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Draft Indian Standard

METAL AIR FLOW BATTERY

Primary Cells and Batteries Sectional Committee ETD 10

Last Date of Comments: 24 August 2024

NATIONAL FOREWORD

(Formal clauses will be added later)

The evolving landscape of energy storage and automotive technology necessitates robust standards that ensure safety, reliability, and efficiency. This standard on Metal Air Flow Batteries (MAFB) represents a significant step forward in the development and deployment of cutting-edge energy storage solutions. MAFBs, with their innovative design and performance characteristics, hold immense potential for a wide array of applications, including electrical energy storage (EES) systems and automotive power sources.

This document provides a comprehensive framework for understanding and utilizing MAFBs. It encompasses key terminology and general aspects critical to this technology, facilitating clear communication and consistency within the industry. The standard elaborates on the essential terms required for defining unit parameters, thus enabling precise measurement and comparison of performance metrics.

In addition to terminology, this standard delineates rigorous test procedures and performance criteria. These guidelines are crucial for evaluating the functionality and durability of MAFBs under various conditions, ensuring that they meet the high standards expected in practical applications. Environmental considerations are also addressed, highlighting the need for sustainable practices in the production, use, and disposal of these batteries.

Draft Indian Standard

METAL AIR FLOW BATTERY

1 SCOPE

This standard relates to metal air flow battery (MAFB) that can be used in electrical energy storage (EES) applications, automobiles and provides the main terminology and general aspects of this technology, including terms necessary for the definition of unit parameters, test procedures, criteria for performance, environmental issues and ensure safety of Metal air flow batteries (MAFB) under intended use and reasonably foreseeable misuse. It also includes the description of MAFB.

2 REFERENCES

Different tests, definitions and terminologies have been referred from following standards:

IS / IEC No.	TITLE
IEC 62932 (Part 1)	Flow battery energy systems for stationary applications - Part 1: Terminology and general aspects
IEC 62932 (Part 2 Sec 1)	Flow battery energy systems for stationary applications - Part 2-1: Performance general requirements and test methods
IEC 62932 (Part 2 Sec 2)	Flow battery energy systems for stationary applications - Part 2-2: Safety requirements
IS 6303	Primary batteries - General
IS 15063	Alkaline manganese dioxide cells - Specification
IS 6303 (Part 5) : 2023	Primary Batteries Part 5 Safety of Batteries with Aqueous Electrolyte
IS 737 : 2008	Wrought aluminium and aluminium alloy sheet and strip for general engineering purposes - Specification
IS 18590 : 2024	Electric Power Train of L Category Vehicles Specific Requirements
AIS 048	

3 TERMS AND DEFINITIONS

For the purposes of this standard, the terms and definitions given in IS 1885 (Part 15) as well as the following shall apply:

3.1 Activation — Transition of MAFB from either OFF state or cold standby to ON state.

3.2 Activation Time — The duration between the transition of MAFB from either OFF state or cold standby to ON state.

3.3 Air — Air is referring to the mixture of gases comprising of oxygen which is one of the reactants in the metal air flow battery's electrochemical reactions.

3.4 Air Filter — A component designed to remove particulate matter and contaminants from the air before it enters the metal air flow stack enclosure

3.5 Air Piping — A network of tubes or hoses used to circulate air back and forth between atmosphere to metal air flow stack enclosure. It may include various pipes, connectors, and other components that ensure the proper delivery of air to the enclosure

3.6 Air Pump — A device used to circulate air back and forth between atmosphere to metal air flow stack enclosure.

3.7 Ambient Temperature — Environmental temperature around a metal air flow battery

3.8 Auxiliary Energy — Energy consumed by all the auxiliary equipment and components of the metal air battery support unit.

3.9 Average Discharge Duration — Average time on discharge which shall be met by a sample of batteries

3.10 Cold Standby — State of MAFB in which no electrical power/energy is supplied from the POMC (Point of Main connection) to the external load and the MABSU is partially active to perform required functions

3.11 Control Unit — Electronic unit associated with a metal air flow battery which monitors and/or manages its state, calculates secondary data, reports that data and/or controls its environment to influence the metal air flow battery's performance, state of energy and/or service life

3.12 Discharge — Operation during which a metal air flow cell/ stack when connected to an external electrical circuit results in electrochemical changes within the cell and releases electrical energy in that external electrical circuit

3.13 End of Discharge — End of discharge limit conditions specified by the manufacturer at which a discharge is terminated

3.14 Enclosure — The part enclosing the internal units and providing protection against direct contact from any direction of access

3.15 Effective Electrical Output Power — Electrical power output at the POMC (Point of Main connection) less by the electrical power input at the POAC (Point of Auxiliary Connection) of the MAFB

3.16 Efficiency — Effective Electrical Output Power per unit of electrical power output at the POMC of the MAFB

3.17 Electrode — The conducting body that contains active materials and through which current enters or leaves a metal air flow cell

3.18 Energy Storage Fluid — Fluid that contains active materials and flows through the metal air flow cell/stack, consisting of liquid, suspension or gas

3.19 Energy Storage Fluid Piping — A network of tubes or hoses used to circulate energy storage fluid back and forth between fluid tank and metal air flow stack enclosure. It may include various pipes, connectors, and other components that ensure the proper and safe delivery of fluid to the enclosure

3.20 Energy Storage Fluid Pump — A device used to circulate energy storage fluid back and forth between energy storage fluid tank and metal air flow stack enclosure

3.21 Energy Storage Fluid Tank — Storage chamber for energy storage fluid. Its design should be at least IP65-compliant

3.22 End Point Power — Specified value of the output power of the MAFB at which standard discharge is terminated

3.23 Energy Capacity (Wh) — The total amount of electrical energy that can be stored in a metal air flow cell

3.24 Energy Capacity Density — The total amount of electrical energy that can be stored in the MAFB per unit weight of metal anode

3.25 Fluid Leakage — Unplanned escape of fluids from a metal air flow cell, stack or MAFB

3.26 Fluid System — Components and equipment destined to store and circulate energy storage fluids, such as tanks, pipes, manual valves, electrical valves, pumps and sensors

3.27 Forced Ventilation — Movement of air and its replacement with fresh air by mechanical means

3.28 Fully Discharged — Condition (status) where, after a discharge process as specified by the manufacturer, the metal air flow battery reaches the end of discharge point

3.29 Gas Release — Emission of gas from the metal air flow battery to the environment

3.30 Heat Exchanger — A device designed to exchange heat between the metal air flow battery and its surroundings, helping to maintain an optimal temperature range for efficient operation and safety.

3.31 Hot Standby — State of MAFB in which no electrical power/energy is supplied from the POMC to the external load and the MABSU is fully active to perform required functions.

3.32 Input Auxiliary Power — Electrical power supplied to all the auxiliary equipment and components of the MABSU

3.33 Interlock — Circuit linking mechanical, electrical or other devices intended to make the operation of a piece of apparatus dependent on the condition or position of one or more others.

3.34 Maximum Ambient Temperature — Highest ambient temperature at which the MAFB is operable and should perform according to specified requirements

3.35 Maximum Input Auxiliary Power — Highest level of power in watt that can be supplied to the MABSU and at which it is operable and performs according to specified conditions

3.36 Maximum Output Power – Highest level of power in watt that can be supplied by the MAFB and at which it is operable and performs according to specified conditions

3.37 Metal — The metal used as anode (negative electrode) can be made up of but not limited to metals like Aluminium, Iron, Lithium, Zinc and their alloys. In case of Aluminium, it should satisfy manufacturer declared specifications or compliant with IS 737: 2008 if manufacturer specifications are not available.

3.38 Metal Air Battery Support Unit (MABSU) — Auxiliary units, such as heat exchanger, ventilation system, safety system, and control unit used in an MAFB, and which are not stacks and not power conversion system

3.39 Metal Air Flow Cell — A cell characterized by the spatial separation of the electrodes and the movement of the energy storage fluids

3.40 Metal Air Flow Battery (MAFB) — Two or more metal air flow cells electrically connected including all components for use in electrochemical energy unit such as metal air battery support unit and stack

3.41 Minimum Ambient Temperature — Lowest ambient temperature at which the MAFB is operable and should perform according to specified requirements.

3.42 Natural Ventilation — Movement of air and its replacement with fresh air because of wind and/or temperature gradients

3.43 Non-Operating State — State of the MAFB when it is not performing any required function

3.44 Off-State — State of the MAFB when it is not delivering electrical energy/power at POMC

3.45 On-State — State of MAFB when it is actively delivering electrical energy/power at POMC

3.46 Operating State — State in which the MABF performs the required functions and includes the ON-state, hot standby and cold standby states.

3.47 Operational Condition — Activity or status where all the different elements of a complex activity such as electrochemical changes and MABSU are brought into a harmonious and efficient relationship.

3.48 Output Power — Electrical power supplied by the metal air flow battery during discharge.

3.49 Point of Auxiliary Connection (POAC) — Reference point where the MABSU is connected to an external power source.

3.50 Point of Auxiliary Measurement (POAM) — Physical location in the MABSU where the energy absorbed from the external power source is to be measured/recorded

3.51 Point of Main Connection (POMC) — Reference point where the MAFB is connected to the final application point.

3.52 Point of Main Measurement (POMM) — Physical location in the (MAFB) circuit where the energy delivered from the stack is to be reproducibly measured/recorded

3.53 Rated Energy — Manufacturer declared value of the energy content of the MAFB when discharged under specified (rated) conditions and measured at the POMM.

3.54 Rated Input Auxiliary Power — Manufacturer declared value of input auxiliary power for a specific set of operating conditions of the MAFB and measured at the POAM.

3.55 Rated Maximum Output Power — Manufacturer declared highest output power level that the MAFB can deliver.

3.56 Rated Output Power — Manufacturer declared value of output power for a specific set of operating conditions of the MAFB

3.57 Sensor — Device which detects/ measures a physical property and records, indicates or responds to it

3.58 Service Life — Duration from the time of MAFB commissioning test to the end of service life

3.59 Shutdown — Regulated or instantaneous shutdown of a MAFB triggered by the shutdown of the end application system, internal or external protection systems, or manual intervention.

3.60 Stack — Group of metal air flow cells, assembled in a contiguous form and usually connected electrically in series

3.61 Standard Discharge — A constant voltage discharge of a metal air flow cell/stack at standard discharge voltage as declared by the manufacturer.

3.62 Standard Discharge Voltage — The voltage declared by the manufacturer at which standard discharge of a metal air flow cell/stack is to be carried out.

3.63 Standby State — State of MAFB in which no electrical power is supplied from the POMC to the external load and the MABSU is partially or fully active to perform required functions

3.64 State of Energy — The remaining energy as a percentage of the maximum available energy under operating conditions as declared by the manufacturer

4 ABBREVIATED TERMS

MABSU	Metal air battery support Unit
MAFB	Metal air flow battery
POAC	Point of auxiliary connection
POAM	Point of auxiliary measurement
POMC	Point of main connection
POMM	Point of main measurement

5 NOMENCLATURE

Refer Annexure C (*Clause* 4.1.5) of IS 6303 : 2018

6 DESCRIPTIVE OVERVIEW OF THE METAL AIR FLOW BATTERY

An overview of a metal air flow battery (MAFB) with its components is given in this section. A MAFB may include all or some of these components to ensure safe operation.

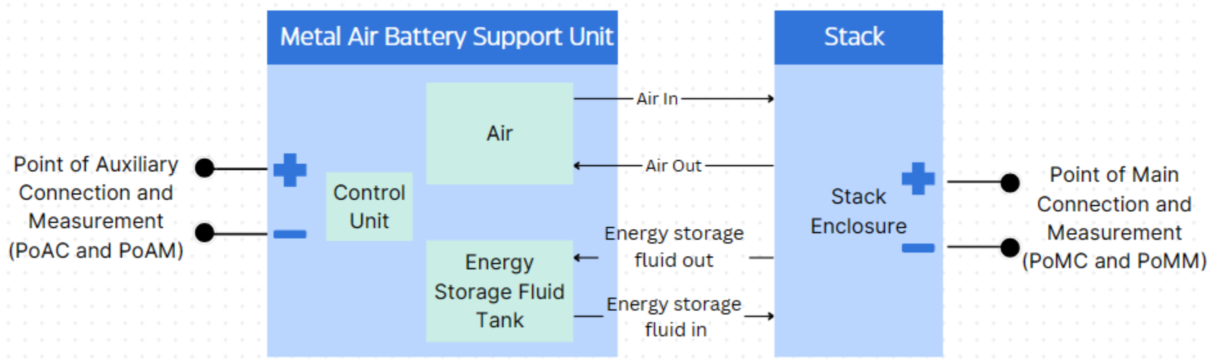

FIG 1 METAL AIR FLOW BATTERY (MAFB)
(Clause 6.1)

6.1 Indicative Diagram of a metal air flow battery (MAFB)

An indicative diagram depicting a metal air flow battery (MAFB) and its elements are shown in fig.1.

6.2 Component list of metal air flow battery (MAFB)

The components which might be included in the elemental blocks are as follows:

1) Stack
   i) Electrodes
   ii) Enclosure

2) Metal air Battery support Unit (MABSU)
   i) Pump
   ii) Tank
   iii) Piping
   iv) Air and air filter
   v) Sensors
   vi) Energy storage fluids
   vii) Heat exchanger
   viii) Control Unit

7 GENERAL TEST CONDITIONS

7.1 Accuracy of Measuring Instruments

7.1.1 *Voltage Measurement* — The instruments used shall be of an accuracy class equal to 0.5% or better. The internal resistance of the voltmeter used shall be at least 1 kohm/V.

7.1.2 *Current Measurement* — The instruments used shall be of an accuracy class equal to 0.5% or better.

7.1.3 *Power Measurement* — The instruments used shall be of an accuracy class equal to 0.5% or better.

7.1.4 *Electric Energy Measurement* — The instruments used shall be of an accuracy class equal to 1% or better.

7.1.5 *Temperature Measurement* — The instruments used shall have a resolution of 0.5 K and the accuracy of the instruments shall be ±0.5K or better.

7.1.6 *Mass Measurement* — The instruments used shall have a resolution of 1 gram and accuracy of the instruments shall be ±1 gram or better.

7.1.7 *Time Measurement* — The instruments used shall have a resolution of 1s and the accuracy of the instruments shall be 1% of the measured time interval or better.

7.2 Ambient Temperature — All tests of a MAFB shall be carried out at an ambient temperature of 27 °C ± 2 K unless otherwise specified in a test clause or agreed by the manufacturer and user. The ambient temperature shall be measured and reported.

7.3 Ambient Humidity — All tests of a MAFB shall be carried out at relative humidity of 60 ± 5 percent RH unless otherwise specified in a test clause or agreed by the manufacturer and user. The ambient humidity shall be measured and reported.

8 GENERAL TEST PROCEDURES FOR PERFORMANCE

8.1 Determination of Maximum Deliverable Output Power

8.1.1 *General* — The maximum deliverable output power is affected by the discharge voltage, temperature, and the auxiliary power needs for the MAFB operation. Any maximum deliverable output power value determined is hence representative or applicable only to the specific operation condition of the MAFB.

The manufacturer's recommended procedures should be followed during metal air flow cell or battery preparation.

8.1.2 *Test Procedures* — The test for determining the maximum deliverable output power shall be in accordance with the following procedures:

a) A Constant Voltage (CV) discharge shall be carried out at the POMC of the MAFB.
b) The conditions of all the components of the MABSU should be noted and as declared by the manufacturer in the ON state. The MABSU shall be supplied by a separate power source. The rating of the power source shall be greater than the maximum receivable input auxiliary power as declared by the manufacturer.
c) The voltage level selected for CV discharge is the voltage of a metal air flow cell multiplied by number of cells in series in the MAFB.
d) The test unit shall be discharged at constant voltage steps with each step of 5 minutes starting from Open circuit voltage to 0.2V multiplied by number of cells in series of the MAFB. The step size/interval shall be equal to 0.1V multiplied by number of cells in series of the MAFB.
e) The total time duration of the discharge shall be recorded. The voltage level at each step shall be kept constant to within ±0.5 % of the set value.

The ambient temperature of the MAFB shall be maintained at a constant temperature of 27 °C ± 2 K. The points within the MAFB indicative of the MAFB temperature shall be declared by the manufacturer and temperature at these points shall be recorded during the test.

The maximum deliverable output power value and voltage at the POMM and the corresponding auxiliary power supplied shall be recorded. The maximum deliverable output power value shall be accompanied with the corresponding voltage at the POMM and temperature of the MAFB.

8.2 Determination of Maximum Input Auxiliary Power

8.2.1 *General* — The maximum input auxiliary power is affected by the operating state, temperature, voltage and delivered output power of the MAFB. Any maximum input auxiliary power value determined is hence representative or applicable only to the specific operation condition of the MAFB. The manufacturer's recommended procedures should be followed during metal air flow cell or battery preparation.

8.2.2 *Test Procedure* — The test for determining the maximum input auxiliary power shall be in accordance with the following procedures:

a) A Constant Voltage (CV) discharge shall be carried out at the POMC of the MAFB.
b) The conditions of all the components of the MABSU should be noted and as declared by the manufacturer in the ON state. The MABSU shall be supplied by a separate power source. The rating of the power source shall be greater than the maximum input auxiliary power as declared by the manufacturer.
c) The voltage level selected for CV discharge is the voltage at which the maximum deliverable output power is recorded.
d) The test unit shall be discharged at constant voltage for 5 minutes during which the voltage shall be kept constant to within ±0.5 % of the set value.

The ambient temperature of the MAFB shall be maintained at a constant temperature of 27 °C ± 2 K. The points within the MAFB indicative of the MAFB temperature shall be declared by the manufacturer and temperature at these points shall be recorded.

The maximum input auxiliary power value at the POAM, delivered output power, current and voltage at the POMM and the corresponding auxiliary power supplied shall be recorded. The maximum input power value shall be accompanied with the corresponding voltage, delivered output power at the POMM and temperature of the MAFB.

8.3 Determination of Energy Capacity Density

8.3.1 *Determination of Energy Capacity Density During Standard Discharge*

8.3.1.1 *General* — This test is for determining the energy capacity density of the MAFB by measuring the total discharge energy output from the MAFB during standard discharge per unit weight metal anode. The manufacturer's recommended procedures should be followed during metal air flow cell or battery preparation.

8.3.1.2 *Test procedures* — The test for determining the energy capacity shall be in accordance with the following procedures:

a) The total weight of the metal anode in each metal air flow cell/stack of the MAFB shall be measured before test.
b) A Constant Voltage (CV) discharge shall be carried out at the POMC of the MAFB at standard discharge voltage as declared by the manufacturer.
c) The conditions of all the components of the MABSU should be noted and as declared by the manufacturer in the ON state. The MABSU shall be supplied by a separate power source. The rating of the power source shall be greater than the maximum input auxiliary power as declared by the manufacturer.
d) The standard discharge voltage at the POMC shall be kept constant to within ±0.5 % of the set value throughout the duration of the test.
e) The delivered output power, current and voltage at the POMM shall be recorded in intervals of 1 second.
f) The test shall be carried out till the delivered output power falls to the end point power as declared by the manufacturer.
g) The energy capacity is the time summation/integration of the output power till end of point power. The energy capacity density is obtained by dividing the energy capacity with the total metal anode weight in kg.

The energy capacity shall be accompanied with the corresponding standard discharge voltage and maximum output power at POMM, end point power and temperature of the MAFB.

The ambient temperature of the MAFB shall be maintained at a constant temperature of 27 °C ± 2 K. The points within the MAFB indicative of the MAFB temperature shall be declared by the manufacturer and the temperature at these points shall be recorded during the test.

8.3.2 *Determination of Energy Capacity Density During Peak Power Discharge*

8.3.2.1 *General* — This test is for determining the energy capacity density of the MAFB by measuring the total discharge energy output from the MAFB during peak power discharge per unit weight metal anode.

The manufacturer's recommended procedures should be followed during metal air flow cell or battery preparation.

8.3.2.2 *Test procedures* — The test for determining the energy capacity shall be in accordance with the following procedures:

a) The total weight of the metal anode in each metal air flow cell/stack of the MAFB shall be measured before test.
b) A Constant Voltage (CV) discharge shall be carried out at the POMC of the MAFB at the maximum deliverable output power voltage point obtained in 8.1.
c) The conditions of all the components of the MABSU should be noted and as declared by the manufacturer in the ON state. The MABSU shall be supplied by a separate power source. The rating of the power source shall be greater than the maximum input auxiliary power as declared by the manufacturer.
d) The standard discharge voltage at the POMC shall be kept constant to within ±0.5 % of the set value throughout the duration of the test.
e) The delivered output power, current and voltage at the POMM shall be recorded in intervals of 1 second.

f) The test shall be carried out till the delivered output power falls to the end point power as declared by the manufacturer.
g) The energy capacity is the time summation/integration of the output power till end of point power. The energy capacity density is obtained by dividing the energy capacity with the total metal anode weight in kg.

This energy capacity shall be accompanied with the corresponding discharge voltage and maximum output power at POMM, end point power and temperature of the MAFB.

The ambient temperature of the MAFB shall be maintained at a constant temperature of 27 °C $\pm$ 2 K. The points within the MAFB indicative of the MAFB temperature shall be declared by the manufacturer and the temperature at these points shall be recorded during the test.

8.4 Determination of Efficiency

8.4.1 *General* — The efficiency of the MAFB is affected by the delivered output power and the input auxiliary power consumption during the discharge of the MAFB. Any energy efficiency determination is hence representative or applicable only to the MAFB at the specified power levels.

The temperature and conditions of the MABSU shall be recorded and reported.

The manufacturer's recommended procedures should be followed during metal air flow cell or battery preparation.

8.4.2 *Calculation*

a) Effective maximum output power = (maximum deliverable output power - maximum input auxiliary power)
b) E_{PMAX} = (Effective maximum output power)/ (maximum deliverable output power)

Where E_{PMAX} is the maximum efficiency obtained at maximum deliverable output power at a constant MAFB ambient temperature of 27 °C $\pm$ 2 K.

9 OTHER GENERAL ASPECTS

9.1 Identification Labels and Markings

9.1.1 *Name Plate Information* — The name plate/label(s) shall include the following information:

a) manufacturer's name,
b) serial number (optional),
c) date of commissioning (optional),
d) maximum DC voltage(V), current(A) and power(kW) in operation,
e) rated energy capacity density (kWh/kg),
f) transport weight (kg) (optional),
g) chemical type of battery (active materials shall be indicated),

9.1.2 *Warning Label Information and Location* — The warning labels shall be placed at such a position that they are visible from any direction of approach to the MAFB where hazards can be present. The safety symbols and possibly associate information shall be explained and/or included in the MAFB instruction manual.

9.2 Electrical Specifications

The electrical specifications of the MAFB may be as per the Table 1 or defined by the manufacturer.

TABLE 1 ELECTRICAL SPECIFICATIONS
(Clause 9.2)

Sl No.	Electrical Specifications	Values
(1)	**(2)**	**(3)**
i)	Open Circuit Voltage	1.50 V -2.30V
ii)	End point Power	$0.01*P_{0max}$
iii)	Nominal Voltage	1.20 V
iv)	Energy Capacity Density	Greater than 1500 Wh/kg of metal anode at standard discharge Voltage
v)	Activation time	< 1min
vi)	Standard discharge Voltage	1.20 V
vii)	Average Discharge Duration	Greater than 0.6*t hours at standard discharge voltage

*Above values are for Aluminum air flow battery

Where't' is thickness of metal anode in mm for prismatic metal air flow cell, P_{0max} is maximum deliverable output power

10 SAFETY TESTS

The tests to be performed that ensure evaluation of safety of a MAFB are described in this section.

10.1 Transport

Depending on the conditions of transportation, a MAFB might encounter different kinds of stimulus which might affect safety, Table 2 enlists these simulated conditions and tests to be performed for evaluation.

TABLE 2 TRANSPORT

(Clause 10.1)

Sl No.	Test	Intended Use Simulation	Requirements	Procedure Reference
(1)	**(2)**	**(3)**	**(4)**	**(5)**
i)	Electrical test	Storage after partial use	No leakage, No fire, No explosion	IS 6303 (Part 5) : 2023,Clause 6.3.2.1
ii)	Environmental/ Mechanical tests	Transportation - Shock	No leakage, No fire, No explosion	IS 18590 : 2024,Clause 9.4.2
		Transportation - Vibration	No leakage, No fire, No explosion	IS 18590 : 2024,Clause 9.4.2

iii)	Climatic-temperature	Climatic-temperature cycling	No leakage, Nofire, No explosion	IS 6303 (Part 5) : 2023,Clause 6.3.2.4

10.2 Misuse

A MAFB might encounter abuse because of intended or untended misuse which might affect its safety. Table 3 enlists these simulated conditions and tests to be performed for evaluation.

TABLE 3 MISUSE

(Clause 10.2)

Sl No.	Test	Intended Use Simulation	Requirements	Procedure Reference
(1)	(2)	(3)	(4)	(5)
i)	Electrical test	Incorrect Installation	No fire, No explosion	IS 6303 (Part 5) : 2023, Clause 6.4.2.1
		External short circuit	No fire, No explosion	IS 6303 (Part 5) : 2023, Clause 6.4.2.2
		Over discharge	No fire, No explosion	IS 6303 (Part 5) : 2023, Clause 6.4.2.3
ii)	Environmental /Mechanical test	Free fall	No fire, No explosion	IS 6303 (Part 5) : 2023, Clause 6.4.2.4
		Penetration test	No fire, No explosion	AIS 048, Clause 2.2.4
		Crust test	No fire, No explosion	As per 10.2.1
iii)	Human mistake	Reversal of energy storage fluid flow direction	No fire, No explosion	As per 10.2.2

10.2.1 *Crush Test* — The test is performed to characterize cell responses to external load forces that may cause deformation. The test shall be performed as follows:

a) Perform the test at 100% State of Energy of cell or with metal anode inside the cell required for 100% State of Energy whichever is applicable and as defined by the manufacturer.
b) The cell shall be placed on an insulated flat surface and be crushed with a crushing tool of round or semiconductor bar, or sphere or hemisphere with a 150mm diameter. It is recommended to use the round bar to crush a cylindrical cell, and the sphere for a prismatic cell. The force for the crushing shall be applied in direction nearly perpendicular to a layered face of positive and negative electrodes inside cell. The crushing tool shall be selected so that the cell is deformed nearly in proportion to the increase of crushing force.
c) The force shall be released when a deformation of 15% or more of initial cell dimension occurs, or the force of 20 times the weight of cell applied. The cells remain on test for 24 h.
d) Examples of crush test are shown in fig.2.

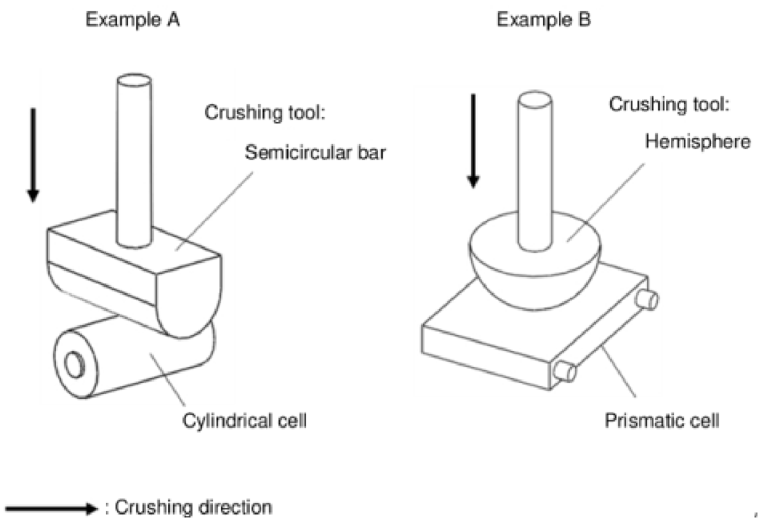

FIGURE 2 EXAMPLE OF CRUSH TEST
(Clause 10.2.1)

10.2.2 *Reversal of Energy Storage Fluid Flow Direction* — The electrical energy stored in an MAFB can be released in an undesired manner due to reversal of the flow of the energy storage fluid. Because of its considerable level of energy and subsequent high current, the heat generated can melt metal, produce sparks, cause explosion, or vaporize fluid. Alternately the MAFB might not perform as per the rated manufacturer specification.

To avoid such human mistake during installation or operation, markings can be provided.

To simulate such human mistake, a test must be performed to characterize MAFB responses to reversal of energy storage fluid direction. The test shall be performed as follows.

a) The ambient temperature of the MAFB shall be maintained at a constant temperature of 27 °C + 2 K.
b) State of Energy should be 100% and the MAFB must be in ON-state.
c) The flow of energy storage fluid flowing in and out of the stack in the MAFB should be reversed in direction to that specified by the manufacturer in normal use.
d) A Constant Voltage (CV) discharge shall be carried out at the POMC of the MAFB at standard discharge voltage as declared by the manufacturer.
e) The MABSU shall be supplied by a separate power source. The rating of the power source shall be greater than the maximum input auxiliary power as declared by the manufacturer.
f) The delivered output power, current and voltage at the POMM shall be recorded in intervals of 1 second.
g) The test shall be carried out for a minimum of 2 minutes or until the output power falls to the end point power as declared by the manufacturer, whichever is earlier.

11 TRANSPORT, STORAGE, DISPOSAL AND ENVIRONMENTAL ASPECTS

11.1 Packing and Transport — For protection against hazards, appropriate measures shall be taken, such as emptying the fluids from the stack or discharging before transportation, proper insulation of terminals and other protective measures as specified by the manufacturer to avoid any hazardous chemical changes during packing and transportation.

11.2 Dismantling, Disposal, and Recycling — For dismantling, disposal and recycling follow manufacturer guidelines.

12 SAFETY REQUIREMENTS AND PROTECTIVE MEASURES

12.1 General — The metal air flow battery differs from other batteries, in that a system for circulating the energy storage fluid is present. The fluid circulating system consists of tanks, pumps, piping, sensors and some safety-relevant devices.

From a chemical safety point of view, since fluid is contained in tanks, pipes and stacks, the sealing is an important factor. If there is also a possibility of any gaseous emissions as declared by the manufacturer, appropriate countermeasures shall be implemented.

12.2 Short-Circuits — The electrical energy stored in an MAFB can be released in an uncontrolled manner due to short-circuiting the terminals. Because of its considerable level of energy and subsequent high current, the heat generated can melt metal, produce sparks, cause explosion, or vaporize fluid.

To avoid short-circuits protective devices such as insulation shrouds, fuses and circuit breakers shall be installed in a way that a short-circuit does not occur under any foreseeable conditions.

a) For protective measures, the MAFB may mitigate a short-circuit fault which occurs outside stacks by stopping the supply of energy and fluids to the metal–air flow battery cells;
b) Stopping power conversion system and opening circuit breaker(s); and,
c) Interrupting the short-circuit current path by using fuses between stacks.

It is suggested that each stack has a fuse to break the short-circuit path. Specific location and quantity of fuses and/or circuit breakers shall be decided between the manufacturer and the system user in consideration of cell protection and system safety.

12.3 Hazards of Gaseous Emissions

12.3.1 *General* — Metal-air Flow batteries can produce gases in small quantities that can be flammable and/or corrosive in nature. The quantities produced depend on the operating conditions of the MAFB and their release to the environment shall be managed with adequate safety features (e.g. ventilation, absorption traps, and scrubbers).

The gas emission and its mitigation shall be considered in the metal air flow battery design process. It is suggested to install necessary gas monitoring equipment with alarms and appropriate interlocks.

12.3.2 *Types of Gases*

12.3.2.1 *Flammable gases* — The risk level of flammable gases increases if the following hazards coincide:

a) Accumulation of combustible gases,
b) Their mixture with oxygen,
c) Presence of ignition sources.

The MAFB shall have protective measures against the above hazards, including but not limited to:

a) Reduction in the generation and dilution of combustible gases,
b) Prevention of diffusion of gases outside the volume where they are generated
c) Elimination of ignition sources

12.3.2.2 *Corrosive gases* — The risk level of corrosive gases increases if the following hazards coincide:

a) Generation and accumulation of corrosive gases,
b) Human access to the vicinity of corrosive gases.

The MAFB shall have protective measures against the above hazards, including but not limited to:

a) Construction of the system with corrosion-resistant material
b) Elimination and dilution of corrosive gases,
c) Collection of toxic gases by a scrubber
d) Limitation of human access.

12.3.3 *Ventilation*

12.3.3.1 *General* — The manufacturer shall specify the ventilation requirements for the compartment where the MAFB is installed. This specification shall involve the warning signs, operator access limitation, mitigation of static discharges, numbers of air exchanges in m^3/h required air flow patterns and exhaust direction. The safety requirements and procedures for personnel and user handling shall be specified. The manufacturer shall provide data and a measurement method used to determine the gas emission rating, and ventilation measures shall be implemented.

Ventilation is required to ensure the necessary thermal management and that no combustible or harmful gases reach a critical concentration level. The ventilation requirement shall be met by either one or a combination of the following methods:

a) Natural ventilation
b) Forced ventilation through the room or enclosure.

12.3.3.2 *Natural ventilation* — When natural ventilation is used, battery rooms or enclosures shall be equipped with an inlet and an outlet for the air with a minimum free opening area which meets the ventilation requirements.

12.3.3.3 *Forced ventilation* — When forced ventilation is used, gases which are released from the MAFB into the room or enclosure shall be expelled to the atmosphere using a ventilation system, which may combine an opening and fan. If forced ventilation is essential for the safe operation of the MAFB, then an appropriate interlock shall prevent its operation when the forced ventilation is not operating or has failed.

12.3.4 *Warning Sign* — Appropriate warning signs which prohibit sparks, smoking, open flame, and electrostatic discharges shall be placed at the entrance of the hazardous area.

12.3.5 *Close Vicinity to Emissions* — The dilution of gases is not always fully achieved in the close vicinity of the exhaust of released gases or at the outlet of direct forced ventilation, therefore a safety distance from the outlet shall be observed. The dispersion of gases depends on the gas emission rate and the type of ventilation close to the source of emission.

12.4 Hazard Posed by Liquids

12.4.1 *General* — The impact of the energy system fluid involved in the MAFB leakage can be categorized in terms of toxicity, corrosiveness, environmental impacts, and flammability.

Since the energy storage fluids are flowing through the fluid system, there is a possibility that a leakage will continue unattended or unmitigated if the detection of the leakage and/or the protection against the leakage are inappropriate. In addition, fluids supplied to the stacks may be stored in the common tank in a large volume while:

a) Ensuring the sealing performance of the fluid system,
b) Incorporating corrosion resistance in the design and the material of the parts that come into contact with the energy storage fluids,
c) Detecting leakage and taking appropriate measures,
d) Preventing leakage to the surroundings, and,
e) Providing information and markings concerning the fluid.

12.4.2 *Detection of Energy Storage Fluid Leakage* — Leakage shall be detected by appropriate protection measures such as a leakage sensor. The detection and protective functions shall be verified appropriately.

The detection of the fluid shall initiate the necessary countermeasures such as stopping the pumps and closing the valves.

12.4.3 *Protective Measures Against Leakage* —The MAFB must have a leakage collection provision such as a collecting tray (also known as collecting basin) under the tanks which is stable to the energy storage fluid and has a volume at least equal to the largest tank of the MAFB. Refer to the local safety regulations for other or additional protective measures.

12.5 Operational Hazards and Measures

12.5.1 *General* — When the MAFB is designed to work with other equipment upstream and/ or downstream, such as control centre upstream, a signal interface or other means shall be provided to enable a coordinated operation, including start, stop, emergency shutdown and discharge.

Improper integration can cause unintentional operation which potentially leads to a hazardous situation.

Proper coordinated operation shall be confirmed by appropriate methods.

12.5.2 *Start* — The MAFB shall be started only when the starting condition is achieved through ensuring that:

a) All safeguards are in place and are functional,
b) The safety conditions have been fulfilled for restart after a stop,
c) Non-hazardous conditions are verified for intentional restarting actuation,
d) Suitable interlocks are provided for correct sequential starting.

12.5.3 *Remote Monitoring and Control Systems* — An MAFB that can be operated remotely shall have a local, labelled switch or other means to disconnect the system from remote signals that may be used while a local operator performs inspection or maintenance.

The implementation of a remote monitoring system shall be considered in order to check if the system is operating safely. The data collected automatically from the MAFB inquiry can help to evaluate its state of health and the remaining life of its components. Diagnosis is performed by monitoring the change of capacity or changes in the measured parameters. These data can be transmitted through an information network in a timely manner.

12.5.4 *Protection* — The MAFB shall be equipped with appropriate protective devices to detect abnormal situations and initiate an emergency stop.

12.5.5 *Auxiliary Power Failure* — In case of an auxiliary power failure to the MABSU, the MAFB shall be designed in such a way to ensure safe shutdown of the system. This may include:

a) Necessary detection of loss of power in the MAFB,
b) The trigger of an alarm informing on the situation at the designated terminal,
c) Initiation of a proper designated shutdown including separation from the POMC, and
d) Stopping of the pumps and closing of the designated valves

As an example, this can be facilitated through integrating a UPS for supporting the Control Unit operation and/or supplying power from a separate secure source.

12.6 Safety Requirement for Stacks — The Stacks in a MAFB might be subjected to abuse during operation. To ensure safety, they must be evaluated as per the tests enlisted in table 4.

TABLE 4 LIST OF VERIFICATION TESTS FOR STACKS FOR PROTECTIVE MEASURES
(Clause 12.6)

Sl No.	**Test**	**Test Category**	**Test Object**	**Acceptance Criteria**
(1)	**(2)**	**(3)**	**(4)**	**(5)**
i)	External Short circuit	Type test	Stack	The test is passed if there is no fire, explosion, or fluid leakage.
ii)	Heat shock strength	Type test	Stack	There shall be no visible fluid leakage.
iii)	Leakage	Routine test	Stack	There shall be no visible fluid leakage.

12.6.1 *External short-circuit of the stack*

12.6.1.1 *Requirements*— An external short-circuit of the stack shall not cause fire, explosion or electrolyte leakage.

12.6.1.2 Test Category—This test is classified as a type test.

12.6.1.3 *Number of samples*—One (1) sample shall be tested.

12.6.1.4 *Test*

This test shall be conducted as follows:

a) The ambient temperature must be maintained at a constant temperature of 27 °C + 2 K.
b) Place the sample stack in the system designated for this test.
c) Perform the test with each cell having metal anode as required for 100% State of Energy.
d) Ensure that the energy storage fluid would flow through the stack in a manner as it would in normal operation of the MAFB in on-state.

e) Connect the positive and negative terminals of the sample stack with a resistance of not more than 20mΩ until 1) the battery is completely discharged, 2) the integrated protective device has acted, 3) the battery structure has failed, or 4) for 10 minutes whichever occurs first.

This test can be destructive and shall be carried out in an appropriate test facility under the supervision of qualified person(s).

NOTE It is assumed that external short-circuit of a stack occurs when metal bars or wires touch a terminal of the stack in the MAFB. The electrical resistance of this short-circuit is assumed to be 20mΩ.

12.6.1.5 *Acceptance criteria* —The test is passed if there is no fire, explosion or electrolyte leakage.

12.6.2 *Heat shock strength*

12.6.2.1 *Requirements* —The stack shall withstand the thermal-induced mechanical stress when the fluid circulation starts.

12.6.2.2 *Category*—This test is classified as a type test.

12.6.2.3 *Number of samples*— One (1) sample of the stack or the sub-stack shall be tested.

12.6.2.4 *Test*

The temperature parameters used in 12.6.2.4 are defined as follows:

$T_{maxfluidmanufacturer}$: maximum energy storage fluid temperature specified by the manufacturer,
$T_{minfluidmanufacturer}$: minimum energy storage fluid temperature specified by the manufacturer,
$T_{maxfluid} = T_{maxfluidmanufacturer} + 5$ K
$T_{minfluid} = T_{minfluidmanufacturer} - 5$ K

This test shall be conducted as follows:

a) The ambient temperature must be maintained at a constant temperature of 27 °C + 2 K.
b) Perform the test with each cell having metal anode as required for 100% State of Energy.
c) Ensure that the energy storage fluid at a temperature of $T_{minfluid}$ would flow through the stack in a manner as it would in normal operation of the MAFB in on-state for 1h with the maximum inlet pressure which the manufacturer specifies.
d) Ensure that the energy storage fluid at a temperature of $T_{maxfluid}$ would flow through the stack in a manner as it would in normal operation of the MAFB in on-state for 1h with the maximum inlet pressure which the manufacturer specifies.
e) Repeat the procedures from a) to d) nine times.
NOTE The heat shock conditions are imposed 10 times in total.

12.6.2.5 *Acceptance criteria* —There shall be no visible fluid leakage.

12.6.3 *Leakage of the stack*

12.6.3.1 *Requirements*—The intended use of the stack shall not cause leakage of the fluids.

12.6.3.2 *Category*—This test is classified as a routine test.

12.6.3.3 *Number of samples*—All the stacks shall be tested.

12.6.3.4 *Test*

This test shall be conducted as follows:

a) The ambient temperature must be maintained at a constant temperature of 27 °C + 2 K.
b) Circulate the energy storage fluid at the manufacturer's specified flow rate.
c) Keep the fluid's temperature within the manufacturer's specified range of the rated temperature,
d) The fluid pressure applied at the inlet of the stack must be at the maximum operating pressure as specified by the manufacturer.
e) Maintain the test pressure for at least 1h, or longer, as necessary, to complete the leak checks, while inspecting all external surfaces of the stack for any signs of leaks.

12.6.3.5 *Acceptance criteria* —There shall be no visible fluid leakage.

13 SAMPLING AND QUALITY ASSURANCE

13.1 Sampling — Refer Clause 7 of IS 6303:2018

13.2 Quality Plan — The manufacturer shall prepare and implement a quality plan that defines procedures for the inspection of materials, components, cells and batteries and which covers the whole process of producing each type of cell or battery. Manufacturers should understand their product capabilities and should institute the necessary controls as they relate to product safety.

14 EXAMPLE CHEMISTRIES OF METAL AIR FLOW BATTERIES

Some of the commonly available chemistries of metal air flow batteries are enlisted in table 5.

TABLE 5 EXAMPLE CHEMISTRIES OF METAL AIR FLOW BATTERIES
(Clause 14)

SI. No.	Negative Electrode	Energy Storage Fluid	Positive Electrode
(1)	(2)	(3)	(4)
i)	Aluminium (Al)	Alkaline aqueous	Air
ii)	Zinc (Zn)	Alkaline aqueous	Air
iii)	Iron (Fe)	Alkaline aqueous	Air
iv)	Li (Li)	Non aqueous	Air

15 PROCEDURE FOR CONDUCTING A STANDARD CYCLE

A standard cycle will start with a standard discharge followed by a standard electrical or mechanical charge, whichever applicable.

15.1 Standard Discharge

15.1.1 *Discharge Rate* — The discharge procedure including termination criteria shall be defined by the manufacturer.

Discharge with 1C current if Constant Current (CC) discharge is applicable. If Constant Voltage (CV) discharge is applicable, then it should be discharged at the standard discharge voltage.

15.1.2 *Discharge Limit (End Voltage or end Power or End Current)* — Specified by the manufacturer.

15.1.3 *Rest Period After Discharge* — Minimum 30 min

15.2 Standard Charge

15.2.1 *Standard Electrical Charge* — The charge procedure including termination criteria shall be defined by the manufacturer.

Charge with C/3 current if Constant Current (CC) charge is applicable. If Constant Voltage (CV) charge is applicable, then it should be charged at the standard charge voltage.

15.2.2 *Standard Mechanical Charge* — Specified by the manufacturer