Sealed Lead Acid / Lithium Equivalent Ah

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A lithium battery can use 100% of its storage capability (measured as Amp-Hour, Ah), while a lead-acid battery for starting applications (not a deep cycle) typically only uses 30%. Lithium battery's cranking power does not drop-off because of its flat discharge curve, so a smaller Ah battery can actually crank your engine longer.

Here is the background information, math and testing!

What is an Ah-hour?

A typical Amp Hour specification might read, "100 AH @ 20HR".

The specification is saying that the battery will provide 100 Ah over a 20 hour period, at rate of 5 amps (100Ah/20hr = 5 amps).

These slow discharge rates are a good measure for "deep cycle" batteries used for storage, but not a good measure for "starter" batteries, because starter batteries typically have discharge current in the hundreds or amps!

Below is the specification for the Yuasa YTX series batteries. Notice the YTX14 is only a 12Ah battery for 10 hour discharge (very slow discharge rate).

Battery Type	Capacity AH (10H-R)	(± 1/16 in)			(± 2 mm)			Assembly Figure (As Per Cover Polarity)	Weight with Acid (lbs.)	Type (Refer to page 6)	Volume (Liter)
		L	W	H	L	W	H				
YTX9	8	6	3 7/16	4 3/16	150	87	105	+ –	6.6	5	N/A
YTX12	10	6	3 7/16	5 1/8	150	87	130	+ –	9.2	5	N/A
YTX14	12	6	3 7/16	5 3/4	150	87	145	+ –	9.7	5	N/A
YTX14L	12	6	3 7/16	5 3/4	150	87	145	– +	9.7	5	N/A
YTX15L	13	6 7/8	3 7/16	5 1/8	175	87	130	– +	11	4	N/A
YTX20	18	6 7/8	3 7/16	6 1/8	175	87	155	+ –	13.9	4	N/A
YTX20L	18	6 7/8	3 7/16	6 1/8	175	87	155	– +	13.9	4	N/A
YIX30L	30	6 9/16	5	6 7/8	166	126	175	– +	22	4	N/A

What is depth of discharge?

Depth of discharge is an expression of what percent of a batteries capacity (Ah) has been used. So for example, if the YTX14 in the example above had 6Ah of energy used of the 12Ah total capacity, you would say the depth of discharge was 50% (% used / 100%).

Lead acid battery manufacturers design batteries with different specifications, for different applications. For example, typical lead acid energy storage batteries are designed for 50 – 80% depth of discharge. Which means you can use 50 – 80% of the total available energy in the battery. Typical lead acid engine starting batteries are designed for 20-50% depth of discharge. The difference in the ratings has to do with the construction of the battery, like the thickness of the lead plates. A lead acid starter battery will not be reliable for deep discharging.

Below is an excerpt from a lead acid battery manufacturer's documentation. Here it states that a typical starter battery is rated at 20% depth of discharge!

BATTERY INFORMATION

Typical 12-volt lead-acid batteries have a voltage of about 14 volts when fully charged and 11 volts fully discharged. Most amateur radio equipment does not operate properly below 11.5 volts. You cannot practically exceed the depth of discharge at which battery voltage under load drops to below that figure. Oversized loads or excessive duty cycle causes rapid depletion of battery capacity, so battery systems must be sized for the expected load.

Cranking amps tell nothing about how long a starting battery can run your transmitter. **Cold Cranking Amps (CCA) represent the current a ">starting" battery provides continuously for 30 seconds at zero degrees. F before voltage is drops to 1.7 volts per cell** at which point it is fully discharged. MCA or Marine Cranking Amps are measured at 32 degrees. F. Reserve capacity is the time a starting battery can sustain a 25-amp load before cell voltage drops to 1.7vpc. A 12-volt battery has six cells, so at 1.7 vpc, a discharged battery has only 10.2 volts. Most 12-volt radio equipment fails to function properly before a lead-acid battery is fully discharged. Discard any 12-volt battery with open-circuit voltage below 10.2 volts, it probably has a bad cell and probably will not accept a full recharge.

Performance measurements for "deep cycle" batteries are amp-hour capacity at a specified depth of discharge (DoD). Amp-hour capacity is current available over time, measured at 80 degrees. F. DoD is percentage of capacity available during a charge-discharge cycle. Amp-hour ratings of deep cycle batteries are based upon a discharge rate at 1/20 capacity, expressed as C over 20". A marine battery rated 200ah at C20, when discharged continuously at 10 amps, at 80° F., sustains the load for 20 hrs. Starting batteries are designed for 20% DoD, gel cells 25%, "deep cycle" batteries from 50% to 80%.

How does discharge rates effect lead acid batteries Ah?

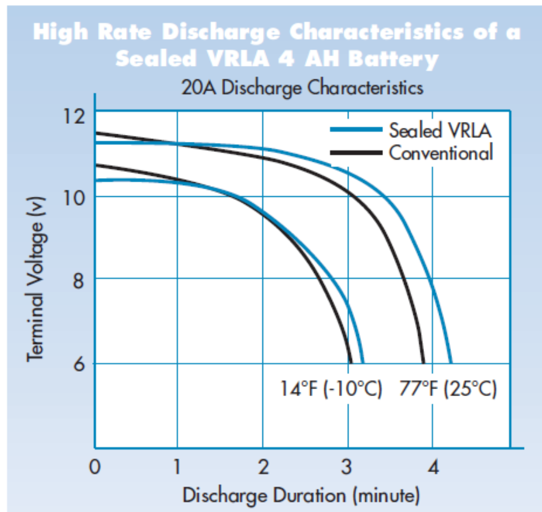
At a high rate of discharge, like cranking an engine, the voltage of a lead acid battery drops significantly. This is a problem if you are trying to start a vehicle because most modern vehicle with electronic ignition require 10.5V or more. The Society of Automotive engineers states that voltage below 9.3V is unusable for starting a vehicle.

Below is a graph from Yuasa showing a 25A discharge curve of an YTX4. So at a 25A discharge rate, at room temperature, the battery voltage drops below 9.3V within 3 minutes of use, and a small fraction of consumed Ah.

Discharge Characteristics

Think about what types of vehicles a sealed VRLA battery goes into: most aren't like the family car, driven day-in, day-out. They're probably used once in a while, or maybe even stored for weeks or months at a time.

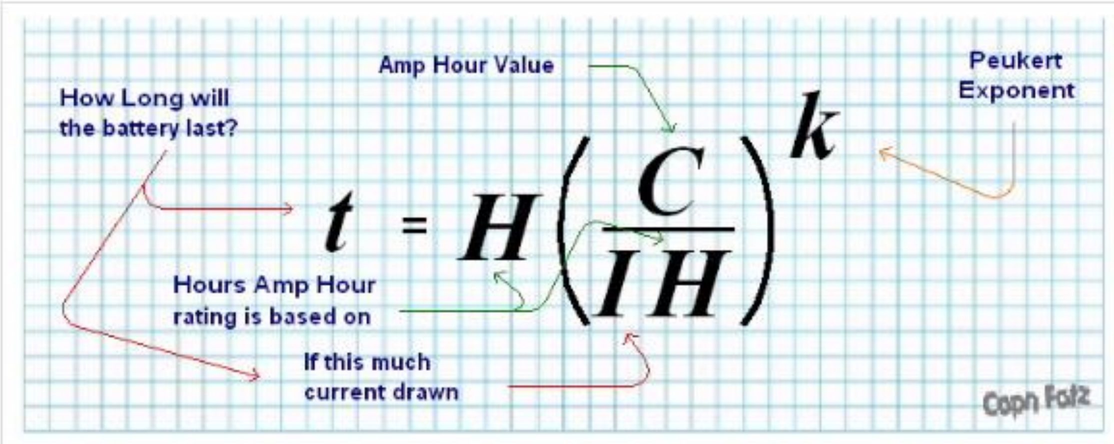
That demands a special kind of battery – one with extra power to reliably start that engine, every time. In YUASA's sealed VRLA batteries, the plate groups are specially designed to deliver that. The graph to the right shows the increase in discharge time of a sealed VRLA battery compared to a conventional Yumicron battery at both cold and room temperatures. The graph below shows the cold temperature performance of the sealed VRLA battery as the load increases. "C" equals the Amp Hour Capacity Rating of the battery.



A common misconception about lead acid batteries and in particular lead acid batteries designed for starting vehicles is that usable Ah does not change depending on the use. The reality is, usable Ah is dependent on the discharge rate. That means the usable Ah of an YTX4 is different at 2A, as it is at 25A, as it is at 80A. The mathematical equation that explains this non-linearity is Peukert's Law.

Per Wikipedia Peukert's Law states that the capacity available from a battery varies according to how rapidly it is discharged. A battery discharged at high rate will give fewer ampere hours than one discharged more slowly.

That equation is this…



- **t** - Time in hours. Its the time that the battery will last given a particular rate of discharge (the current).
- **H** – The discharge time in hours that the Amp Hour specification is based on. For example, if you had a 100 Amp Hour battery at a 20 hour discharge rate, H would equal 20.
- **C** – The battery capacity in Amp Hours based on the specified discharge time. For a 100 Amp Hour battery, this would be
- **I** – This is the current that we're solving for. For example, if we wanted to know how long a battery would last while drawing 7.5 amps, we would enter it here.
- **k** – the Peukert Exponent. Every battery has its own Peukert exponent. Sometimes the manufacturer will provide it and other times we may need to figure it out.

So what would an YTX4's (4Ah rated starter battery) usable Ah be if calculated using a typical starting current like 80A.

T=10(3/(80A*10))^1.15=.016hr OR   80A for .021Hr = 1.29Ah

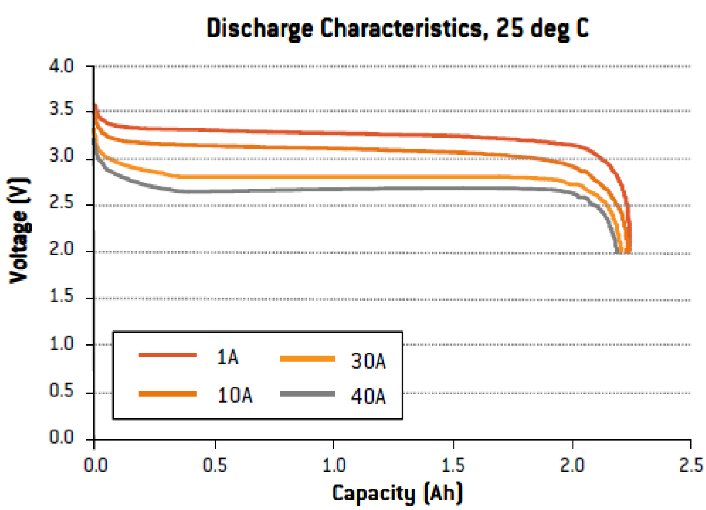
So as a starter battery designed for 80A starting currents, the YTX4 only has 1.3Ah that is usable.

What about a deep cycle battery rated for 80% depth of discharge, like the popular Odyssey PC680? The PC680s rated Ah is 18, but that is at a very low discharge rate (20 hour rate). At a more commonly used discharge rate like 10 hour rate, it is only rated at 12.8Ah, and at a 1 hour rate it is less than 12Ah output. For example the An

Odyssey PC680 (18 Ah rating) has less usable Ah than an ETX36C (12.4 Ah rating), when discharged in less 2 hours.

Is a lithium battery Ah effected by discharge rate?

The answer is, yes, but very little. As you can see in the curve below for a typical 2.3Ah lithium iron phosphate battery, the discharge curve is very flat and the discharge voltage profiles for low current and high current discharge are tightly grouped. Typically 92 to 100% of the Ah is usable. Another characteristic of a lithium battery that is an advantage in this respect is that they heat up during discharge, which lowers the internal resistance to hold the terminal voltage up. Finally, a lithium battery has a higher nominal resting voltage (13.3V vs 12.9 of AGM) which is also a benefit when it comes to usable energy (discharge current with voltage above 9.3V). Peukert's law could be used but the exponent would be near 1.



Conclusions

A lead acid starter battery Ah rating is not as it would appear. Given the two facts; limited depth of discharge rating per the manufacturer (limited by design life testing), and Peukert’s law, only ~30% of the Ah is usable. Also given the fact that 95% of a lithium batteries Ah is usable, a lithium battery that is 1/3 the Ah rating of a lead acid is actually equivalent. So a 4Ah lithium battery could be considered to be equivalent to a 12Ah lead acid, thus the justification for EqAh up to 3 times the true Ah.

References

Source1

University of Colorado, lecture ECEN 4517/5517

Source2

Yuasa datasheet for VRLA product line

Source3

Odyssey datasheet for PC680

Source4

D. Doerffel, S.A. Sharkh, *A critical review of using the Peukert equation for determining the remaining capacity of lead–acid and lithium-ion batteries*, Journal of Power Sources, 155 (2006) 395–400