Prüfbericht-Nr.: *Test report no.:*	**CN236VWK 001**	**Auftrags-Nr.:** *Order no.:*	**244516874**	Seite 1 von 38 *Page 1 of 38*
Kunden-Referenz-Nr.: *Client reference no.:*	**2097732**	**Auftragsdatum:** *Order date:*	2023-05-21	
Auftraggeber: *Client:*	REPT BATTERO Energy Co., Ltd. No.205, Binhai 6th Road, Konggang New District,Longwan District, Wenzhou 325000 Zhejiang, P.R.China			
Prüfgegenstand: *Test item:*	Rechargeable Prismatic Lithium-ion Cell			
Bezeichnung / Typ-Nr.: *Identification / Type no.:*	CB71			
Auftrags-Inhalt: *Order content:*	Test report			
Prüfgrundlage: *Test specification:*	UL 9540A: 2019 (Fourth Edition)			

Wareneingangsdatum: *Date of sample receipt:*	2023-05-15	
Prüfmuster-Nr.: *Test sample no:*	Engineering sample	
Prüfzeitraum: *Testing period:*	2023.05.15 - 2023.06.19	
Ort der Prüfung: *Place of testing:*	See clause 1.1 of main report	
Prüflaboratorium: *Testing laboratory:*	TUV Rheinland (Shanghai) Co., Ltd.	
Prüfergebnis*: *Test result*:*	See main report	

geprüft von: *tested by:*	Simon Wang	**genehmigt von:** *authorized by:*	Bowen Dong
Datum: *Date:* 2023.07.05		**Ausstellungsdatum:** *Issue date:* 2023.07.05	
Stellung / *Position:*	**Project Engineer**	**Stellung** / *Position:*	**Reviewer**

Sonstiges / *Other:*

Zustand des Prüfgegenstandes bei Anlieferung: *Condition of the test item at delivery:*	Prüfmuster vollständig und unbeschädigt *Test item complete and undamaged*

* Legende:	P(ass) = entspricht o.g. Prüfgrundlage(n)	F(ail) = entspricht nicht o.g. Prüfgrundlage(n)	N/A = nicht anwendbar	N/T = nicht getestet
** Legend:*	*P(ass) = passed a.m. test specification(s)*	*F(ail) = failed a.m. test specification(s)*	*N/A = not applicable*	*N/T = not tested*

Introduction

Model fire codes and energy storage system standards require energy storage systems to comply with UL 9540, which in turn requires battery cells and modules to comply with UL 1973. Compliance with these standards reduces the risk of batteries and battery energy storage systems (BESS) creating fire, shock or personal injury hazards. However, they don't evaluate the ability of the BESS installed as intended and with fire suppression mechanisms in place if necessary, from contributing to a fire or explosion in the end use installations.

To address these fire and explosion hazards associated with the installation of a BESS, the fire and other codes require energy storage systems to meet certain location, separation, fire suppression and other criteria. Those codes also provide a means to provide an equivalent level of safety based on large scale fire testing of anticipated BESS installations.

UL 9540A is intended to provide a test method that can be used as a basis for validating the safety of a BESS installation in lieu of meeting the specific criteria provided in those codes. The data generated can be used to determine the fire and explosion protection required for installation of a BESS.

The test method is initiated through the establishment of a thermal runaway condition that leads to combustion within the BESS. The test method outlined in UL 9540A consists of several steps – cell level testing, module level testing, unit level testing and installation level testing. The cell and module level testing steps are information gathering steps to inform the unit and installation level testing.

The following outlines the information that may gathered as part of the testing:

a) Cell level – An individual cell fails in a manner that leads to thermal runaway and fire through a suitable method such as external heating. Data such as off-gassing contents, temperatures at venting and temperatures at thermal runaway are recorded.

b) Module level – One or more cells within a BESS module fail in the manner determined during the cell level testing. Data such as fire propagation in the module, temperatures on the failed cells and surrounding cells, off-gassing contents and heat release data are gathered.

c) Unit level – A complete BESS is installed surrounded by target (e.g. dummy) BESS and walls separated at a distance as intended in its installation. The module level test is repeated on a module located in the BESS in the most unfavorable location. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; observation of fire propagation from BESS to target units and walls as well as observance of explosions or evidence of re-ignition within the BESS; and heat release and off-gassing contents are gathered.

d) Installation level – This test is a repeat of the unit level test with the test conducted within a test room and with the intended fire suppression system installed as well as any overhead cables (that can lead to fire propagation) installed. This test is intended to validate the fire suppression system for the BESS installation. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; fire propagation from the BESS to target units, walls or overhead cables and any observable explosion incidents or re-ignition within the BESS; and off-gassing contents (if needed) and heat release are gathered.

Contents

1 General information

1.1 Test specification

Standard: ANSI/CAN/UL 9540A:2019 (Fourth Edition)

Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

This report presents the result of cell level tests of UL 9540A: 2019.

All tests were conducted at TUV Rheinland (Shanghai) Co., Ltd. and TUV Rheinland's partner labs that were under supervision of TÜV Rheinland's engineer.

Testing period: 2023.05.15 ~ 2023.06.19

Refer to Clause 4 for test and measurement instruments.

1.2 General remarks

This report is descriptive and provide the test data only.

The test results presented in this report relate only to the object tested.

This report shall not be reproduced, except in full, without the written approval of the testing laboratory.

Throughout this report a ☐ comma / ☒ point is used as the decimal separator.

1.3 List of attachments

The following attachments resulting from the tests, provided with separate page number, are included in this report.

Appendix A: Cell vent gas lower flammability limit (LFL) test

Appendix B: Cell vent gas burning velocity (S_u) test

Appendix C: Cell vent gas maximum pressure (P_{max}) test

1.4 Revision information

New report, not applicable.

1.5 Definitions

CELL – The basic functional electrochemical unit containing an assembly of electrodes, electrolyte, separators, container, and terminals. It is a source of electrical energy by direct conversion of chemical energy.

MODULE – A subassembly that is a component of a BESS that consists of a group of cells or electrochemical capacitors connected together either in a series and/or parallel configuration (sometimes referred to as a block) with or without protective devices and monitoring circuitry.

UNIT – A frame, rack or enclosure that consists of a functional BESS which includes components and subassemblies such a cells, modules, battery management systems, ventilation devices and other ancillary equipment.

BATTERY SYSTEM (BS) – Is a component of a BESS and consists of one or more modules typically in a rack configuration, controls such as the BMS and components that make up the system such as cooling systems, disconnects and protection devices.

BATTERY ENERGY STORAGE SYSTEM (BESS) – Stationary equipment that receives electrical energy and then utilizes batteries to store that energy to supply electrical energy at some future time. The BESS, at a minimum consists of one or more modules, a power conditioning system (PCS), battery management system (BMS) and balance of plant components.

a) INITIATING BATTERY ENERGY STORAGE SYSTEM UNIT (INITIATING BESS) – A BESS unit which has been equipped with resistance heaters in order to create the internal fire condition necessary for the installation level test (Section 9).

b) TARGET BATTERY ENERGY STORAGE SYSTEM UNIT (TARGET BESS) – The enclosure and/or rack hardware that physically supports and/or contains the components that comprise a BESS. The target BESS unit does not contain energy storage components, but serves to enable instrumentation to measure the thermal exposure from the initiating BESS.

Note: Depending upon the configuration and design of the BESS (e.g. the BESS is composed of multiple separate parts within separate enclosures), the unit level test can be done at battery system level. In such case, the BESS is be read as BS throughout this report.

NON-RESIDENTIAL USE – Intended for use in commercial, industrial or utility owned locations.

RESIDENTIAL USE – In accordance with this standard, intended for use in one or two family homes and town homes and individual dwelling units of multi-family dwellings.

THERMAL RUNAWAY- The incident when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion. The thermal runaway progresses when the cell's generation of heat is at a higher rate than the heat it can dissipate. This may lead to fire, explosion and gas evolution.

STATE OF CHARGE (SOC) – The available capacity in a BESS, pack, module or cell expressed as a percentage of rated capacity.

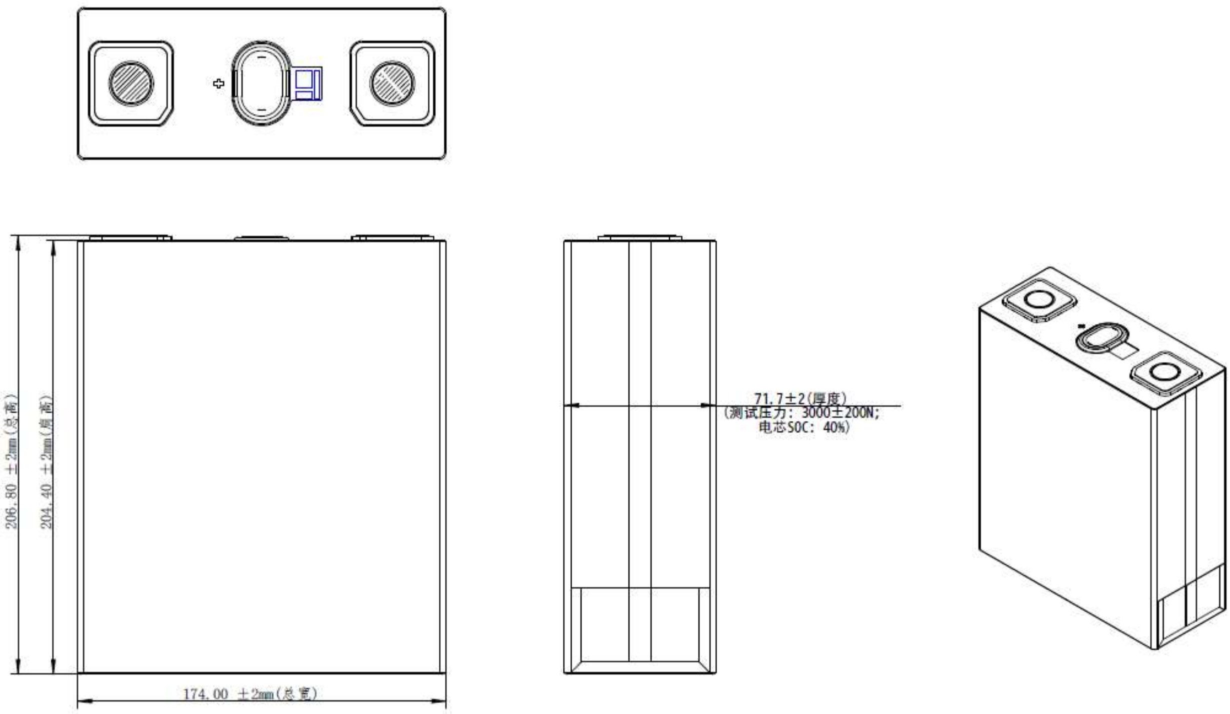
2 General Product Information

2.1 Product information and parameters

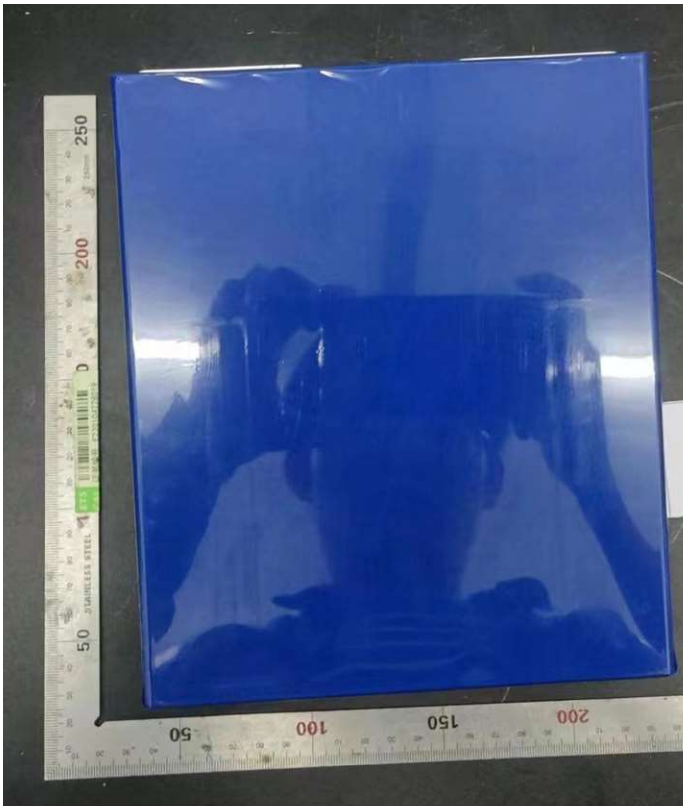
The product information and parameters are provided by the client as below.

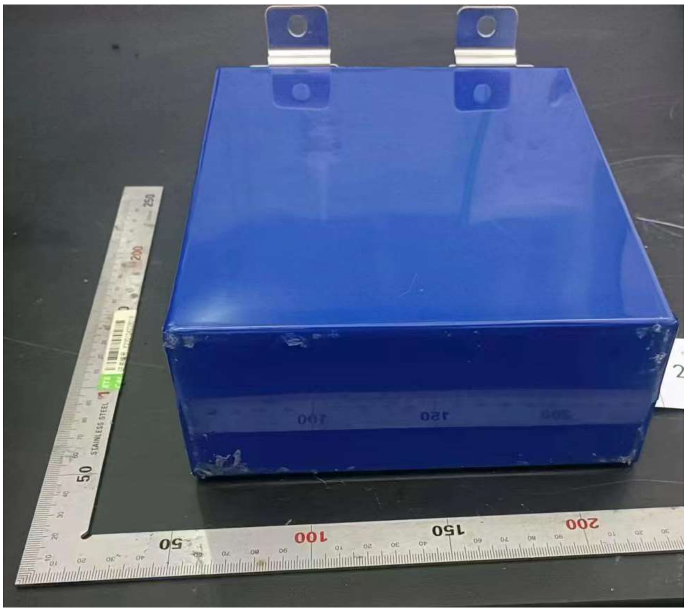
Manufacturer .... :	REPT BATTERO Energy Co., Ltd.	
Model number .... :	CB71	
Chemistry .... :	☒ $LiFePO_4$ ☐ NMC ☐ NCA ☐ LTO ☐ Other:	
Physical configuration......................... :	☒ Prismatic ☐ Cylindrical ☐ Pouch	
	Weight(kg):	5.78±0.3
Electrical rating .... :	Rated capacity(Ah):	320
	Nominal voltage(Vd.c.):	3.2
Standard charge method .... :	Charge current(A):	160
	End of charge voltage(V):	3.65
Standard discharge method .... :	Discharge current(A):	160
	End of discharge voltage(V):	2.5
Compliance with UL 1973................. :	☒ Yes Report No. CN23UEVG 001	

2.2 Diagram with overall dimension



2.3 Photos





3 Cell level test (section 7 of UL 9540A)

3.1 General

This testing is conducted on individual cells and uses various stress conditions such as external heating to force the cells into thermal runaway.

Once the stress mechanism is induced, the test measures the temperature at which the cell vents and then the temperature at which thermal runaway occurs.

The test also measures the volume and pressure of the vent gases that are released from the cells, and the composition of the vent gases.

Cell vent gas with flammable components in its composition should have the following parameters characterized in order to enable deflagration venting design:

a) Measurement of fundamental burning velocity by the vertical tube method described in the Method of Test for Burning Velocity Measurement of Flammable Gases Annex in ISO 817; and

b) Maximum pressure developed in a contained deflagration of an optimum mixture per EN 15967.

Cell level testing performed on the cells used within a BESS module establishes a base line fire test performance that can be evaluated against the fire performance of other battery cells the BESS manufacturer may choose to use within the unit's modules.

If none of the cell samples can be forced into thermal runaway and none of the cell samples vent flammable gases as determined by the ASTM E918 test, during any of the cell level tests, it is not necessary to conduct additional module or unit level testing on BESS that utilize these cells.

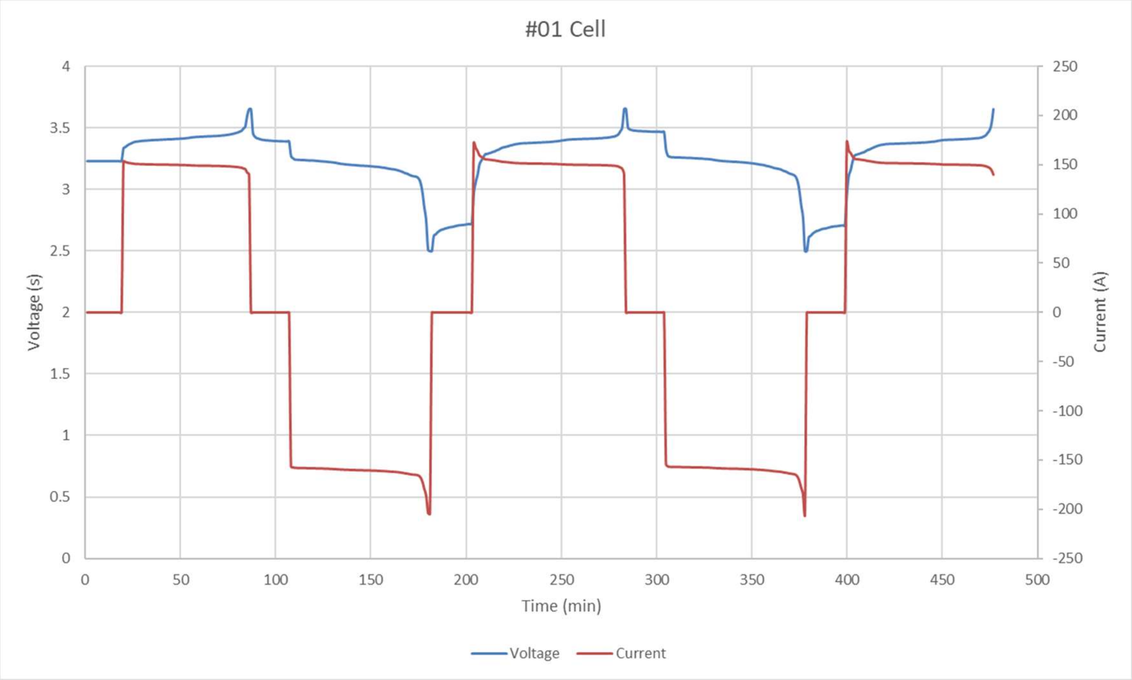
3.2 Sample preparation

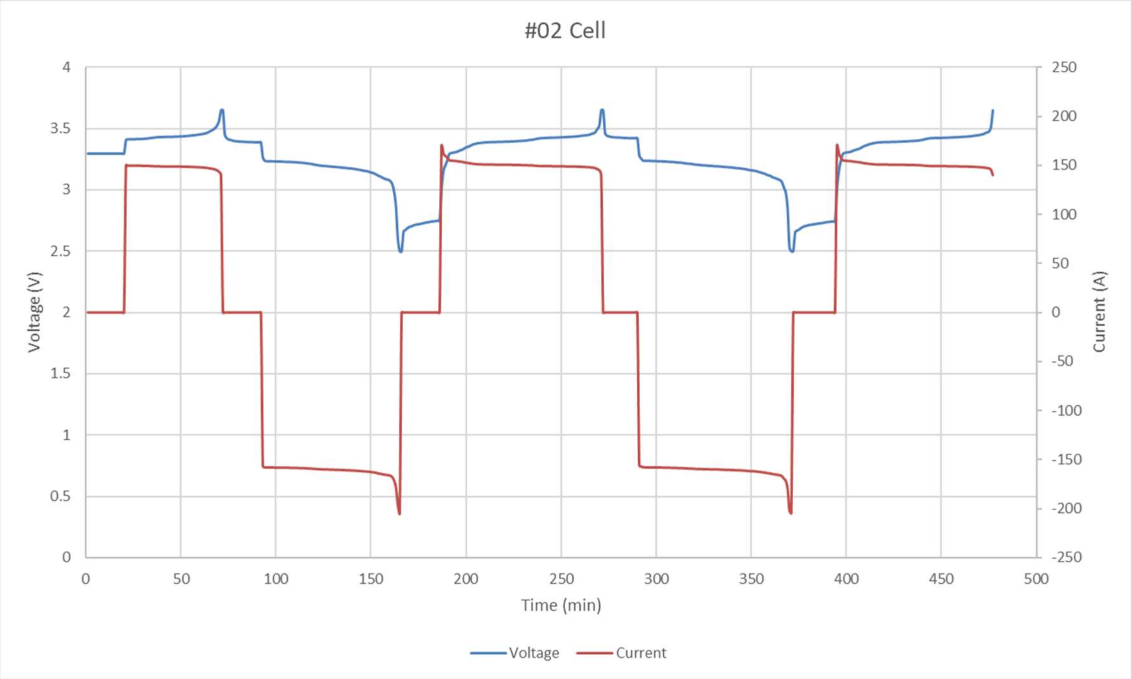
3.2.1 Test method and description

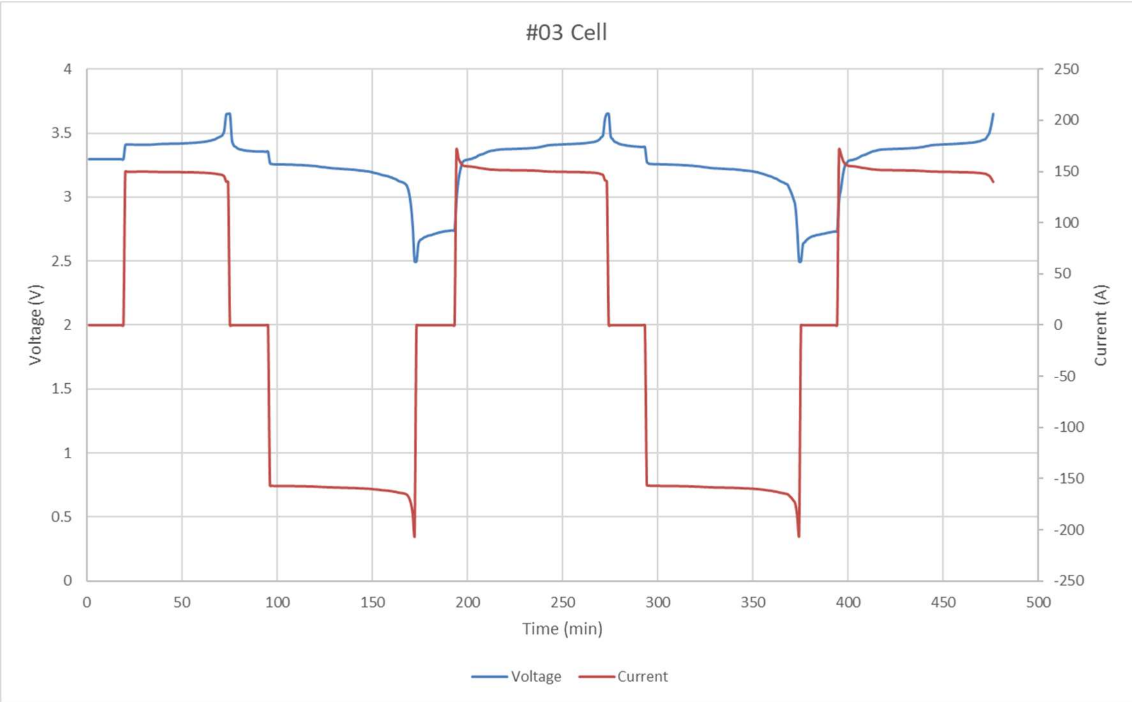
The cells were conditioned, prior to testing, through charge and discharge cycles for 2 cycles using a manufacturer specified methodology (refer to 2.1.1).

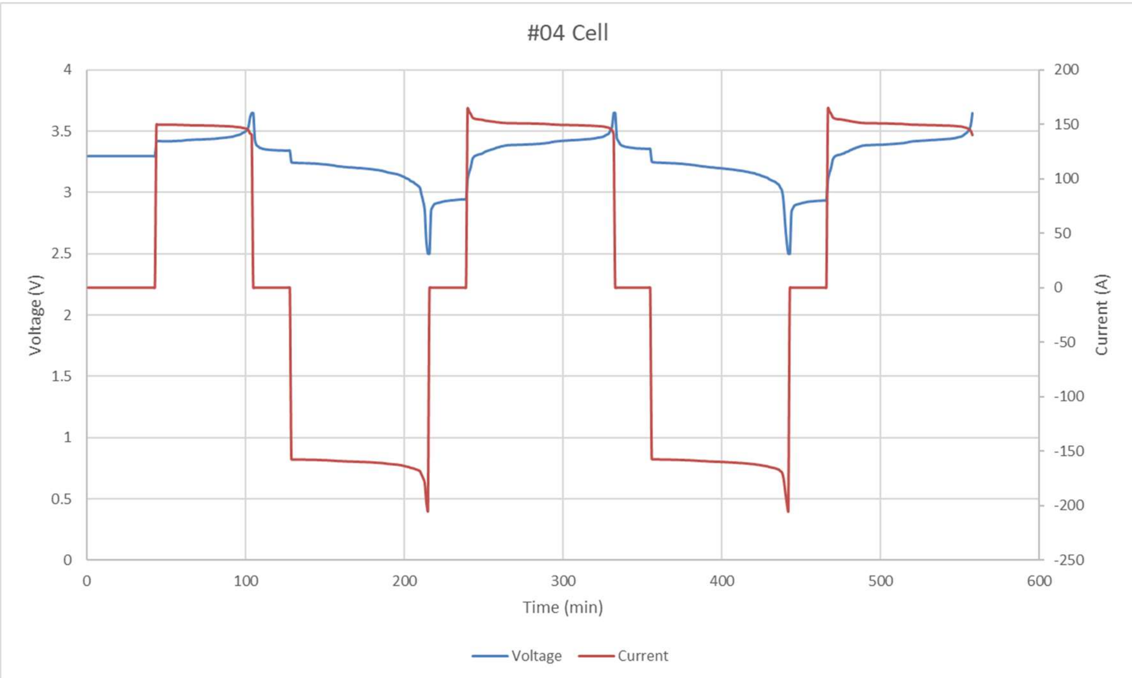
During the cycling, ambient condition is maintained within 25°C±2°C and R.H. 50±5 %.

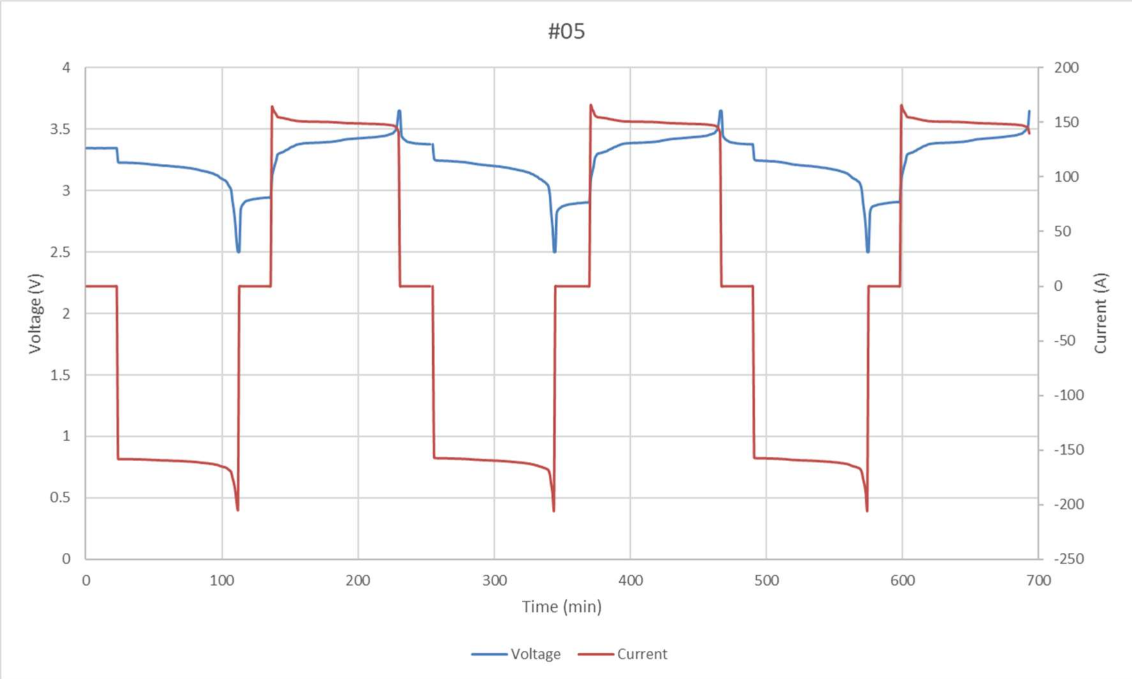
3.2.2 Cell cycling curves






#03 Cell
Voltage (V)
Current (A)
Time (min)
Voltage
Current
0
0.5
1
1.5
2
2.5
3
3.5
4
250
200
150
100
50
0
-50
-100
-150
-200
-250
0
50
100
150
200
250
300
350
400
450
500


#04 Cell
Voltage (V)
Current (A)
Time (min)
Voltage
Current
0
0.5
1
1.5
2
2.5
3
3.5
4
200
150
100
50
0
-50
-100
-150
-200
-250
0
100
200
300
400
500
600


#05
Voltage (V)
Current (A)
Time (min)
Voltage
Current
4
3.5
3
2.5
2
1.5
1
0.5
0
200
150
100
50
0
-50
-100
-150
-200
-250
0
100
200
300
400
500
600
700

3.3 Determination of cell thermal runaway methodology

3.3.1 Test method and description

The cells to be tested were charged to 100% SOC and allowed to stabilize for a minimum of 1 h and a maximum of 8 h before the start of the test.

Two external film heaters rated 220VAC/512 W (size 207mm*174mm*4 mm) were added on the two wide surfaces of cell to induce the cell thermal runaway.

The cell sample and heater were clamped by two steel plate (size 260*250*5 mm) together using four blots during test to simulate the constraint in the BESS module to prevent excessive swelling during the test. Two layers insulation sheet were placed below the heater and two layers on the top of the cell to limit the heat transmit during test.

Thermocouple (type K, 24AWG), Two were located below the heater, at the center of the cell surface. One used for heater controller temperature feedback, the other used to record cell temperature. One thermocouple was located on the opposite side of the cell at the center of the cell surface. The temperature of vent, negative electrode, narrow surface center of cell also record by thermocouple.

A PID controller was used to control the voltage supply to the heater and maintain a 4°C/min to 7°C/min heating rate. Once thermal runaway was observed, the heaters were immediately de-energized.

One thermocouple was located below the heater at the center of the cell surface to feedback the temperature to the controller.

The cell exhibits thermal runaway after reestablish the heating rate. 3 additional samples were repeated to demonstrate repeatability.

The vent temperature and thermal runaway onset temperatures were averaged over the tested samples.

3.3.2 Test result

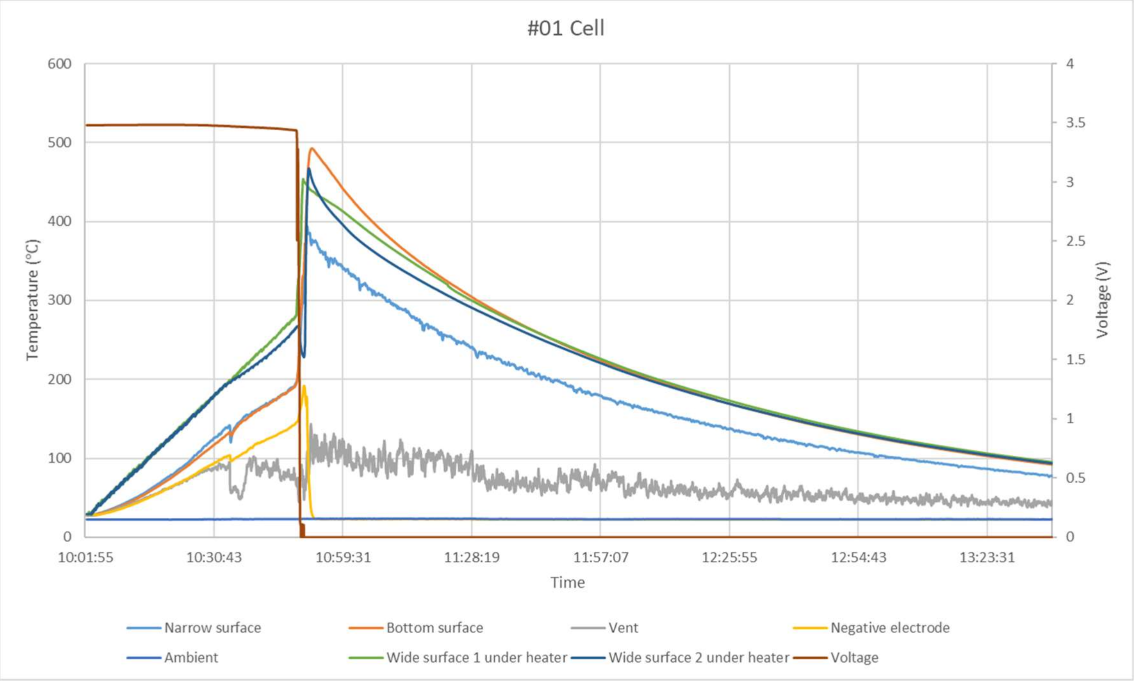
Ambient conditions at the initiation of the test	20.2°C 49% R.H.	20.4°C 54% R.H.	20.9°C 56% R.H.	20.8°C 53% R.H.	22.0°C 53% R.H.
Sample number	#01	#02	#03	#04	#05[1)]
Open circuit voltage before test (V)	3.47	3.42	3.40	3.35	3.39
Cell vent temperature (°C)	139.6	137.3	136.1	160.0	136.7
Cell vent time (min)	32.0	40.0	47.0	41.0	41.0
Thermal runaway onset temperature (°C)	207.1	180.3	182.0	199.0	176.9
Thermal runaway onset time(min)	47.0	49.0	48.0	50.0	49.0
Maximum temperature (°C)	492.6	515.9	511.9	482.3	536.2
Average cell vent temperature (°C)[2)]	143.3				
Average thermal runaway onset temperature (°C)[2)]	192.1				

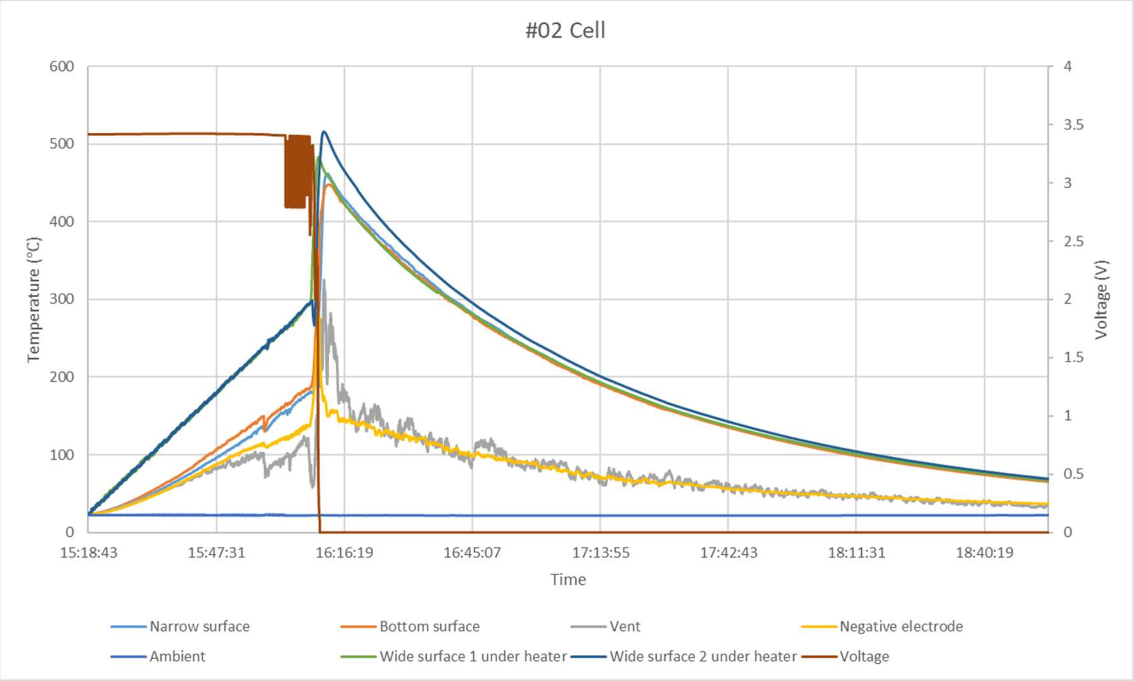
Note:

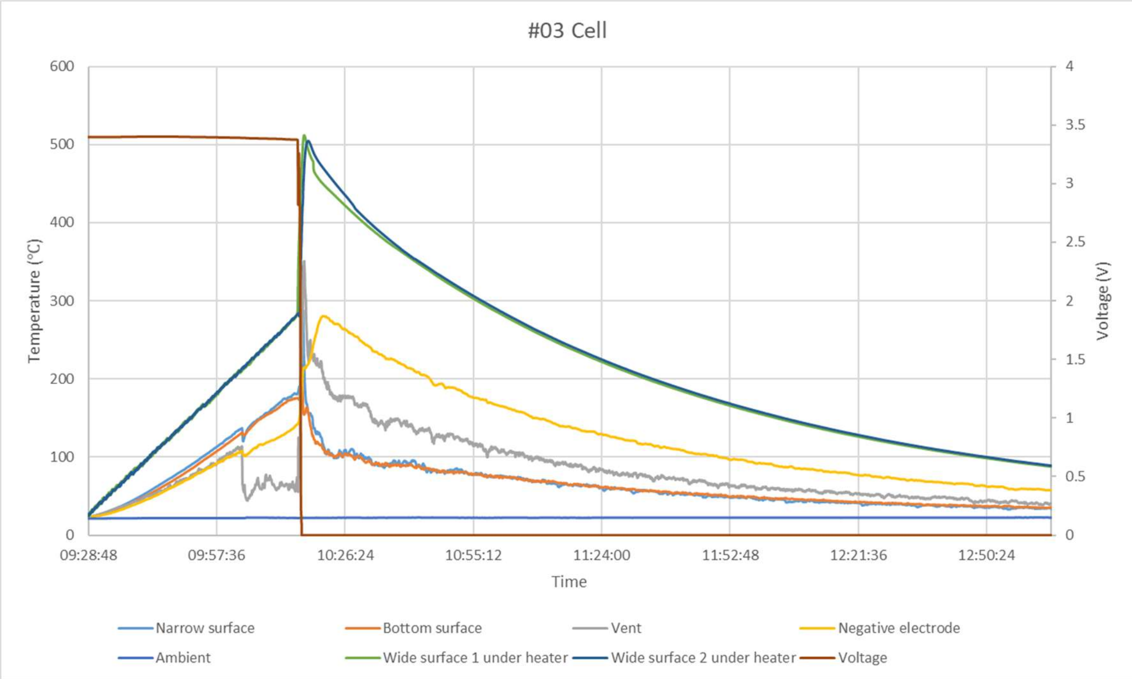
1) The sample is for gas vent capture.

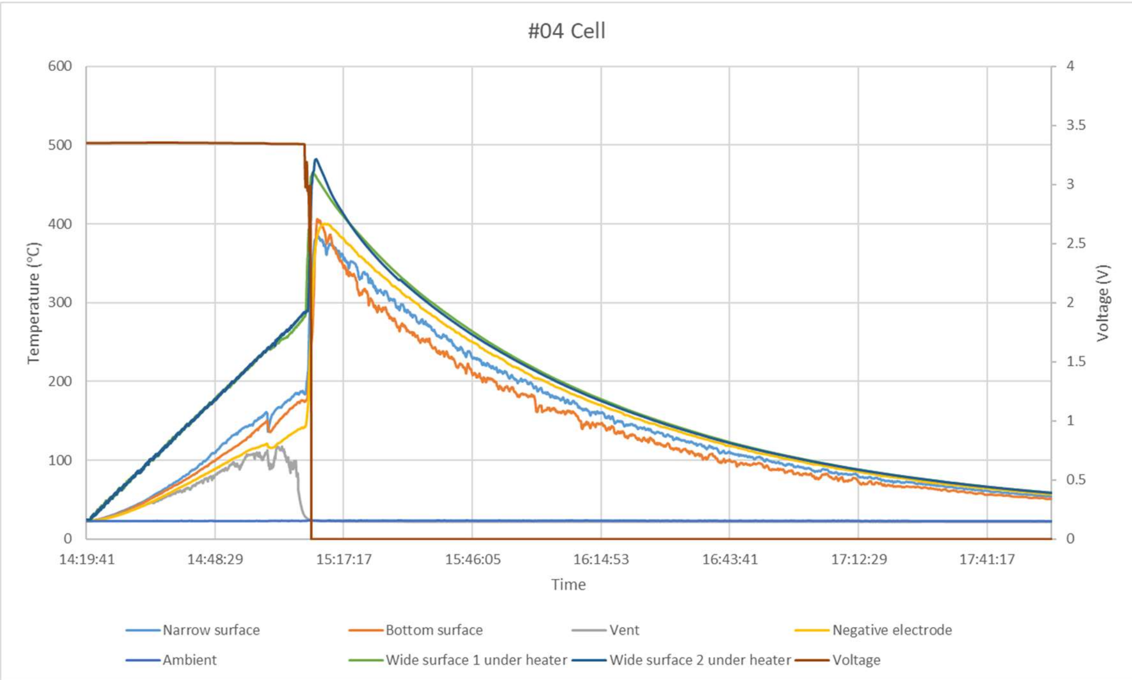
2) The temperatures were averaged over the tested samples (#01, #02, #03, #04) excluding the gas vent capture sample (#05).

3.3.3 Temperature/voltage vs time curve

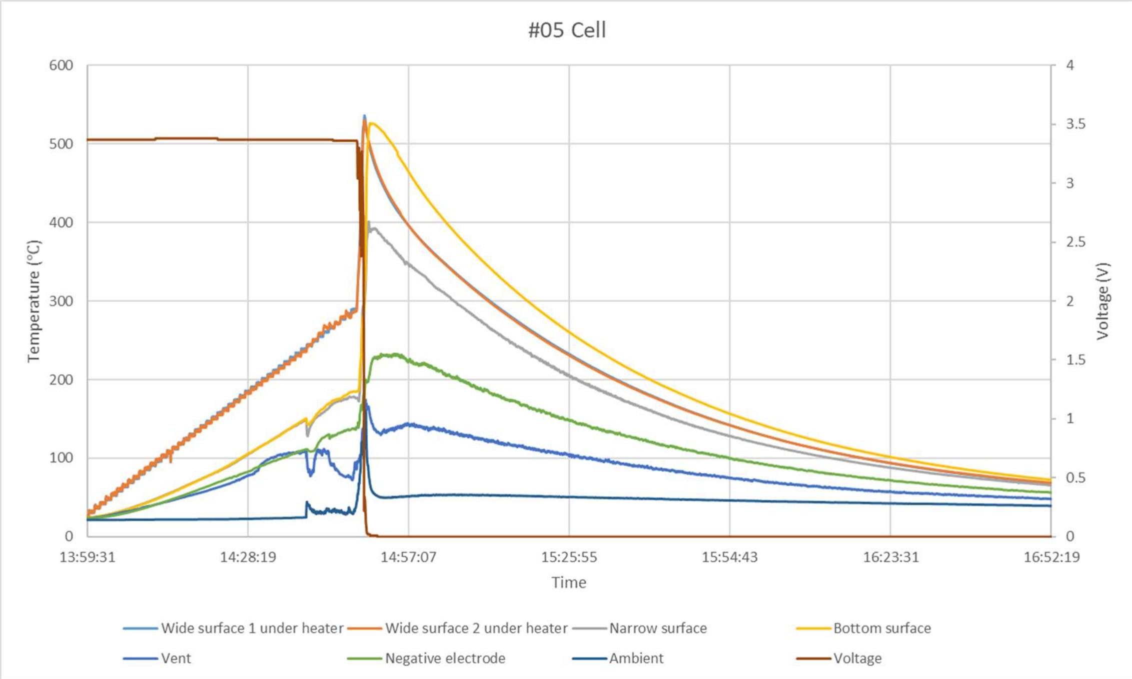








Note: thermocouple on cell vent, used for obverse venting time, damaged when cell venting.


#05 Cell
Temperature (°C)
Voltage (V)
600
500
400
300
200
100
0
4
3.5
3
2.5
2
1.5
1
0.5
0
13:59:31
14:28:19
14:57:07
15:25:55
15:54:43
16:23:31
16:52:19
Time
Wide surface 1 under heater
Wide surface 2 under heater
Narrow surface
Bottom surface
Vent
Negative electrode
Ambient
Voltage

3.4 Cell vent gas generation and capturing

3.4.1 Test method and description

The cells to be tested were charged to 100% SOC and allowed to stabilize for a minimum of 1 h and a maximum of 8 h before the start of the test.

A cell was forced into thermal runaway by the external heating as determined in cell thermal runaway methodology test inside an 82L pressure vessel.

Before testing, the vessel was purged with N_2 to reduce the oxygen content below 1% by volume.

Gas mixtures were collected before and after thermal runaway testing. 0.3L gas collection bag with two valve were used for the gas collection.

1 bag before thermal runaway was used to determine the initial atmospheric inside the vessel. 2 bags after thermal runaway was used to determine the vent gas composition.

Cell weight was measured before and after test for reference.

Pressure was measured before and after thermal runaway to calculate the total gas produced for reference.

3.4.2 Test result

Ambient conditions .... :	21.5°C, 65.2% R.H.
Sample number .... :	#05
Open circuit voltage before test (V) .... :	3.39
Pressure vessel size............................... :	82L
Initial oxygen content by volume (%) .... :	< 0.1 %
Cell weight before test (g)........................ :	5787.2
Cell weight after test (g)........................... :	4686.5
Total vent gas produced (L)..................... :	180 (at 101.3kPa, 298K)

3.5 Determination of cell vent gas composition

3.5.1 Test method

Cell vent gas composition was determined using Gas Chromatography (GC) with detection techniques for quantifying component gases.

Gas analysis was determined in accordance with ISO 6143: 2001 Gas analysis — Comparison methods for determining and checking the composition of calibration gas mixtures)

The gases make up in table 1 approximately 70% of the total volume with the balance of approximately 30% of N_2. HF was measured less than 0.1% in concentration, which was omitted in the table.

Table 2 contains normalized volumetric gas compositions by removing the N_2 contributions. This information was used to synthetically replicated gas mixture for further flammability character parameter tests.

3.5.2 Test result

Table 1: Vent gas components

Gas component	Concentration % (v/v)
CH_4	4.646
C_2H_4	3.103
C_2H_6	0.784
C_3H_6	0.592
C_3H_8	0.199
C_4H_8	0.075
C_4H_{10}	0.144
C_5H_{10}	0.072
C_5H_{12}	0.112
H_2	30.145
CO	6.928
CO_2	19.118
N_2	34.082
Total	100

Table 2: Vent gas components (normalized)

The gas components N2 was removed.

Gas component	Concentration % (v/v)
CH_4	7.048
C_2H_4	4.707
C_2H_6	1.189
C_3H_6	0.898
C_3H_8	0.302
C_4H_8	0.114
C_4H_{10}	0.218
C_5H_{10}	0.109
C_5H_{12}	0.170
H_2	45.731
CO	10.510
CO_2	29.003
Total	100

3.6 Flammability character parameters of the cell vent gas

3.6.1 Test method

Upon determination of the cell vent gas composition, the flammability character parameters were determined on sample of the synthetically replicated gas mixture with maximum uncertainty 2%.

Lower flammability limit (LFL) of the cell vent gas was determined in accordance with ASTM E918, testing at both ambient and cell vent temperatures.

The gas burning velocity was determined in accordance with the Method of Test for Burning Velocity Measurement of Flammable Gases Annex in ISO 817.

The maximum explosion pressure P_{max} was determined on samples of the synthetically replicated gas mixture in accordance with EN 15967.

Below table show the test result only. Detailed test report refer to Appendix A, Appendix B and Appendix C.

References:

ASTM E 918-19 – Standard Practice for Determining Limits of Flammability of Chemicals at Elevated Temperature and Pressure

ISO 817: 2014/Amd 1: 2017 – Refrigerants - Designation and safety classification

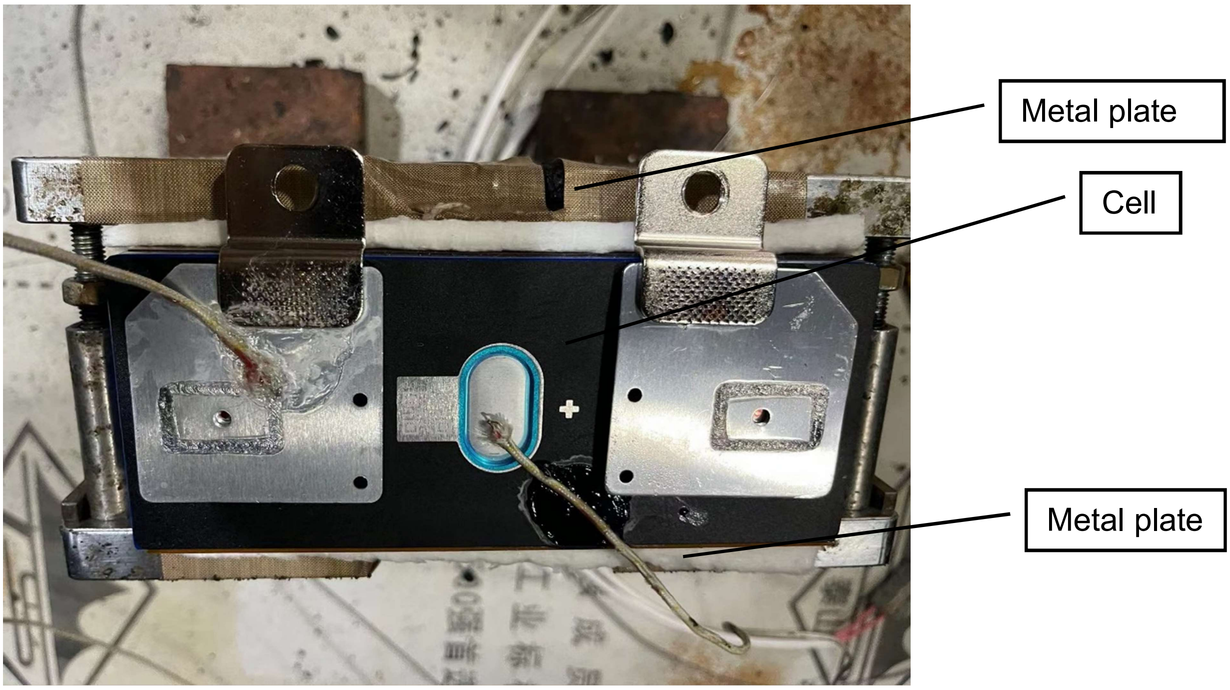
EN 15967: 2011 – Determination of maximum explosion pressure and the maximum rate of pressure rise of gases and vapours

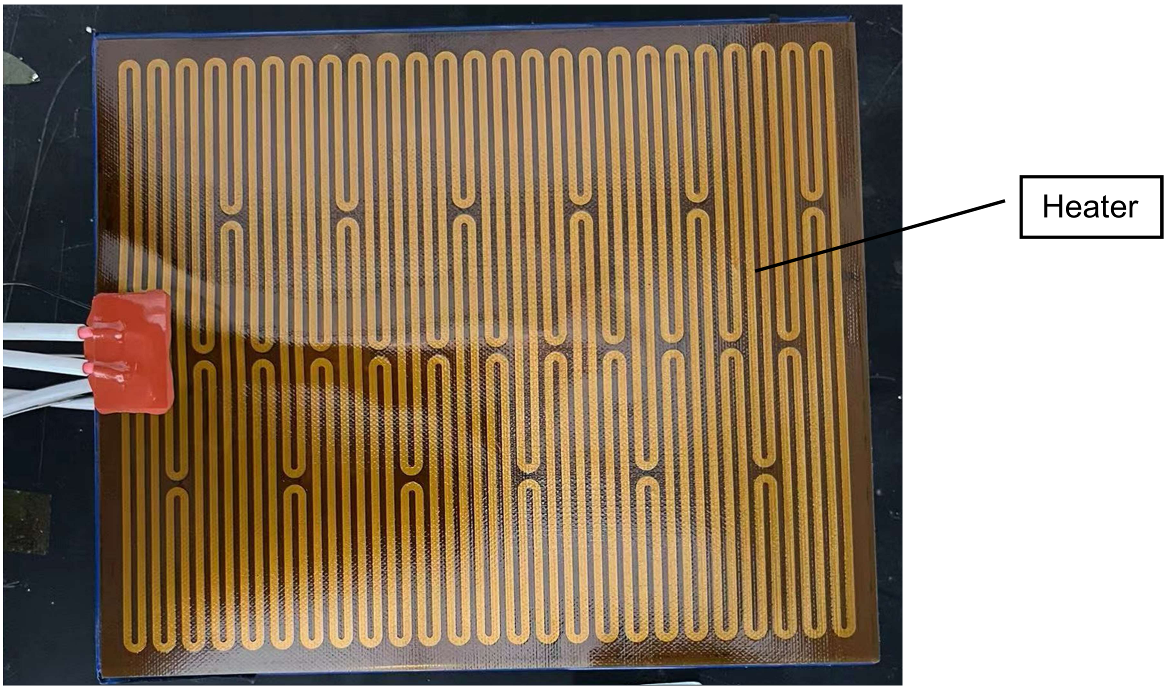
3.6.2 Test result

LFL at 24°C±2°C and 101±3kPa .... :	7.0%	(see Appendix A for details)
LFL at 143.3°C±2°C and 101±3kPa ... :	6.3%	(see Appendix A for details)
Burning Velocity S_u (m/s) at room temperature .... :	0.669	(see Appendix B for details)
P_{max} (MPa) at room temperature .... :	0.693	(see Appendix C for details)

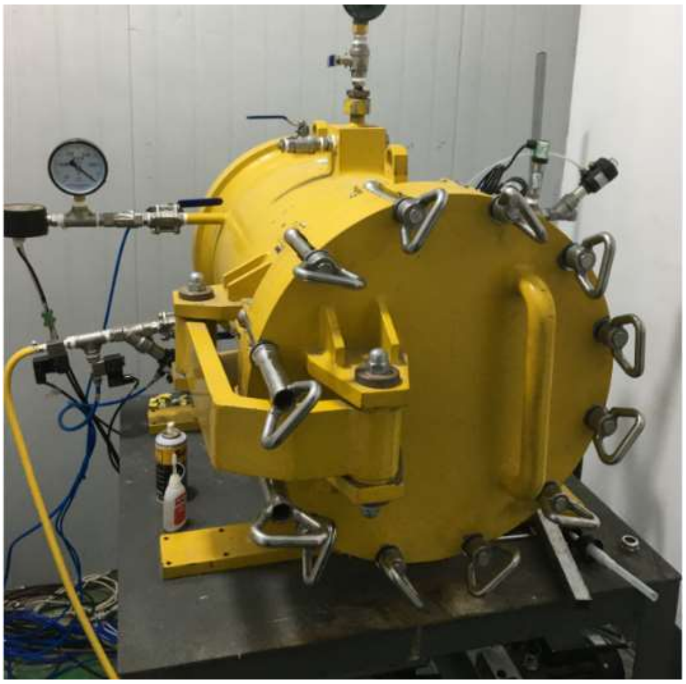
3.7 Photos

Thermal runaway test setup

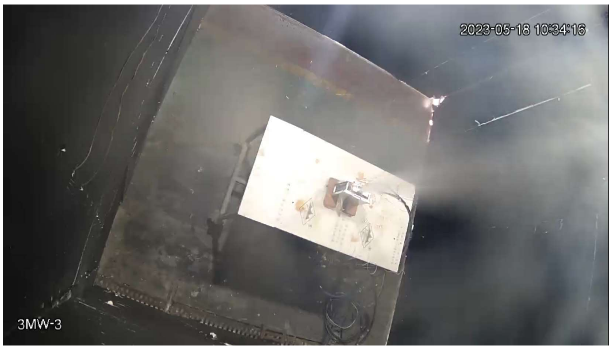




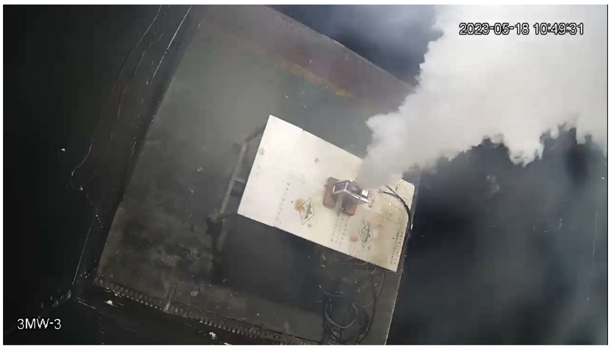
Gas generation and capturing setup



Test sample #01 at ambient condition

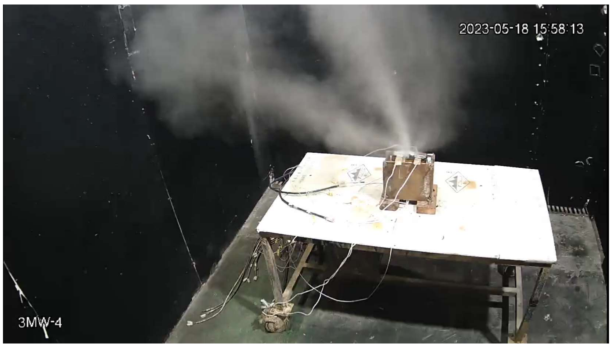


Venting

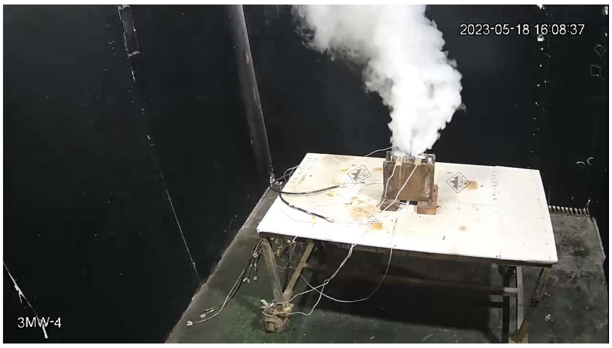


Thermal runaway

Test sample #02 at ambient condition

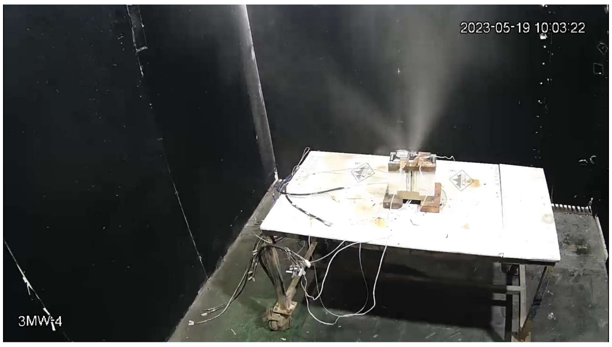


Venting

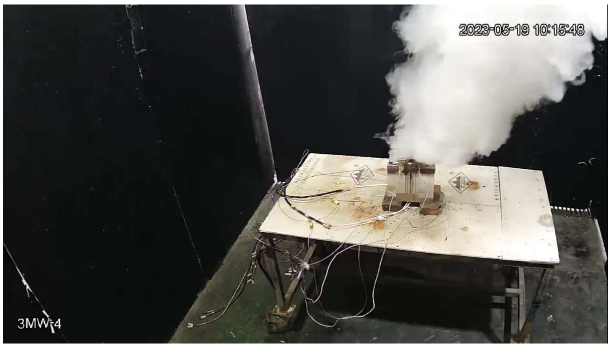


Thermal runaway

Test sample #03 at ambient condition

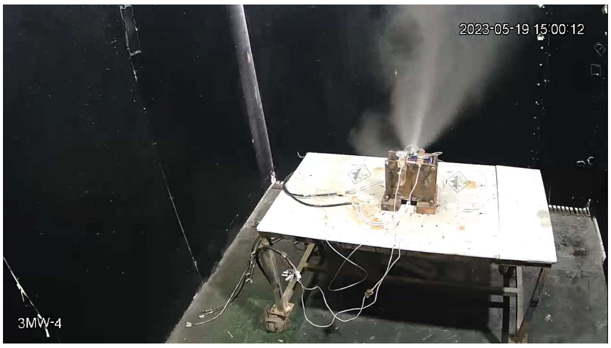


Venting

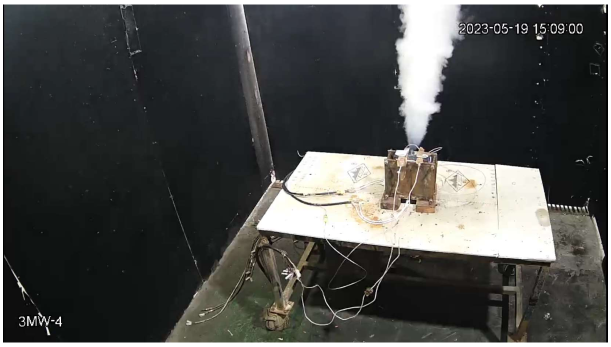


Thermal runaway

Test sample #04 at ambient condition



Venting



Thermal runaway

Cell sample after test

#01 cell

#02 cell

#03 cell

#04 cell

#05 cell

4 List of Test and Measurement Instruments

<table>
<tr><th>No.</th><th colspan="2">Equipment</th><th>Model</th><th>Rating</th><th>Inventory no.</th><th>Last Cal. date</th></tr>
<tr><td>1.</td><td colspan="2">Ambient monitor</td><td>WSB-2-H1</td><td>0-40℃，10-90%RH</td><td>S-055</td><td>2022.07.11</td></tr>
<tr><td>2</td><td colspan="2">Ambient monitor</td><td>WSB-2-H1</td><td>0-40℃，10-90%RH</td><td>S-050</td><td>2023.01.03</td></tr>
<tr><td>3</td><td colspan="2">Ambient monitor</td><td>WSB-2-H1</td><td>0-40℃，10-90%RH</td><td>S-044</td><td>2023.01.03</td></tr>
<tr><td>4</td><td colspan="2">Ambient monitor</td><td>WSB-2-H1</td><td>0-40℃，10-90%RH</td><td>S-056</td><td>2022.07.11</td></tr>
<tr><td>5</td><td colspan="2">Ambient monitor</td><td>WSB-2-H1</td><td>0-40℃，10-90%RH</td><td>S-006</td><td>2022.12.19</td></tr>
<tr><td>6</td><td colspan="2">Charge/discharge equipment</td><td>HRCDS-5V300A</td><td>5V/300A</td><td>S-057</td><td>2022.07.11</td></tr>
<tr><td>7</td><td colspan="2">Ruler</td><td>300mm</td><td>300mm</td><td>S-051</td><td>2023.01.03</td></tr>
<tr><td>8</td><td colspan="2">Electronic scale</td><td>HC311</td><td>0-6000g</td><td>S-047</td><td>2023.02.12</td></tr>
<tr><td>9</td><td colspan="2">Digital multi-meter</td><td>FLUKE101</td><td>0-600V</td><td>S-038</td><td>2023.02.08</td></tr>
<tr><td>10</td><td colspan="2">Heating control equipment</td><td>DTB4824</td><td>0-1000℃</td><td>S-060-3</td><td>2022.07.11</td></tr>
<tr><td>11</td><td colspan="2">Data acquisition equipment</td><td>ADAM-4117
ADAM-4118</td><td>0-10V
0-1000℃</td><td>S-060-1
S-060-2</td><td>2022.07.11
2022.07.11</td></tr>
<tr><td>12</td><td colspan="2">Heating control equipment</td><td>DTB4824</td><td>0-1000℃</td><td>S-028-3</td><td>2023.02.08</td></tr>
<tr><td>13</td><td colspan="2">Data acquisition equipment</td><td>ADAM-4117
ADAM-4118</td><td>0-10V
0-1000℃</td><td>S-028-1
S-028-2</td><td>2023.02.08
2023.01.03</td></tr>
<tr><td>14</td><td colspan="2">Heating control equipment</td><td>DTB4824</td><td>0-1000℃</td><td>S-030-3</td><td>2023.02.08</td></tr>
<tr><td>15</td><td colspan="2">Data acquisition equipment</td><td>ADAM-4117
ADAM-4118</td><td>0-10V
0-1000℃</td><td>S-030-1
S-030-2</td><td>2023.02.08
2023.02.08</td></tr>
<tr><td>16</td><td colspan="2">Heating control equipment</td><td>DTB4824</td><td>0-800℃</td><td>S-058-3</td><td>2022.07.11</td></tr>
<tr><td>17</td><td colspan="2">Data acquisition equipment</td><td>ADAM-4117
ADAM-4118</td><td>0-10V
0-1000℃</td><td>S-058-1
S-058-2</td><td>2022.07.11
2022.07.11</td></tr>
<tr><td>18</td><td colspan="2">Gas Chromatography</td><td>PE Clarus680</td><td>——</td><td>T-177</td><td>2022.11.16</td></tr>
<tr><td>19</td><td colspan="2">Gas Chromatography</td><td>GC-2014C</td><td>——</td><td>T-251</td><td>2023.01.10</td></tr>
<tr><td rowspan="3">20</td><td rowspan="3">Gas acquisition system 82L</td><td>Thermopile</td><td>WRNK-191 K</td><td>0-1000℃</td><td>S-020-1~10</td><td>2023.01.03</td></tr>
<tr><td>Pressure sensor</td><td>BD-801KZ</td><td>0~90kPa</td><td>S-020-11</td><td>2023.02.08</td></tr>
<tr><td>Data acquisition equipment</td><td>DTM
DTB4824
DTM</td><td>0-1000℃
0-1000℃
0-10V</td><td>S-020-12
S-020-13
S-020-14</td><td>2023.01.03</td></tr>
</table>

21	Gas acquisition system 10L	Thermopile	GG-K-30-1000	0-800℃	S-046-1~10	2023.06.15
		Pressure sensor	BD-801KZ	0~90kPa	S-020-11	2023.02.08
		Data acquisition equipment	DTM DTB4824 DTM	0-1000℃ 0-1000℃ 0-10V	S-020-12 S-020-13 S-020-14	2023.01.03
22	Gas acquisition system 86L	Thermopile	GG-K-30-1000	0-800℃	S-052-2~11	2023.06.08
		Pressure sensor	BD-801KZ	0~0.5MPa	S-052-1	2023.06.08
		Data acquisition equipment	ADAM-4117 ADAM-4118 DTB4824	0-10V 0-1000℃ 0-1000℃	S-071-1 S-071-2 S-071-3	2023.06.08
23	Gas acquisition system 340L	Thermopile	GG-K-30-1000	0-800℃	S-071-6~15	2023.06.08
		Pressure sensor	PTX-50G2-TC-A3-CA-HO-PB PTX-50G2-TC-A3-CA-HO-PB	0~2MPa -0.1~1MPa	S-071-4 S-071-5	2023.06.08
		Data acquisition equipment	DTM DTB4824 DTM	0-1000℃ 0-1000℃ 0-10V	S-020-12 S-020-13 S-020-14	2023.01.03
24	Oxygen analyzer		HM-BX-02	0-20.9%	S-014	2022.12.20
25	Gas explosion test system (5L)	Temperature measurement	TJ120-CAXL-116U-10-SMPW-M	0-200℃	S-021-1	2023.02.08
		High frequency dynamic pressure sensor	Kistler 603CAA	0~100MPa	S-021-2	2023.05.26
		Pressure gauge	PTX 50G2-TC-A3-CA-H0-PB	-0.1~+0.5MPa	S-021-3	2023.05.26
		Pressure gauge	PTX 50G2-TC-A3-CA-H0-PB	-0.1~+0.3MPa	S-021-4	2023.05.26
26	Gas flammability testing	Pressure gauge	PTX 50G2-TC-A3-CA-H0-PB	-0.1~+0.15MPa	S-053-1	2023.03.24

	equipment (5L)	Temperature measurement	TJ120-CAXL-116U-10-SMPW-M	0-300℃	S-053-2	2023.03.24
27	Combustible gas combustion rate device	Temperature measurement	TJ120-CAXL-116U-10-SMPW-M	0~200℃	S-022-1	2023.02.08
		Temperature measurement	TJ120-CAXL-116U-10-SMPW-M	0~200℃	S-022-2	2023.02.08
		Pressure gauge	PTX 50G2-TC-A3-CA-H0-PB	-0.1~+0.5MPa	S-022-4	2023.03.24
		straight steel ruler	Shuguang 1m	1000mm	S-040	2022.12.19
		High speed camera	Photron fastcam miniAX50	216000fps	S-022-3	/

Appendix A: Cell vent gas lower flammability limit (LFL) test

Sample information			
Name of Sample	Synthetically replicated gas mixture		
Cylinder volume	8L	Filling pressure	50bar
Certification number	202305310019	Calibration Uncertainty	2%
Calibration date	2023/5/31	Effective date	2024/5/30
Calibrated sample composition			
Gas component	Concentration % (v/v)	Gas component	Concentration % (v/v)
CH4	7.048	C4H8	0.114
C2H4	4.707	C4H10	0.128
C2H6	1.189	C5H10	0.109
C3H6	0.898	C5H12	0.170
C3H8	0.302	CO	10.511
CO2	29.003	H2	Balance

Test Method	ASTM E918-19 Standard Practice for Determining Limits of Flammability of Chemicals at Elevated Temperature and Pressure
Test Item	The lower flammability of gas mixture
Test Apparatus	Test Vessel: 5L closed sphere Ignition system: Fusing Wire
Preparation of Test Mixture	Partial pressure method used inside the vessel; Accuracy: within 0.2% absolute
Symbol and definition	The symbols used in this report are defined as below except otherwise defined: c_s —— Concentration of sample; T_i —— Initial temperature in each trial; p_i —— Initial pressure in each trial; p_{ex} —— Overpressure in each trial; It is considered flame occurred, if pex / pi ≥ 1.07. L_1 —— The minimum sample concentration that gives flame propagation; L_2 —— The maximum sample concentration that does not give flame propagation; LFL —— Lower flammable limit; LFL is expressed as: LFL = (L1+ L2)/2 Concentration defined in this report means volume percentage.
Remark	This report is effective under the specific condition; please seek for the advice of expert for risk assessment in producing, processing, transportation and storage.

LFL test data at room temperature (part)						
Test Condition	Initial Temperature: 24(±2)°C Initial Pressure: 101(±3)kPa					
No.	cs [%]	Ti [°C]	p_i [kPa]	p_{ex} [kPa]	p_{ex} / p_i	Ignition
1	6.9	24	101.23	107.04	1.06	N
2	6.9	24	101.15	105.88	1.05	N
3	7.1	24	101.17	109.02	1.08	Y
4	7.1	24	101.42	109.75	1.08	Y
Test result	L1=6.9%, L2=7.1%, LFL=7.0%					

LFL test data at cell vent temperature (part)						
Test Condition	Initial Temperature: 143.3(±2)°C Initial Pressure: 101(±3)kPa					
No.	cs [%]	Ti [°C]	p_i [kPa]	p_{ex} [kPa]	p_{ex} / p_i	Ignition
1	6.2	143	101.36	107.23	1.06	N
2	6.2	144	101.59	106.57	1.05	N
3	6.4	143	101.44	108.92	1.074	Y
4	6.4	143	101.52	109.37	1.08	Y
Test result	L1=6.2%, L2=6.4%, LFL=6.3%					

Appendix B: Cell vent gas burning velocity (Su) test

Same synthetically replicated gas mixture as LFL test was used for the test. See appendix A for detailed sample information.

Test Method	ISO 817: 2014 / Amd 1: 2017 Refrigerants - Designation and safety classification
Test Item	Burning velocity of flammable gases
Test Apparatus	Test vessel: Glass tube; length 1500 mm; inner diameter 40 mm Ignition system: Electric spark Recorder: High speed camera
Preparation of Test Mixture	Partial pressure method used inside the vessel; Accuracy: within 0.2% absolute
Symbol and definition	The symbols used in this report are defined as below except otherwise defined: c_s —— Concentration of sample; S_S —— Flame propagation speed; a_f —— Cross-sectional area of flame bottom; A_f —— Flame surface area; S_u is calculated as: $S_u = S_S \times \frac{a_f}{A_f}$
Remark	This report is effective under the specific condition; please seek for the advice of expert for risk assessment in producing, processing, transportation and storage.

Burning velocity test data (part)				
Test Condition	Initial temperature: room temperature Initial pressure: atmospheric pressure The oxidant used: synthetic air Smallest flammable substance content increment: 1.0% volume			
No	c_s [%]	S_S [m/s]	a_f / A_f	S_u [m/s]
1	20	1.221	0.424	0.518
2	21	1.324	0.394	0.522
3	22	1.628	0.411	0.669
4	23	1.544	0.409	0.631
5	24	1.516	0.377	0.572
Test result	S_u= 0.669 m/s at room temperature and atmosphere pressure.			

Appendix C: Cell vent gas maximum pressure (Pmax) test

Same synthetically replicated gas mixture as LFL test was used for the test. See appendix A for detailed sample information.

Test Method	EN 15967: 2011 Determination of maximum explosion pressure and the maximum rate of pressure rise of gases and vapours
Test Item	Maximum explosion pressure of the gas mixture
Test Apparatus	Test Vessel: 20L closed sphere Ignition system: Fusing Wire
Preparation of Test Mixture	Partial pressure method used inside the vessel; Accuracy: within 0.2% absolute
Symbol and definition	The symbols used in this report are defined as below except otherwise defined: c_s —— Content of flammable substance by volume; p_{exn} —— Explosive overpressure in the n^{th} ignition test at a certain concentration; p_{ex} —— The average value of the explosion overpressure at a certain concentration; P_{Mean} ——The average value of the explosion overpressure at a certain concentration; P_{Lowest} —— Lowest explosion pressure in 5 (resp. 3) tests; $P_{Highest}$ —— Highest explosion pressure in 5 (resp. 3) tests; P_{max} —— Maximum explosion pressure; p_{max} is expressed as the maximum value of p_{ex}.
Remark	This report is effective under the specific condition; please seek for the advice of expert for risk assessment in producing, processing, transportation and storage.

P_{max} test data (part)							
Test Condition	Initial Temperature: 24(±2)°C Initial Pressure: 101(±3)kPa						
Part of Test Data							
No.	c_s [%]	p_{ex1} [MPa]	p_{ex2} [MPa]	p_{ex3} [MPa]	p_{ex4} [MPa]	p_{ex5} [MPa]	$\overline{p}_{ex}$ [MPa]
1	18.0	0.633	0.639	0.625	/	/	0.632
2	20.0	0.630	0.637	0.636	/	/	0.634
3	21.0	0.669	0.670	0.681	/	/	0.673
4	21.6	0.683	0.685	0.687	/	/	0.685
5	21.8	0.685	0.693	0.692	/	/	0.690
6	22.0	0.682	0.687	0.677	/	/	0.682
7	22.2	0.683	0.686	0.676	/	/	0.682
8	23.0	0.675	0.675	0.676	/	/	0.675
9	24.0	0.663	0.667	0.661	/	/	0.664
10	26.0	0.633	0.639	0.631	/	/	0.634

Determination of the explosion pressure					
No.	C_s [%]	P_{Lowest} [MPa]	$P_{Highest}$ [MPa]	P_{Mean} [MPa]	P_{ex} [MPa]
1	18.0	0.625	0.639	0.632	0.639
2	20.0	0.630	0.637	0.634	0.637
3	21.0	0.669	0.681	0.673	0.681
4	21.6	0.683	0.687	0.685	0.687
5	21.8	0.685	0.693	0.690	0.693
6	22.0	0.682	0.687	0.682	0.687
7	22.2	0.676	0.686	0.682	0.686
8	23.0	0.675	0.676	0.675	0.676
9	24.0	0.661	0.667	0.664	0.667
10	26.0	0.631	0.639	0.634	0.639
Test result					
Content of flammable substance	21.8% volume				
Accuracy	0.2% absolute				
Maximum explosion pressure	0.693 MPa				

End of Test Report