

Subsea Endurance: Technical Review of Subsea Battery Power at Different Temperatures and Rates

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I. INTRODUCTION

According to the Secretary of the Navy in the Report on Autonomous Vehicle Requirements (AUV) for 2025, “Endurance (how far and how fast can the AUV go, and how many sensors need to be supported)” is one of the four core AUV capability characteristics for the future. Most oceanographers or subsea operators would agree: going deeper, staying down longer, and/or using more simultaneous and more powerful instruments/sensors are always on their wish list. This relates directly to endurance.

Endurance subsea most often relates to the amount of and utilization of the power source for the propulsion, instruments, and/or sensors. While many power sources are available, the mainstream source for subsea untethered vehicles, sensors, and instruments are batteries. While various battery types exist, the dominant use for subsea applications is lithium primary and lithium ion secondary batteries.

Batteries are electrochemical devices that perform differently at different temperatures and at different rates of discharge. Thus endurance is affected by both temperature and discharge rate, and even the combination of these within use case operations subsea. This paper will outline test data results and explain the simultaneously measured endurance results and effects of various discharge rates and various temperatures on pressure tolerant lithium ion polymer battery modules. As such, endurance can be properly planned based on real world use case conditions. Subsea endurance for AUVs, sensors, or other instruments can be estimated and maximized where possible based on this test information and analysis.

II. LITHIUM ION BATTERIES IN SUBSEA USE

While various battery types exist, the emerging dominant use for subsea applications is lithium ion secondary batteries based on their relative technology maturity, availability, energy density, and rechargeable characteristics. Such Lithium Ion subsea batteries typically will be available in one of two types:

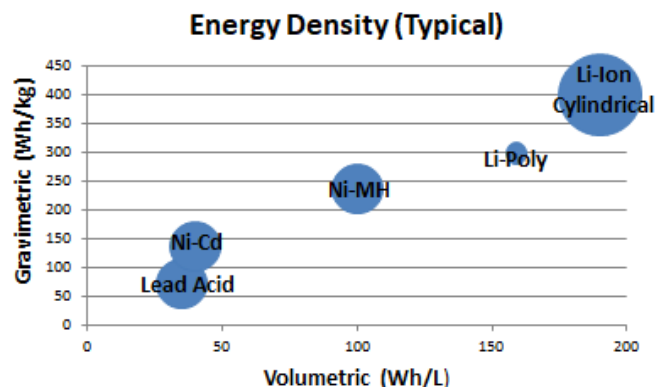
1. 1 Atmosphere: Must be utilized within a pressure vessel that maintains 1 atmosphere
2. Pressure Tolerant: Able to withstand the increased pressure of the Ocean depths.

For the pressure tolerant type of subsea batteries, they can be classified into two types:

1. Use within a Pressure Balanced Oil Filled (PBOF) Case, which itself is put into the ocean water
2. Use directly in the ocean water.

All Lithium Ion batteries must be managed by a battery management system (BMS) to provide safe and reliable operation in standby, storage, charge, and discharge states. These BMS often can also report battery status information and state of health.

Many of the smaller Autonomous Underwater Vehicles (AUV) utilize the 1 atmosphere lithium ion type batteries within cylindrical shaped 1 atmosphere pressure vessels, typical of the “torpedo” shaped AUVs. Some manned submersibles and larger AUVs utilize pressure tolerant subsea batteries, be it either within a PBOF case or utilized direct in the ocean water via a flooded compartment.



As you can see in this battery energy density (typical) chart the Lithium Ion Polymer (Li-Poly) battery cell technology used in the batteries for this test is near the highest range of energy density battery solutions, and the only technology we have been able to validate as pressure tolerant at subsea

pressures. Southwest Electronic Energy Corporation (SWE) SeaSafe II and SeaSafe Direct batteries, utilized for this temperature and rate sensitive subsea performance testing, are made with cells of this Lithium Ion Polymer type and are of the pressure tolerant class

III. BATTERY PERFORMANCE TEST PARAMETERS

Lithium Ion batteries are electrochemical devices that perform differently at different temperatures and at different rates of discharge. Thus subsea endurance, which in this case is:

- delivered battery capacity and
- delivered battery voltage

under particular subsea use case conditions is affected by both temperature and discharge rate combined within the subsea use case conditions. The delivered battery capacity measured will be compared to the nominal rated capacity operating at a nominal load and a typical room temperature. Also, the voltage measured will be compared to open circuit voltage and the voltage at different discharge rates, identifying the voltage droop that will likely occur with higher current loads and/or lower ambient operating temperatures.

Charge rates and subsea pressure can affect battery capacity and discharge. However, tests have shown that the effect of these parameters is a lower order factor.

Consequently, this paper will discuss test data results showing both delivered capacity and delivered battery voltage subsea endurance and the effects of a range of relevant discharge rates and temperatures on pressure tolerant lithium ion polymer battery module subsea endurance.



The following section seeks to show some key performance characteristics of the SWE SeaSafe II® and SWE SeaSafe Direct® battery modules. These batteries utilize a series of 31 Amp Hour lithium polymer battery cells managed by a proprietary pressure tolerant BMS, all built into a

pressure tolerant battery module. In each set of tests, four different subsea battery modules, as briefly described in the above figure, are tested:

1. The 1st module tested is a 29.6 Volt nominal battery module called the SeaSafe II 30V battery module. It is an 8 series configuration of cells managed by a built-in, pressure-tolerant BMS, all interconnected and specialty potted into a case to provide a pressure tolerant battery module. This module is used within oil and interconnected with other modules within a PBOF case.
2. The 2nd module tested is a 29.6 Volt nominal battery module called the SeaSafe Direct 30V battery module. It is an 8 series configuration of cells managed by a built-in, pressure-tolerant BMS, all interconnected and specialty potted into a case to provide a pressure tolerant battery module that uses subsea cables and connectors to be subsea ocean-direct tolerant. This module is used directly within the ocean and interconnected with other modules via subsea tolerant connectors and cables.
3. The 3rd module tested is a 25.9 Volt nominal battery module called the SeaSafe II 24V battery module. It is a 7 series configuration of the cells managed by a built-in, pressure-tolerant BMS, all interconnected and specialty potted into a case to provide a pressure tolerant battery module. This module is used within oil and interconnected with other modules within a PBOF case.
4. The 4th module tested is a 25.9 Volt nominal battery module called the SeaSafe Direct 24V battery module. It is a 7 series configuration of the cells managed by a built-in, pressure-tolerant BMS, all interconnected and specialty potted into a case to provide a pressure tolerant battery module that uses subsea cables and connectors to be subsea ocean-direct tolerant. This module is used directly within the ocean and interconnected with other modules via subsea tolerant connectors and cables.

IV. DISCHARGE PERFORMANCE PLOTS

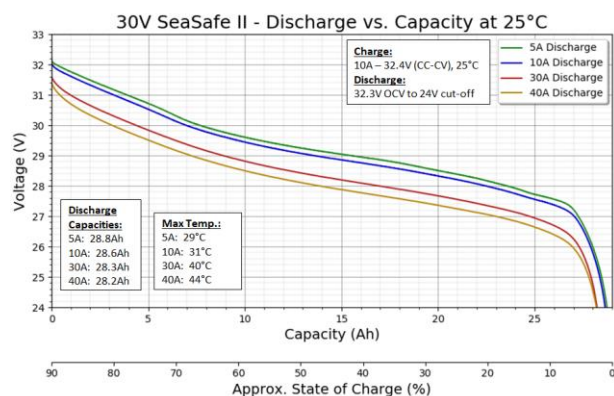
A. Test Setup Scenarios

The initial set of performance tests are based on 25°C to set a baseline of performance at typical topside nominal temperatures based on different continuous discharge current rates. This will show the effect of higher current loads on capacity delivered for the range of a fully charged battery to a completely discharged battery.

Note that all batteries used in this test are set to a BMS managed maximum “full charge” of 90% State of Charge

(SOC). This 90% SOC is the standard setting for the SeaSafe battery product line to avail reliable and long lasting battery life. It has the effect of limiting the 31Ah cells within the pack to a net 28Ah “full” SOC capacity. Consequently, the expected capacity delivered within the following tests to be considered full capacity delivered would be about 28Ah. Anything less than 28Ah capacity delivered would be a function of degradation from high amperage load currents and/or low operating temperatures. Data that these tests will report will provide insights into capacity delivered under different rate of discharge and different ambient operating temperature conditions.

B. Discharge Profiles at Room Temperature: 25°C (Capacity vs. Voltage) Plots



The above battery discharge test chart is for a 30V SeaSafe II battery module at 25°C temperature and different continuous current rates of 5A, 10A, 20A, and 40A respectively. The discharge voltage at 90% SOC starts at 32.3V OCV and is considered fully discharged and the test is stopped when it reaches 24V.

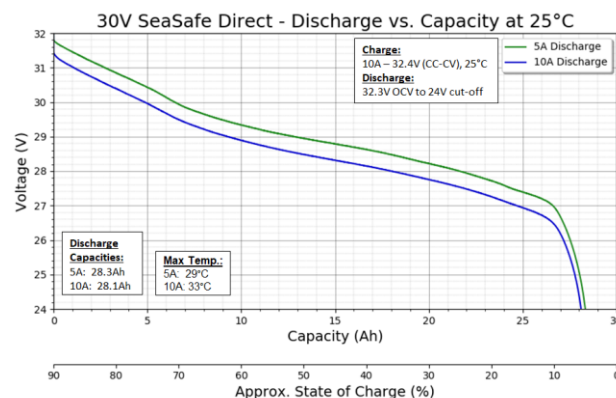
You can see that the higher the discharge rate, the lower the discharge voltage sustained throughout the entire discharge curve. At this 25°C temperature, the voltage droop difference between discharge voltage at 5A and discharge voltage at 40A is about -1.1V on average. The voltage droop for 10A and 30A constant discharge curves relative to the 5A discharge curve falls expectedly in between that of the 40A discharge curve, at about -0.8V average for 30A, and about -0.2V for 10A.

This droop in instantaneous power based on voltage droop at each particular continuous current rate would need to be considered in the available power calculations for the particular battery application load, be it motors, or sensors, or control/communications, and/or combinations thereof.

Note that the discharge capacities of all four tested continuous current discharge rates at 25°C operating temperature delivered more than the “full” 28Ah nominal rated capacity of the battery module, ranging from 28.2Ah at 40A rate to 28.8Ah at 5A rate. This shows that the cells

operate very effectively at 25°C ambient operating temperature.

Also note that the battery internal operating temperature was higher at the higher discharge rates. While operating at 25°C ambient in air with no cooling circulation, the battery module reached a maximum internal temperature of 44°C when discharging at 40 A continuous, and as low as 29°C maximum operating temperature when discharging at 5A continuous. These maximum internal operating temperatures are well below the SeaSafe II specified maximum operating temperature of 60°C. Also, in actual application within oil in the PBOF case in the ocean, the heat sink of the oil cooled by the ocean water would further reduce the battery internal temperature.



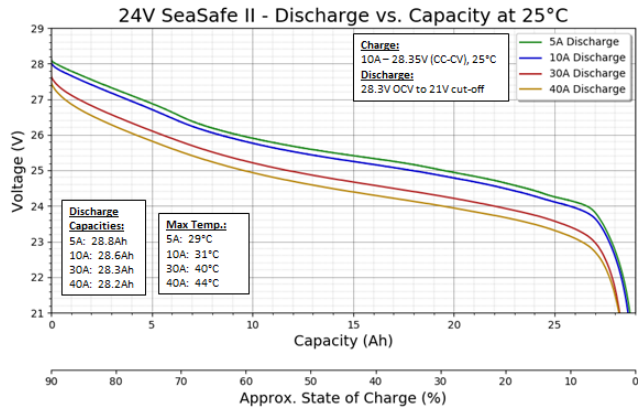
The above battery discharge test chart is for a 30V SeaSafe Direct battery module at 25°C temperature and different continuous current rates of 5A and 10A respectively. Note the limit of 10A continuous discharge current on the SeaSafe Direct battery module specification due to the subsea connector max current rating. The discharge voltage at 90% SOC starts at 32.3V OCV and is considered fully discharged and the test is stopped when it reaches 24V.

The voltage droop for 10A constant discharge curve relative to the 5A discharge curve is about -0.4V average. This is somewhat more significant than in the SeaSafe II due to the subsea cabling and connector higher resistance of the SeaSafe Direct relative to the cable and connector in the SeaSafe II.

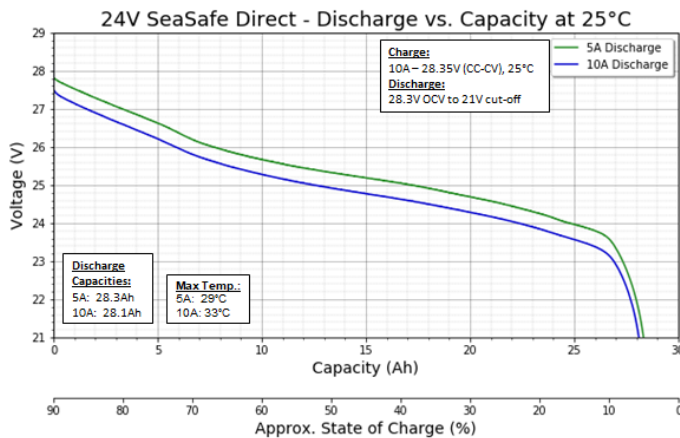
Note that the discharge capacities of both tested continuous current discharge rates at 25°C operating temperature delivered more than the “full” 28Ah rated capacity, ranging from 28.1Ah at 10 A rate to 28.3Ah at 5A rate. This shows that the cells operate very effectively at 25°C ambient operating temperature.

Also note that the battery internal operating temperature was slightly higher at the higher discharge rate. While operating at 25°C ambient in air with no cooling circulation, the battery module reached a maximum internal temperature of 33°C when discharging at 10A continuous, and 29°C maximum operating temperature when discharging at 5A continuous. Once again, these maximum internal operating

temperatures are well below the SeaSafe Direct specified maximum operating temperature of 60°C. Also, in an actual application direct in the ocean, the heat sink of the ocean water would further reduce the internal operating temperature.



The above battery discharge test chart is for a 24V SeaSafe II at 25°C temperature and different continuous current rates of 5A, 10A, 20A, and 40A respectively. The discharge voltage at 90% SOC starts at 28.3V OCV and is considered fully discharged and the test is stopped when it reaches 21V. On the 24V battery module, you can see again that the higher the discharge rate, the lower the discharge voltage sustained throughout the entire discharge curve. At this 25°C temperature, the voltage droop difference between discharge voltage at 5A and discharge voltage on the 24A module is about -1.1V on average. The voltage droop for 10A and 30A constant discharge curves relative to the 5A discharge curve falls expectedly in between that of the 40A discharge curve, at about -0.8V average for the 30A and about -0.2V for 10A. As expected, this is similar voltage droop as the 30V SeaSafe II at the same continuous current test levels.



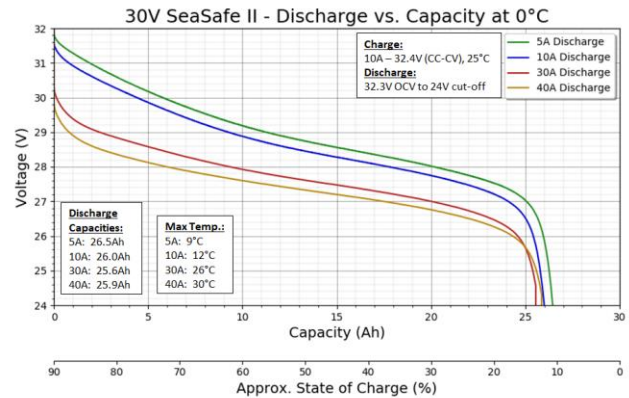
The above battery discharge test chart is for a 24V SeaSafe Direct battery module at 25°C temperature and different continuous current rates of 5A and 10A respectively. As in the 30V SeaSafe Direct, the limit of 10A continuous discharge current on the SeaSafe Direct battery module specification is due to the subsea connector max current rating. The discharge voltage at 90% SOC starts at 28.3V OCV and is

considered fully discharged and the test is stopped when it reaches 21V.

The voltage droop for 10A constant discharge curve relative to the 5A discharge curve is about -0.4V average, similar to the 30V SeaSafe Direct battery module. Once again, this is somewhat more significant than in the SeaSafe II due to the subsea cabling and connector higher resistance of the SeaSafe Direct relative to the cable and connector in the SeaSafe II.

C. Discharge Profiles at Subsea Temperature: 0°C (Capacity vs. Voltage) Plots

Now we repeat at 0°C temperature the same discharge tests with the same continuous current rates that we did at the 25°C temperature. This provides a corresponding set of test data that is merely differentiated by -25°C ambient operating temperature and represents the ambient operating temperature of the deep ocean.



The above battery discharge test chart is for a 30V SeaSafe II battery module at 0°C ambient temperature, representing deep sea ambient temperature, and different continuous current rates of 5A, 10A, 20A, and 40A similar to prior respectively. The discharge voltage at 90% SOC starts at 32.3V OCV and is considered fully discharged and the test is stopped when it reaches 24V.

At 0°C, there is a voltage droop impact at all four continuous rates of discharge current when compared to the corresponding rate at 25°C ambient operating temperature, ranging from about -1.4V worst case for 40A at about 75% SOC, to as little as -0.3V for 5A at start 90% SOC. You can see that the higher the discharge rate, the lower the discharge voltage sustained throughout the entire discharge curve, and the more significant the relative impact of the 0°C temperature. At the 0°C temperature, the voltage droop difference between discharge voltage at 5A and discharge voltage at 40A ranges from as significant as -2.1V to about -1.1V depending on SOC level.

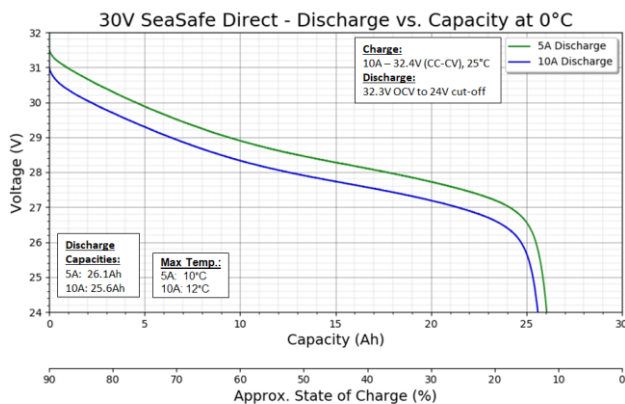
The voltage droop for 10A and 30A constant discharge curves relative to the 5A discharge curve falls expectedly in between that of the 40A discharge curve, ranging from a more

significant -1.6V at higher SOC to about -1.0V for the 30A, and about -0.3V average for 10A.

One can see that this droop in instantaneous power based on voltage droop at each particular continuous current rate would need to also consider the expected operating temperature of the use case, as the 0°C operating temperature has a more significant negative impact on battery power delivered.

Also note that the discharge capacities of all four tested continuous current discharge rates at 0°C operating temperature did not deliver the “full” 28Ah rated capacity. Instead, at 0°C operating ambient operating temperature, the delivered capacities were from 25.9Ah at 40A rate to 26.5Ah at 5A rate. This shows that the cells operate less effectively at 0°C ambient operating temperature, due to the chemical nature of the cells not being as chemically active at this freezing temperature level.

Again, note that the battery internal operating temperature was higher at the higher discharge rates. While operating at 0°C ambient in air with no cooling circulation, the battery module reached a maximum internal temperature of 30°C when discharging at 40A continuous, and as low as 9°C maximum operating temperature when discharging at 5A continuous. These maximum internal operating temperatures are well below the SeaSafe II specified maximum operating temperature of 60°C. Also, in actual application direct in the ocean, the heat sink of the ocean water would likely further reduce the internal operating temperature of the battery module.



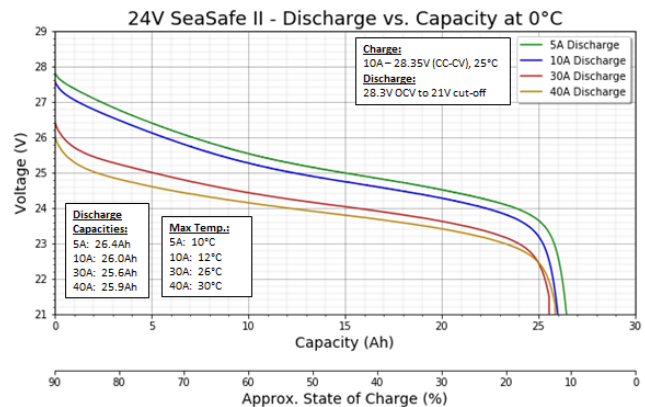
The above battery discharge test chart is for a 30V SeaSafe Direct battery module at 0°C temperature and different continuous current rates of 5A and 10A respectively. Note again the limit of 10A continuous discharge current on the SeaSafe Direct battery Modules due to the subsea connector max current rating. The discharge voltage at 90% SOC starts at 32.3V OCV and is considered fully discharged and the test is stopped when it reaches 24V.

The voltage droop for 10A constant discharge curve relative to the 5A discharge curve is slightly more pronounced

at 0°C temperature than it was at 25°C temperature, at about -0.5V average versus -0.4V average prior.

Note that the discharge capacities of both tested continuous current discharge rates at 0°C operating temperature did not deliver the “full” 28Ah rated capacity, but came close, ranging from 25.6Ah at 10A rate to 26.1Ah at 5A rate. This shows that the cells operate less effectively at 0°C ambient operating temperature.

Also note that the battery internal operating temperature was slightly higher at the higher discharge rate. While operating at 0°C ambient in air with no cooling circulation, the battery module reached a maximum internal temperature of 12°C when discharging at 10A continuous, and 10°C maximum operating temperature when discharging at 5A continuous. Once again, these maximum internal operating temperatures are well below the SeaSafe Direct specified maximum operating temperature of 60°C. Also, in actual application direct in the ocean, the heat sink of the ocean water would further reduce the internal operating temperature.



The above battery discharge test chart is for a 24V SeaSafe II battery module at 0°C ambient temperature, representing deep sea ambient temperature, and different continuous current rates of 5A, 10A, 20A, and 40A similar to prior respectively. The discharge voltage at 90% SOC starts at 28.3V OCV and is considered fully discharged and the test is stopped when it reaches 21V.

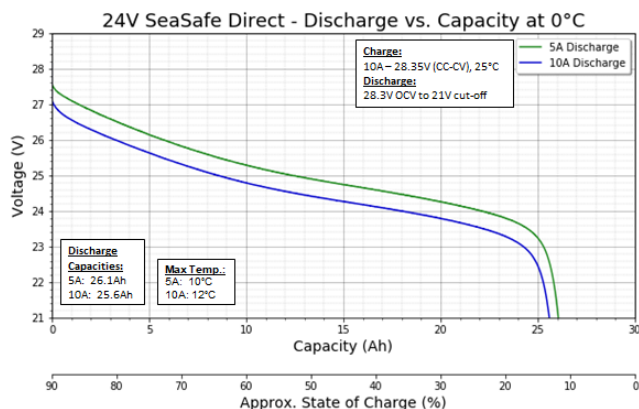
At 0°C, there is a voltage droop impact at all four continuous rates of discharge current when compared to the corresponding rate at 25°C ambient operating temperature, once again ranging from about -1.4V worst case for 40A at about 75% SOC, to as little as -0.3V for 5A at start 90% SOC. You can see that the higher the discharge rate, the lower the discharge voltage sustained, throughout the entire discharge curve, and the more significant the relative impact of the 0°C temperature. At the 0°C temperature, the voltage droop difference between discharge voltage at 5A and discharge voltage at 40A ranges from as significant as -2.1V to about -1.1V depending on SOC level.

The voltage droop for 10A and 30A constant discharge curves relative to the 5A discharge curve falls expectedly in between that of the 40A discharge curve, ranging from a more significant -1.6V at higher SOC to about -1.0V for the 30 A, and about -0.3V average for 10A.

One can see that this droop in instantaneous power based on voltage drop at each particular continuous current rate would need to also consider the expected operating temperature of the use case, as the 0°C operating temperature has a more significant negative impact on battery power delivered.

Also note that the discharge capacities of all four tested continuous current discharge rates at 0°C operating temperature did not deliver the “full” 28Ah rated capacity. Instead, at 0°C operating ambient operating temperature, the delivered capacities were from 25.9Ah at 40A rate to 26.5Ah at 5A rate. This shows that the cells operate less effectively at 0°C ambient operating temperature, due to the chemical nature of the cells not being as chemically active at this freezing temperature level.

Again, note that the battery internal operating temperature was higher at the higher discharge rates. While operating at 0°C ambient in air with no cooling circulation, the battery module reached a maximum internal temperature of 30°C when discharging at 40A continuous, and as low as 9°C maximum operating temperature when discharging at 5A continuous. These maximum internal operating temperatures are well below the SeaSafe Direct specified maximum operating temperature of 60°C. Also, in actual application within oil in the PBOF case in the ocean, the heat sink of the oil cooled by the ocean water would likely further reduce the internal operating temperature of the battery module.



The above battery discharge test chart is for a 24V SeaSafe Direct battery module at 0°C temperature and different continuous current rates of 5A and 10A respectively. Note again the limit of 10A continuous discharge current on the SeaSafe Direct battery Modules due to the subsea connector max current rating. The discharge voltage at 90% SOC starts at 28.3V OCV and is considered fully discharged and the test is stopped when it reaches 21V.

The voltage droop for 10A constant discharge curve relative to the 5A discharge curve is similar at 0°C temperature than it was at 25°C temperature, at about 0.4V average.

Note that the discharge capacities of both tested continuous current discharge rates at 0°C operating temperature did not deliver the “full” 28Ah rated capacity, but came close, ranging from 25.6 Ah at 10A rate to 26.1Ah at 5A rate. This shows that the cells operate less effectively at 0°C ambient operating temperature.

Also note that the battery internal operating temperature was slightly higher at the higher discharge rate. While operating at 0°C ambient in air with no cooling circulation, the battery module reached a maximum internal temperature of 12°C when discharging at 10A continuous, and 10°C maximum operating temperature when discharging at 5A continuous. Once again, these maximum internal operating temperatures are well below the SeaSafe Direct specified maximum operating temperature of 60°C. Also, in actual application direct in the ocean, the heat sink of the ocean water would further reduce the internal operating temperature.

V. BATTERY SYSTEM CONFIGURATION AND IMPLICATIONS FOR SUBSEA ENDURANCE

To increment the battery system voltage, one would combine the SeaSafe battery modules in series into a string, incrementing the voltage of the battery system by the module voltage times the number of modules in series within the battery string. Each module in series within the battery string would behave as related to the individual module test graph for its respective current load. Pay attention to relative voltage droop when considering subsea use case conditions, since voltage droop will affect every module within the string.

For constant power or power focused applications, one can choose to increase the voltage of the battery system to lower the current required to meet the same power delivery. This approach would lead to additional modules in series to achieve the increased voltage in order to lower the current, and thus voltage droop would reduce.

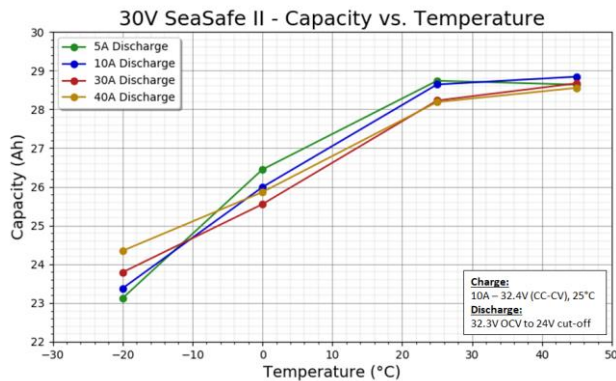
Another approach to lower the current load on the battery from the application is to combine SeaSafe battery module strings in parallel, with appropriate Diode ORing between series strings. This would share the current load demand among each battery series string connected in parallel roughly proportional. One needs to take care of appropriate intermediate “current hogging” derating for likely oscillations of peak current on a single string among the net current of the shared strings during current sharing.

For subsea endurance, adding additional series strings in parallel not only increases battery system capacity, but it can

also mitigate battery system voltage droop during peak load periods by lessening the per string current load demand.

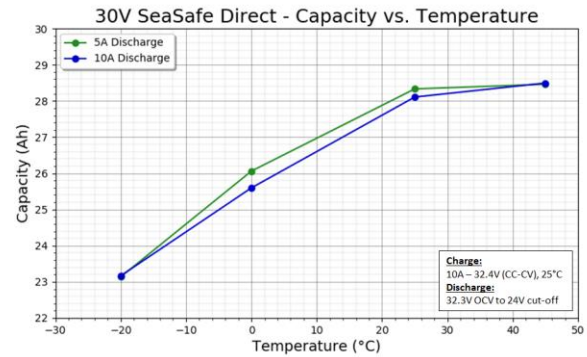
VI. SUBSEA ENDURANCE: BATTERY DISCHARGE CAPACITY DELIVERED VS. TEMPERATURE AT DIFFERENT DISCHARGE RATES

Now we look at a summary of battery discharge capacity delivered vs. temperature at different discharge rates combined, based on the methodology used to generate the discharge curve plots in the prior detail section. In these following summary plots, the previous viewed test temperatures of 25°C and 0°C are joined by a colder test temperature of -20 °C and a warmer temperature of +45°C.

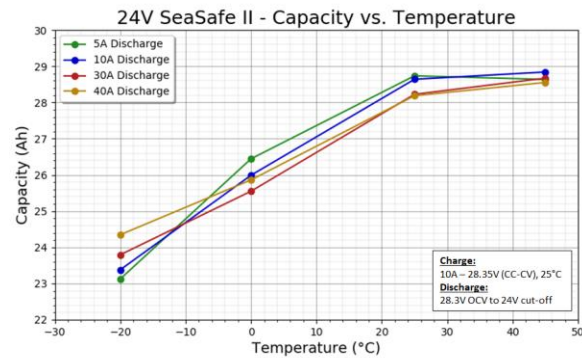


This summary plot of the 30V SeaSafe II Capacity vs. Temperature at different continuous discharge rates clearly shows the effect of ambient operating temperature on the delivered capacity performance of the batteries. The rated nominal capacity of 28Ah is exceeded for all discharge rates at 25°C and at 45°C. However, for the colder operating temperature discharge rates, it is clear that the colder the temperature, the lower the delivered capacity. Discharge at 0°C delivered from about 25.5Ah to 26.5Ah while -20°C delivered 23.1Ah to 24.4Ah.

It is interesting to note that at the colder -20°C ambient operating temperature, the higher discharge rates of 40A and 30A delivered higher Ah capacities than did the lower discharge rates of -10A and -5A. This might be counter-intuitive since one might expect the power delivered to be lower at the lower sub-zero °C ambient temperature as discussed prior, due to more extensive voltage droop at the even lower ambient temperature. The reason for higher relative capacity delivered at -20°C is likely because the higher current rate discharge caused the internal temperature of the battery cells to increase based on self-heating more than they do at the lower discharge currents. Thus the slightly warmer internal temperature cell begins to operate more efficiently, which results in slightly higher discharge capacity delivered.

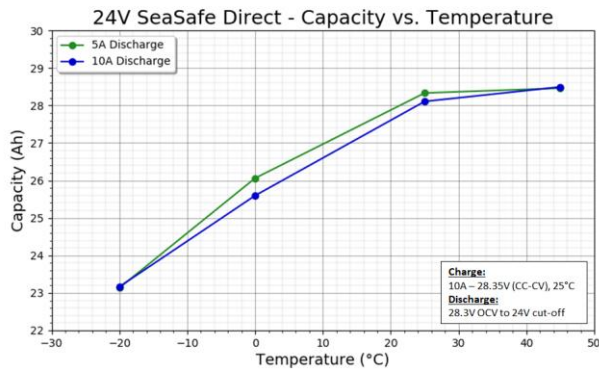


This summary plot of the 30V SeaSafe Direct Capacity vs. Temperature at different continuous discharge rates clearly shows the effect of ambient operating temperature on the delivered capacity performance of the batteries. The rated nominal capacity of 28Ah is again exceeded for all discharge rates at 25°C and at 45°C. However, for the colder operating temperature discharge rates, again the colder the temperature causes lower delivered capacity. Discharge at 0°C delivered from about 25.6Ah to 26.1Ah while -20°C delivered 23.1Ah.



For this summary plot of the 24V SeaSafe II Capacity vs. Temperature at different continuous discharge rates clearly shows the effect of ambient operating temperature on the delivered capacity performance of the batteries similar to that of the 30V battery test. The rated nominal capacity of 28Ah is exceeded for all discharge rates at 25°C and at 45°C.

However, for the colder operating temperature discharge rates, it is clear that the colder the temperature, the lower the delivered capacity. Discharge at 0°C delivered from about 25.5Ah to 26.5Ah while -20°C delivered 23.1Ah to 24.3Ah. Once again, similar to the 30V SeaSafe II battery discussed above, it is interesting to note that at the colder -20°C ambient operating temperature, the higher discharge rates of 40A and 30A delivered higher Ah capacities than did the lower discharge rates of 10A and 5A, likely for the same internal self-heating reasons.



Finally, this summary plot of the 24V SeaSafe Direct Capacity vs. Temperature at different continuous discharge rates again shows the effect of ambient operating temperature on the delivered capacity performance of the batteries. The rated nominal capacity of 28Ah is again exceeded for all discharge rates at 25°C and at 45°C with a range of 28.1Ah to 28.4Ah and 28.5Ah respectively. However, again for the colder operating temperature discharge rates, the colder temperature causes lower delivered capacity. Discharge at 0°C delivered from about 25.6Ah to 26.1Ah while -20°C delivered 23.1Ah.

VII. ENDURANCE TECHNICAL TAKEAWAYS REGARDING SUBSEA BATTERIES

Given assessment of the test data presented and discussed prior, following are some key technical takeaways regarding endurance (measured in delivered Ah capacity under subsea operation) of subsea batteries:

- Lithium Ion batteries, including Lithium Ion Polymer test data reviewed in this paper, are among the highest endurance subsea battery technologies available in production today.
- Discharge rate effects battery endurance:
 - Higher discharge rates typically deliver relatively lower battery capacity.

- Higher discharge rates typically cause voltage droop that may affect the application based on power delivered or minimum voltage requirements.
- One should plan application use-case capacity to be delivered using Capacity at discharge test charts to interpolate expected value based on use-case discharge rates.
- Ambient operating temperature affects battery endurance:
 - Higher temperatures (25°C and above) deliver nominal or higher than rated capacity.
 - This is relevant to lab tests and topside tests.
 - Lower temperatures, especially “freezing” 0°C or lower temperatures, have the most negative impact on endurance by delivering lower than nominal rated capacity.
 - The lower the temperature, the lower the expected capacity expected to be delivered.
 - One should plan application use-case capacity to be delivered using Capacity at specific subsea temperature discharge test charts where that temperature will reflect likely worst case (coldest) subsea operating temperature.
- Be sure to adjust battery system voltage, peak current, power, and capacity plans for battery utilization and endurance based on discharge rate and ambient operating temperature based effects of the use-case application.
 - Plan for more batteries in series to maintain adequate application battery system voltage if necessary at high discharge rates and/or sub-freezing ambient operating temperatures.
 - Plan for more parallel battery strings to share the application power load to ensure sufficient application peak current is available if high peak or pulse currents are required without commensurate voltage droop to maintain sufficient battery system voltage.