CSA GROUP

Laboratory Test Data - UL 9540A Checklist and Test Result (Cell Level)

ORIGINAL TEST DATA

The results relate only to the items tested.
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Master Contract:	304401	Model:	NPS-3777AH	Page number 1 of 23
Project / Network:	80192231	Description:	Lithium battery cell	

Standard(s): ANSI/CAN/UL 9540A:2019 Fourth Edition, Dated November 12, 2019 - Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

Testing Laboratory Name:	CCIC-CSA International Certification Co., Ltd. Kunshan Branch
Address:	2F-1, Building C12, No 555 Dujuan Road, Kunshan Economic & Technical Development Zone, Kunshan, Jiangsu, China 215331
Testing Program:	**Custom Test** : Cover Latter ☒, Testing Only ☐

If tests were performed at another facility, then described below:

Testing Laboratory Name:	ChuWeiNeng Testing Technology (Shanghai) Co.Ltd
Address:	Building 3, No.1065 Beihe Highway, Jiading District, Shanghai
Facility Qualification Number:	N/A

	As above / or describe otherwise
Customer:	Australia National Power Storage Holding Pty Ltd.
Address:	Chatswood West Willoughby, New South Wales 2067 Australia

Tested By: Jiaming Huang
Name, Title

Jiaming Huang — 2024-05-24 - 2024-08-07
Signature — *Date (YYYY-MM-DD)*

☒ **Reviewed by:**
☒ **Witnessed by:**
Name, Title

Marvin Peng — 2024-05-24 - 2024-08-07
Signature — *Date (YYYY-MM-DD)*

Version6.1 : 2022-08-02

Master Contract:	304401	Model:	NPS-3777AH	Page number 2 of 23
Project / Network:	80192231	Description:	Lithium battery cell	

Cell Level Test Summary	
Manufacturer:	Australia National Power Storage Holding Pty Ltd.
Brand name / Trademark:	N/A
Model number:	NPS-3777AH
Nominal cell voltage, (V)	3.2
Cell capacity, (Ah)	3777
Cell chemistry:	LFP
Physical format of cell:	Prismatic
Approximate dimension, (mm)	1095×203×294
Mass, (kg)	110±0.5
Cell certification available?, (Yes/No)	Yes
Standard(s) used to certify product:	UL 1973, 3rd Edition
Certification organization name and its certificate number:	CSA, Report number 80192227
Method used to initiate thermal runaway:	External heater
Average temperature at which cell first vented excluding gas collection sample, (°C)	145.5
Average temperature prior to thermal runaway excluding gas collection sample, (°C)	226.5
Location of maximum temperature:	Large surface of cell
Flammable gas generation, (Liter)	1576.8
Total gas generation, (Liter)	2380
Lower flammability limit (LFL) at ambient temperature (25 ± 5°C), (%)	8.1
Lower flammability limit (LFL) at average gas vent temperature, (%)	7.1
Burning velocity, (Cm/Sec)	0.335
Maximum pressure P_{max}, (psig)	104.8

Gas composition:

Gas Component	Gas Type	Gas Volume in percentage (%)
CH_4	Methane	7.293
C_2H_6	Ethane	1.418

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Cell Level Test Summary

C_2H_4	Ethylene	5.019
C_3H_8	Propane	0.427
C_3H_6	Propylene	0.122
C_4H_{10}	Isobutane	0.862
C_4H_{10}	n-Butane	0.032
C_2H_2	Acelylene	0.186
C_4H_8	n-Butylene	0.279
C_4H_8	2-Methylpropene	0.103
C_5H_{12}	Isopentane	0.005
C_5H_{12}	Pentane	0.112
C_5H_{10}	n-Pentane	0.047
H_2	Hydrogen	39.374
CO	Carbon Monoxide	6.378
CO2	Carbon Dioxide	38.343
Total	---	100

Additional Information:	Heater: Size:190mm×160mm, Rated power: 220V,900W. Quantity: 8

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Performance - Cell Level Test		
Requirement	**Comments**	**Verdict**
Thermal runaway cannot be induced in the cell.	Thermal runaway induced on cell using film heater	F
Cell does not present a flammability hazard when mixed with any volume of air, as determined in accordance with ASTM E918 at both ambient and vent temperature.	Cell presented flammability hazard when tested in accordance with ASTME918, module and unit level test required	F
Summary of Result: Module level testing is required based on above performance condition indicated in Section 7.7 of UL 9540A 4th Edition.		

Possible test case verdicts:

- Test case does not apply to the test object: N/A
- Test object does meet the requirement: P (Pass)
- Test object does not meet the requirement: F (Fail)

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Project / Network:	80192231	Description:	Lithium battery cell	

Clause	Requirement + Test	Result - Remark	Verdict
	Construction		
5	**General**	---	---
5.1	**Cell**	---	---
5.1.1	Cell chemistry:	Li-ion (LFP)	---
	Physical format of cell:	Prismatic	---
	Nominal voltage rating, (V)	3.2	---
	Nominal capacity rating, (Ah)	3777	---
	Approximate dimension, (mm)	1095×203×294	---
	Mass, (kg)	110±0.5	---
5.1.2	Cell certification available?, (Yes/No)	Yes	---
	Standard(s) used to certify product:	UL 1973, 3rd Edition	---
5.1.3	Cell Level Test Report	Under certification	---
	Performance		
7	**Cell Level**	---	---
7.1	**General**	---	---
7.1.1	Establish effective method by forcing a cell into a thermal runaway in a repeatable manner.	Test Method: Film heater	P
	Vent gas composition was gathered and analyzed.	See table 4 for details	P
	Cell temperature was monitored to determine the temperature when cell vents.	See below	P
	Cell temperature was monitored to determine thermal runaway as defined in UL 9540A 4th Edition.	See below	P
7.2	**Sample**	---	---
7.2.1	Prior to testing, cell samples were conditioned for minimum 2 charge (100% SOC) - discharge (Specified end of discharge voltage) cycle as per manufacturer specified method.	See Attachment 2	P
	Cells were functional after minimum 2 charge discharge cycle.	Confirmed	P
	During conditioning a relationship between open circuit voltage and SOC was determined through measurement of voltage and SOC.	Confirmed, client declared charge/discharge procedure followed, see Attachment2	P
	Ambient temperature during cell conditioning.	Confirmed	P
7.2.2	The tested cells had 100% SOC at the start of the test. The samples were allowed to stabilize for a minimum of one	Confirmed	P

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Clause	Requirement + Test	Result - Remark	Verdict
	hour and a maximum of 8 h before the start of the test.		
7.2.3	Cells with flexible laminate casings were constrained during test in manner that simulate constraint in the BESS module to prevent excessive swelling during test.	Prismatic cell with jig to constrain cells when testing	P
7.3	**Determination of thermal runaway methodology**	**---**	**---**
7.3.1	General	See below	P
7.3.1.1	Ambient temperature during cell testing.	See Table 3	P
7.3.1.2	Propensity of cell to exhibit thermal runaway demonstrated by externally applied film heater.	Heater type: Film heater Heater dimension (mm): 190×160×0.36 Number of heaters used: 8	P
	A surface heating rate of 4° C (7.2° F) to 7° C (12.6° F) per minute shall be applied to the cell.	☒ 4.5 ° C/min heating ramp was used for testing	P
	Maximum surface temperature endpoint criteria was determined based on cell design and cell chemistry.	Considered	P
	Thermal runaway method used, when external heating with flexible heater was not able to cause the cell to exhibit thermal runaway.	☐ Mechanical: ☐ Electrical Stress: ☐ Alternate heating sources: ☐ Other(explain):	N/A
7.3.1.3	Detail of thermal runaway test method when another method used as reference in 7.3.1.2.	Film heater was used for testing	N/A
7.3.1.4	Monobloc battery such as lead acid or nickel cadmium, was treated as individual cell for this testing.	Li-ion cell	N/A
7.3.1.5	Surface temperature at which internal short circuiting within the cell will occur that could lead to thermal runaway.	See below	N/A
	Surface temperature hold point. For lithium ion cell, hold point was between 5°C (9°F) and 15°C (27°F) greater than the melting temperature of the cell separator material as determined from differential scanning calorimetry (DSC) data of the separator in accordance with UL 2591 (UL 746A).	Cell was heated directly until thermal runaway initiated following UL 9540A Certification Requirement Decision	N/A
	If thermal runaway is not achieved at holding temperature after period of 4h,	See above	N/A

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Clause	Requirement + Test	Result - Remark	Verdict
	heating rate according to 7.3.1.3 was reestablished.		
7.3.1.6	If cell is susceptible to thermal runaway by external heating, cell was heated until thermal runaway has occurred.	Confirmed, Film heater method used for testing	P
	If cell is not susceptible to thermal runaway by external heating, another method included in 7.3.1.2 was used.	See above	N/A
	If using another external heating method, temperature ramp and maximum surface temperature as outlined in 7.3.1.2 and 7.3.1.5 was used.	See above	N/A
7.3.1.7	Cell's exterior surface temperature was measured continuously, averaging over every 60 seconds	Confirmed	P
	The maximum of these averages was documented for each thermocouple location.	Confirmed	P
	Location of thermocouple during test.	☒ Below the heater film at center of cell surface: T2, T7-2. T9.T15.T20-2.T22 ☒ Near positive cell terminal: T27 ☒ Other(explain): Near vent: T28 Large surface not covered by heater: T4, T17	P
7.3.1.8	The temperature at which the cell case vents due to internal pressure rise.	Confirmed	P
	The thermocouple located below the heater film at the center of the cell surface is used for this measurement.	Confirmed	P
	If using the other cell abuse methods, the thermocouples would be located at the same locations on the cells as noted in 7.3.1.7.	See above	N/A
7.3.1.9	The temperature at the onset of thermal runaway was documented.	See Table 3 for details	P
	Onset of thermal runaway was determined by the point at which the rate of change of the surface temperature of the cell exceeds that of the externally applied heat input if utilizing the external heater method.	Considered, see table 3 for the onset temperature for thermal runaway.	P

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Clause	Requirement + Test	Result - Remark	Verdict
	In cases where cell venting may occur first, cell was heated continuously until thermal runaway occurs.	Confirmed	P
	With other stress methods, it was necessary to continue applying the stress such as mechanical or electrical stress until onset of thermal runaway occurs.	External heating method used	P
	Separator information was available or at the manufacturer's discretion, the thermal ramp was conducted continuously without a hold point until thermal runaway.	Thermal ramp was conducted continuously without holding point considered	P
7.3.1.10	When using methods other than the heater method, the stresses (i.e. electrical or mechanical) were applied to the cell until thermal runaway occurs.	Film heater method used	N/A
7.3.1.11	If the cell exhibits thermal runaway behavior (using any method), 3 additional samples were tested using the same method and exhibit thermal runaway to demonstrate repeatability.	See Table 3 for details	P
	The vent temperature and thermal runaway onset temperatures were averaged over the tested samples (Excluding the gas vent capture sample).	See Table 3 for details	P
7.3.2	Flow battery thermal runaway determination tests	Li-ion battery cell	N/A
7.4	**Cell vent gas composition test**	**---**	**---**
7.4.1	Cell vent gas was generated and captured by forcing a cell into thermal runaway with the methodology developed in 7.3, inside a pressure vessel, which is large enough to accommodate cells, but not so large as to influence measurement of the gas composition.	Confirmed: 400L pressure vessel used for testing.	P
	The test was initiated with an initial condition of atmospheric pressure and less than 1% oxygen by volume.	See Table 4 for details	P
	The initial atmospheric conditions prior to testing was noted.	See Table 4 for details	P
7.4.2	Cell vent gas composition was determined using Gas Chromatography (GC)	See Table 4 for details	P
	Hydrogen gas was measured with a sensor capable of measuring in excess of 30% by volume.	See Table 4 for details	P

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Clause	Requirement + Test	Result - Remark	Verdict
	The initial atmospheric conditions prior to testing was noted.	See Table 4 for details	P
7.4.3	The lower flammability limit of the cell vent gas was determined in accordance with ASTM E918, testing at both ambient and cell vent temperatures.	See Table 4 for details	P
7.4.4	The burning velocity of the cell vent gas was determined in accordance with Annex in ISO 817.	See Table 4 for details	P
7.4.5	The P_{max} of the cell vent gas was determined in accordance with EN 15967.	See Table 4 for details	P
7.5	**Off gas composition for flow battery systems.**	---	---
7.5.1	The off gas composition from the flow battery testing of 7.3.2 shall be determined by conducting the test method of 7.3.2.2: 1. In a closed container and capturing the off gasses generated, and 2. By collecting the off gasses generated at vent openings and vent ducts during the overcharge and short circuit testing of 7.3.2.4 and 7.3.2.6 as applicable to the flow battery technology	Li-ion battery cell	N/A
	Composition of these captured gases and their flammability limit shall be determined through the methods outlined in 7.4.2 and 7.4.3 at both ambient temperature and the maximum temperature measured.	Li-ion battery cell	N/A
7.5.2	The volume of flammable gases measured during the testing were scaled to the maximum energy reservoir for the intended flow battery system.	Li-ion battery cell	N/A
7.6	**Cell level test report**	---	---
7.6.1	Cell level report include information indicated in item a) through m)	Confirmed	P
7.6.2	Flow battery report include information indicated in item a) through k)	Li-ion battery cell	N/A

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Table 1 – Cell charge/discharge specification			
Charging method	CC-CV	Discharging method	CC
Charge current, (Adc)	1888.5	Discharge current, (Adc)	1888.5
Charge voltage, (Vdc)	3.65	---	---
Charge end current, (Adc)	180	Discharge end voltage, (Vdc)	2.5
Manufacturer recommended charge temperature, (°C)	0-60	Manufacturer recommended discharge temperature, (°C)	-30-60

Table 2 – Cell rest duration				
Sample Number	Final charge end time		Test start time	
	Date (YYYY-MM-DD)	Time (HH:MM AM/PM)	Date (YYYY-MM-DD)	Time (HH:MM AM/PM)
202305013-1	2024-05-24	09:13 AM	2024-05-24	12:01 AM
202305013-2	2024-05-27	10:09 PM	2024-05-27	17:43 PM
202305013-3	2024-05-28	15:51 PM	2024-05-28	19:04 PM
202305013-4	2024-05-31	09:17 AM	2024-05-31	13:58 AM
202305013-5	2024-06-24	14:03 PM	2024-06-24	19:15 PM
Ambient temperature during cell conditioning				
Ambient Lab Temperature, (°C)		Relative Humidity, (%RH)		
24.2 to 25.2		61 to 68		

Table 3 – Determination of thermal runaway methodology					
Sample Number	Note 1				Note 2
	202405013-1	202405013-2	202405013-3	202405013-4	202405013-5
Open circuit voltage before test, (Vdc)	3.500	3.353	3.575	3.460	3.526
Cell charge capacity after final charge cycle, (Ahr)	3741.36	3741.36	3752.66	3772.13	3516.16@
External film heater ramp rate, (°C/min)	4.5	4.5	4.5	4.5	4.5
Temperature at which gases are first vented, (ºC)	140.1/ 148.1	147.7/ 140.0	143.8/ 135.3	156.9/ 152.3	164.5/ 174.8
Temperature prior to thermal runaway, (ºC)	147.5 / 175.9	211.1 / 243.2	281.1/ 255.8	240.9 / 256.5	219.9/ 213.1
Location of maximum temperature prior to thermal runaway	Cell surface under heater	Cell surface under heater	Cell surface under heater	Cell surface under heater	Cell surface under heater
Average temperature at which gases are first vented, (ºC)	145.5				---
Average temperature prior to thermal runaway, (ºC)	226.5				---
Other method used to initiate thermal runaway: N/A					

Table 3 – Determination of thermal runaway methodology	
Note: The capacity was over manufacturer's declaration which is 90% of the full capacity.	
Ambient temperature during cell testing	
Ambient Lab Temperature, (°C)	Relative Humidity, (%RH)
24.2 to 25.2	61 to 68
Note 1: Sample tested outside pressure vessel Note 2: Sample tested inside pressure vessel for cell vent gas composition test	

Table 4 – Cell vent gas composition test	
Sample Number:	202404020-5
Pressure vessel volume (liter):	400
An initial condition of atmospheric pressure (kPa):	101.3
An initial condition of oxygen by volume (%):	0.14
Flammable gas generation volume(Liter):	1576.8
Total gas generation volume (Liter):	2380
LFL limit at ambient temperature (%):	8.1
LFL limit at cell vent temperature (%):	7.1
Burning velocity (cm/sec):	0.335
Maximum pressure P_{max} (kPa):	722.9
Ambient temperature during cell testing	
Ambient Lab Temperature, (°C)	Relative Humidity, (%RH)
24.2 to 25.2	61 to 68

Gas composition

Gas Component		Volume Released (After thermal runaway) (%)
Carbon Monoxide	CO	

Table 4 – Cell vent gas composition test

Total	---	100

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Attachments

(Add additional raw data, proof of product certification, photos, videos etc for attachment as needed. Following are just example, update attachment list as needed)

Index of Attachments

Master Contract:	304401	Model:	NPS-3777AH	Page number 14 of 23
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Attachment 1 - Cell UL 1973 certification

Insert certificate here

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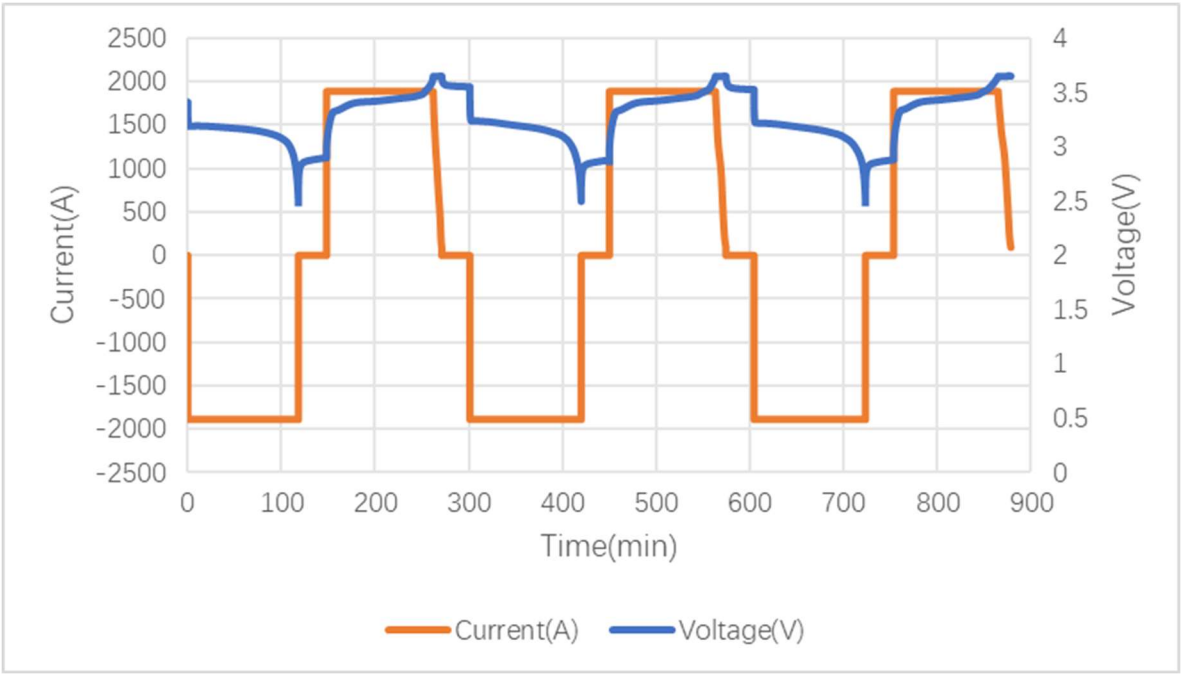
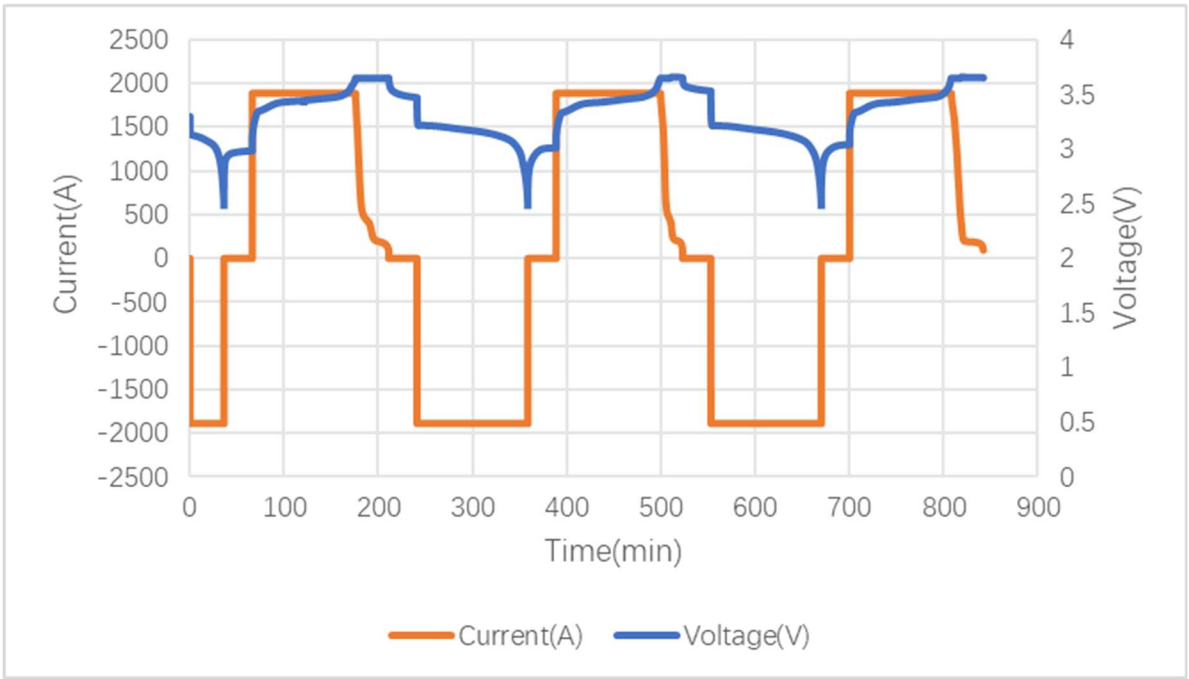
Attachment 2 - Cell charge/discharge conditioning graphs

Sample Number: 202405013-1



Sample Number: 202405013-2



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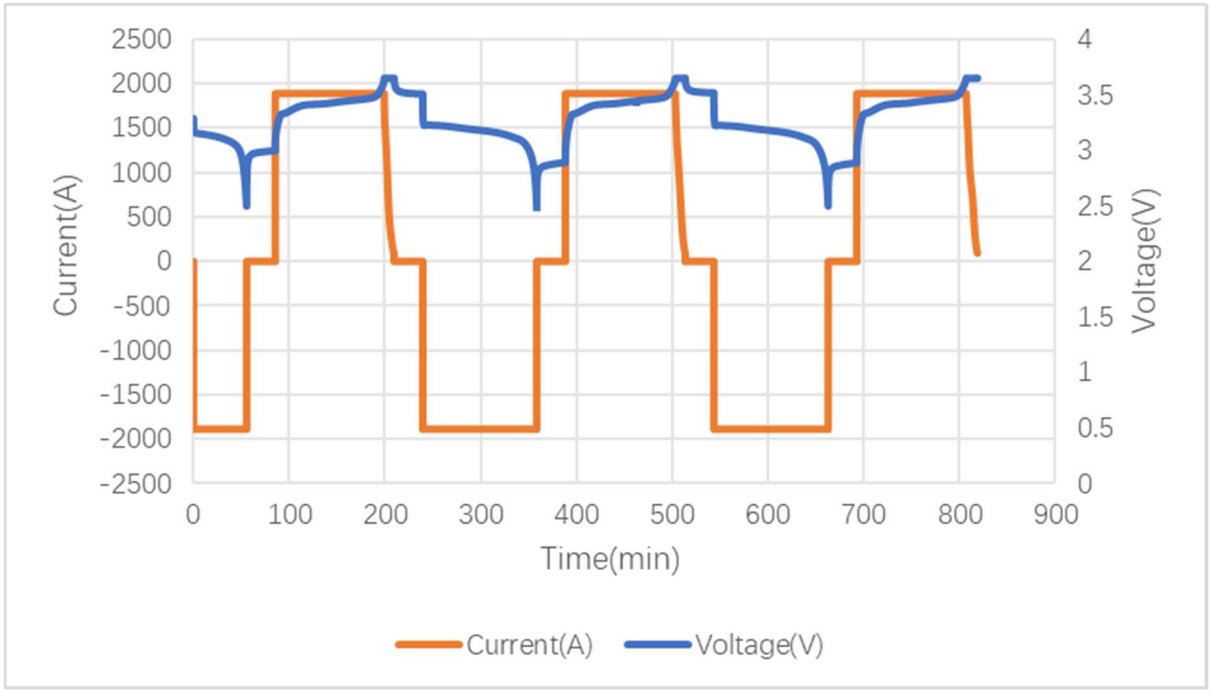
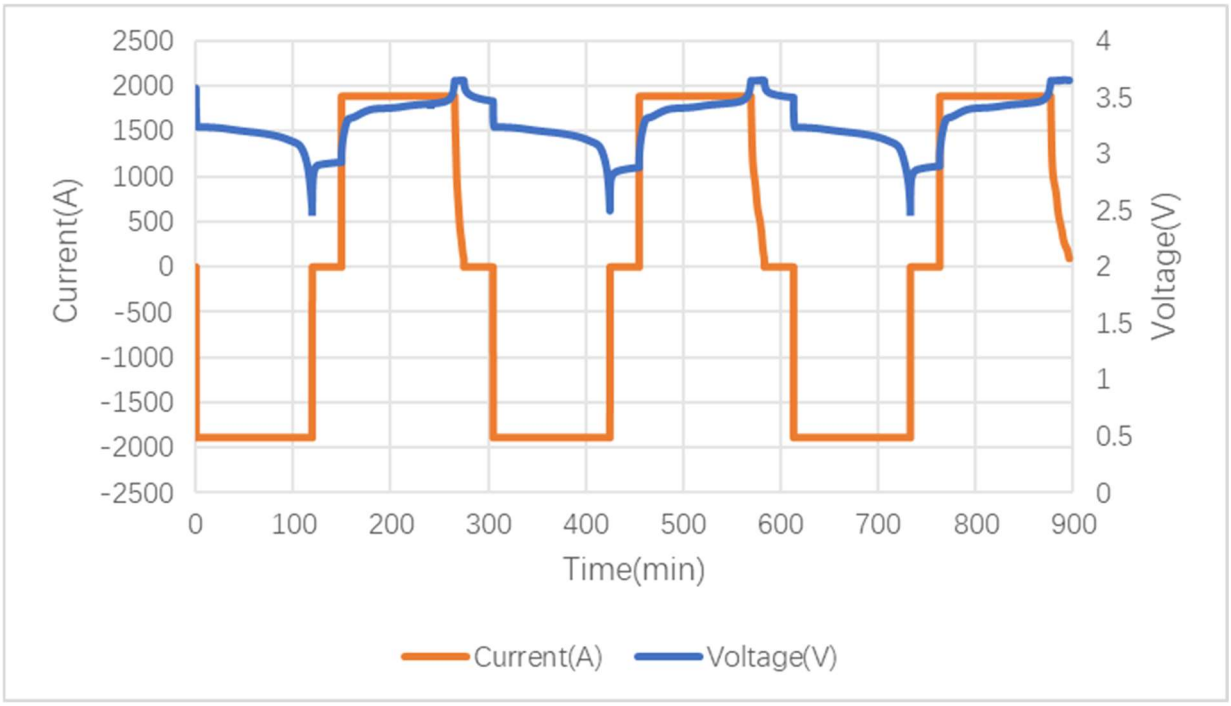
Attachment 2 - Cell charge/discharge conditioning graphs

Sample Number: 202401022-3



Sample Number: 202405013-4



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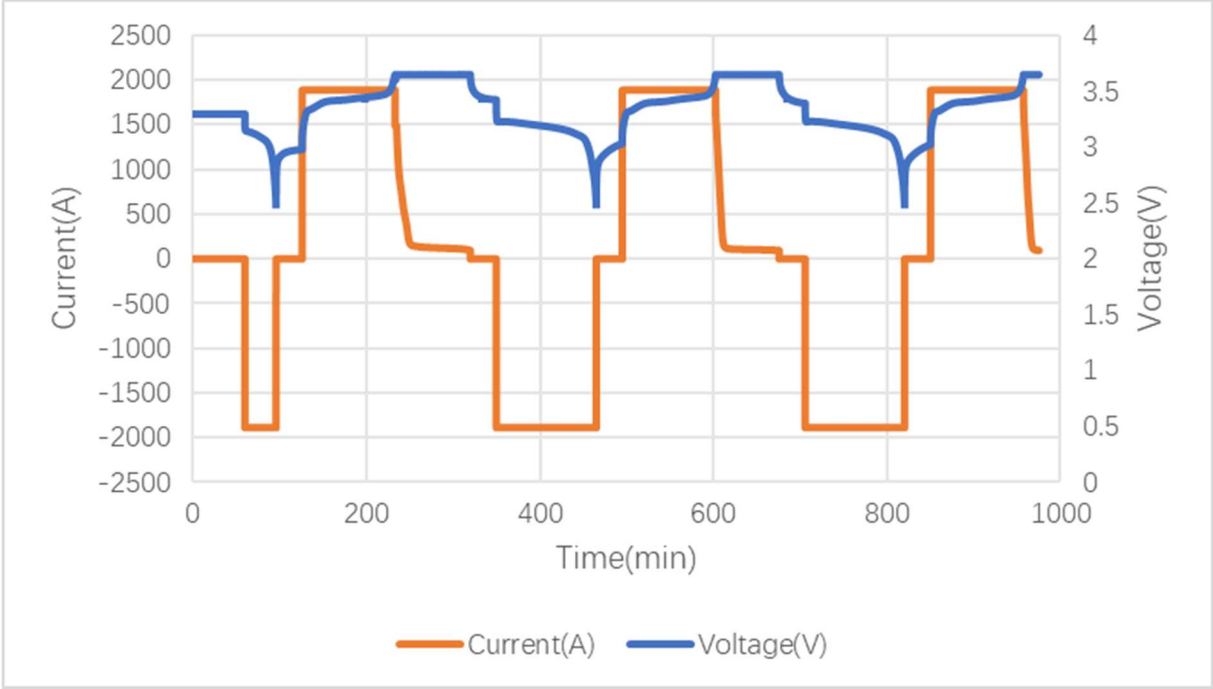
Attachment 2 - Cell charge/discharge conditioning graphs

Sample Number: 202405013-5



Attachment 3 – Photos
photos during testing of each sample, such as before start of test, during venting, during thermal runaway, after thermal runaway, add more picture as needed.

General sample photos	
Insert photo here	Insert photo here
Figure XX:	Figure XX:
Insert photo here	Insert photo here
Figure XX:	Figure XX:

Photos with heater and thermocouple installation	
Insert photo here	Insert photo here
Figure XX:	Figure XX:
Insert photo here	Insert photo here
Figure XX:	Figure XX:

Sample Number:	
Insert photo here	Insert photo here
Figure XX: At test start (Time in HH:MM)	Figure XX: During cell venting (Time in HH:MM)

Attachment 3 – Photos

photos during testing of each sample, such as before start of test, during venting, during thermal runaway, after thermal runaway, add more picture as needed.

Insert photo here	Insert photo here
Figure XX: During thermal runaway (Time in HH:MM)	Figure XX: After thermal runaway-1
Insert photo here	Insert photo here
Figure XX: After thermal runaway-2	Figure XX: After thermal runaway-3

Sample Number:

Insert photo here	Insert photo here
Figure XX: At test start (Time in HH:MM)	Figure XX: During cell venting (Time in HH:MM)
Insert photo here	Insert photo here
Figure XX: During thermal runaway (Time in HH:MM)	Figure XX: After thermal runaway-1
Insert photo here	Insert photo here
Figure XX: After thermal runaway-2	Figure XX: After thermal runaway-3

Sample Number:

Attachment 3 – Photos

photos during testing of each sample, such as before start of test, during venting, during thermal runaway, after thermal runaway, add more picture as needed.

Insert photo here	Insert photo here
Figure XX: At test start (Time in HH:MM)	Figure XX: During cell venting (Time in HH:MM)
Insert photo here	Insert photo here
Figure XX: During thermal runaway (Time in HH:MM)	Figure XX: After thermal runaway-1
Insert photo here	Insert photo here
Figure XX: After thermal runaway-2	Figure XX: After thermal runaway-3

Sample Number:

Insert photo here	Insert photo here
Figure XX: At test start (Time in HH:MM)	Figure XX: During cell venting (Time in HH:MM)
Insert photo here	Insert photo here
Figure XX: During thermal runaway (Time in HH:MM)	Figure XX: After thermal runaway-1

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Attachment 3 – Photos photos during testing of each sample, such as before start of test, during venting, during thermal runaway, after thermal runaway, add more picture as needed.	
Insert photo here	Insert photo here
Figure XX: After thermal runaway-2	Figure XX: After thermal runaway-3
Sample Number:	
Insert photo here	Insert photo here
Figure XX: At test start (Time in HH:MM)	Figure XX: During cell venting (Time in HH:MM)
Insert photo here	Insert photo here
Figure XX: During thermal runaway (Time in HH:MM)	Figure XX: After thermal runaway-1
Insert photo here	Insert photo here
Figure XX: After thermal runaway-2	Figure XX: After thermal runaway-3

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Attachment 4 - Cell temperature/voltage graph during testing
Sample Number:
Insert graph here
Sample Number:
Insert graph here
Sample Number:
Insert graph here
Sample Number:
Insert graph here
Sample Number:
Insert graph here

End of Report….

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Note: Save Equipment list in different file. When submit report for review upload equipment list in test data folder of main project folder bin.


UL%209540A%20Equipment%20List.doc