unit time (s^{-1}) .

The above formula holds for an instantaneous and homogenous mixing at the source of release given ideal flow conditions of fresh air. In practice, ideal conditions rarely exist. Therefore a correction factor f is introduced to denote the effectiveness of the ventilation.

$$V_z = f \times \left(\frac{dV}{dt}\right)_{\min} / c$$

where f is the ventilation effectiveness factor, denoting the efficiency of the ventilation in terms of its effectiveness in diluting the EXPLOSIVE atmosphere, f ranging from 1 (ideal) to typically 5 (impeded air flow). For BATTERY installations the ventilation effectiveness factor is f = 1,25.

M.8.2.4 Calculation of distance d

The term $(dV/dt)_{min}$ including all factors corresponds with the hourly ventilation air flow Q (in m³/h) for secondary BATTERIES calculated under

$$Q = f \times \left(\frac{dV}{dt}\right)$$

$$Q = 0.05 \times (N) \times I_{\text{gas}} \times C_{\text{rt}} \times 10^{-3}$$
 [m³/h]

This hourly ventilation air flow *Q* can be used to define a hypothetical volume. Assuming a hemispherical dispersal of gas, a volume of a hemisphere $V_z = 2/3 \pi a^3$ can be defined, where *d* is the distance from the source of release.

This results in the calculation formula for the distance d, with c = 1 air change per hour within the hemisphere: