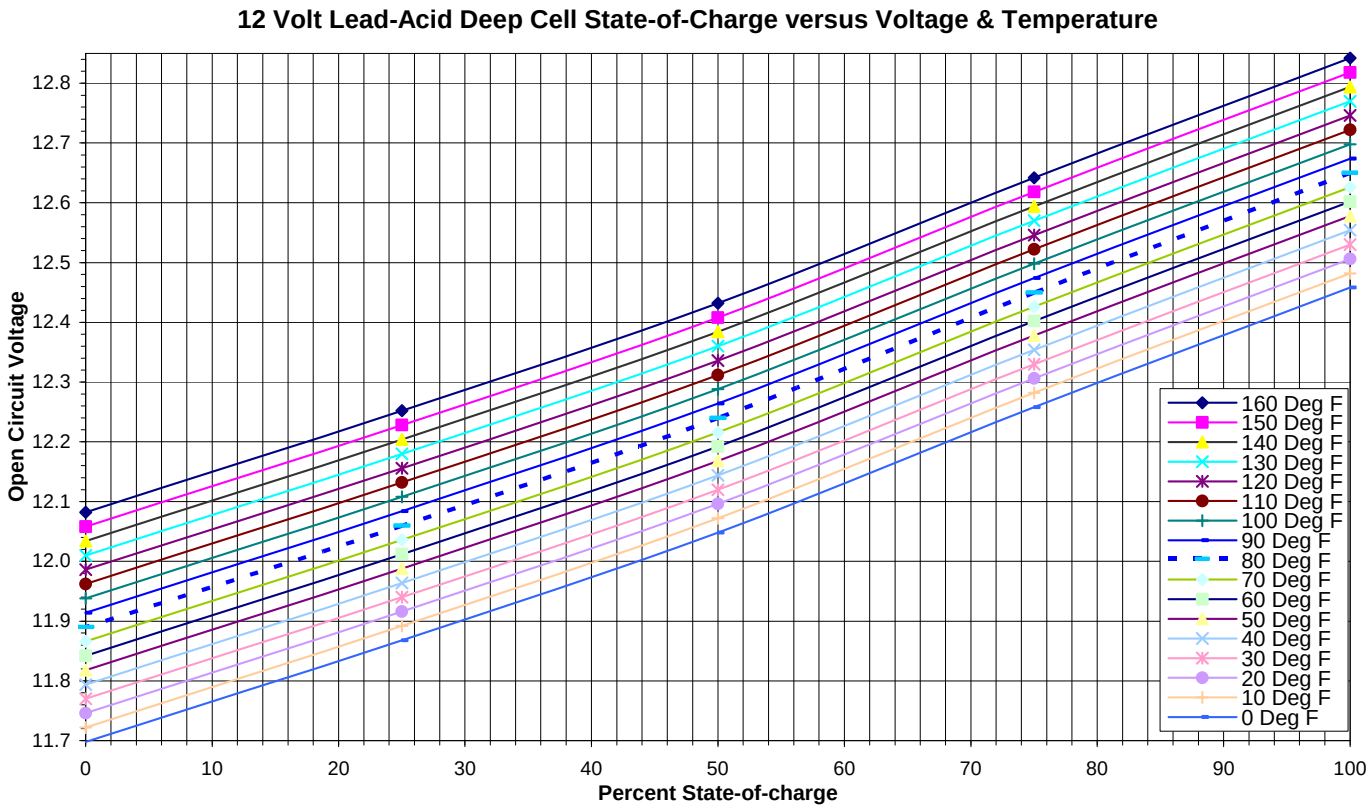
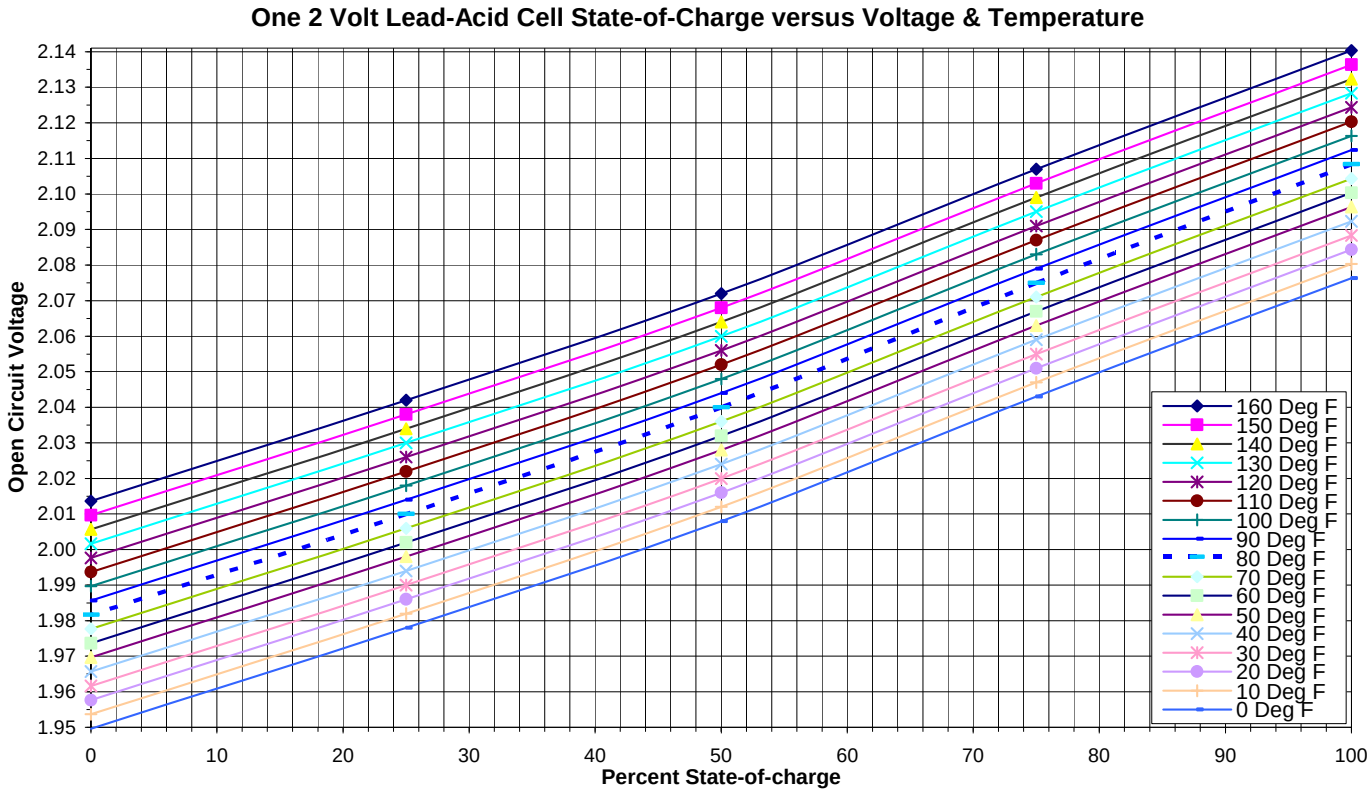
Subject: Testing your Batteries after the PS
Sent: 15 Jun 02
Revised: 8 April 2010

Testing the state of charge of Lead-Acid batteries will be a much-needed skill after the PS. I found the following useful in understanding how to properly do the testing. Print the following plotted graphs or charts for easer reference.




One 2 Volt Lead-Acid Cell State-of-Charge versus Voltage & Temperature
Open Circuit Voltage
2.14
2.13
2.12
2.11
2.10
2.09
2.08
2.07
2.06
2.05
2.04
2.03
2.02
2.01
2.00
1.99
1.98
1.97
1.96
1.95
0
10
20
30
40
50
60
70
80
90
100
Percent State-of-charge
160 Deg F
150 Deg F
140 Deg F
130 Deg F
120 Deg F
110 Deg F
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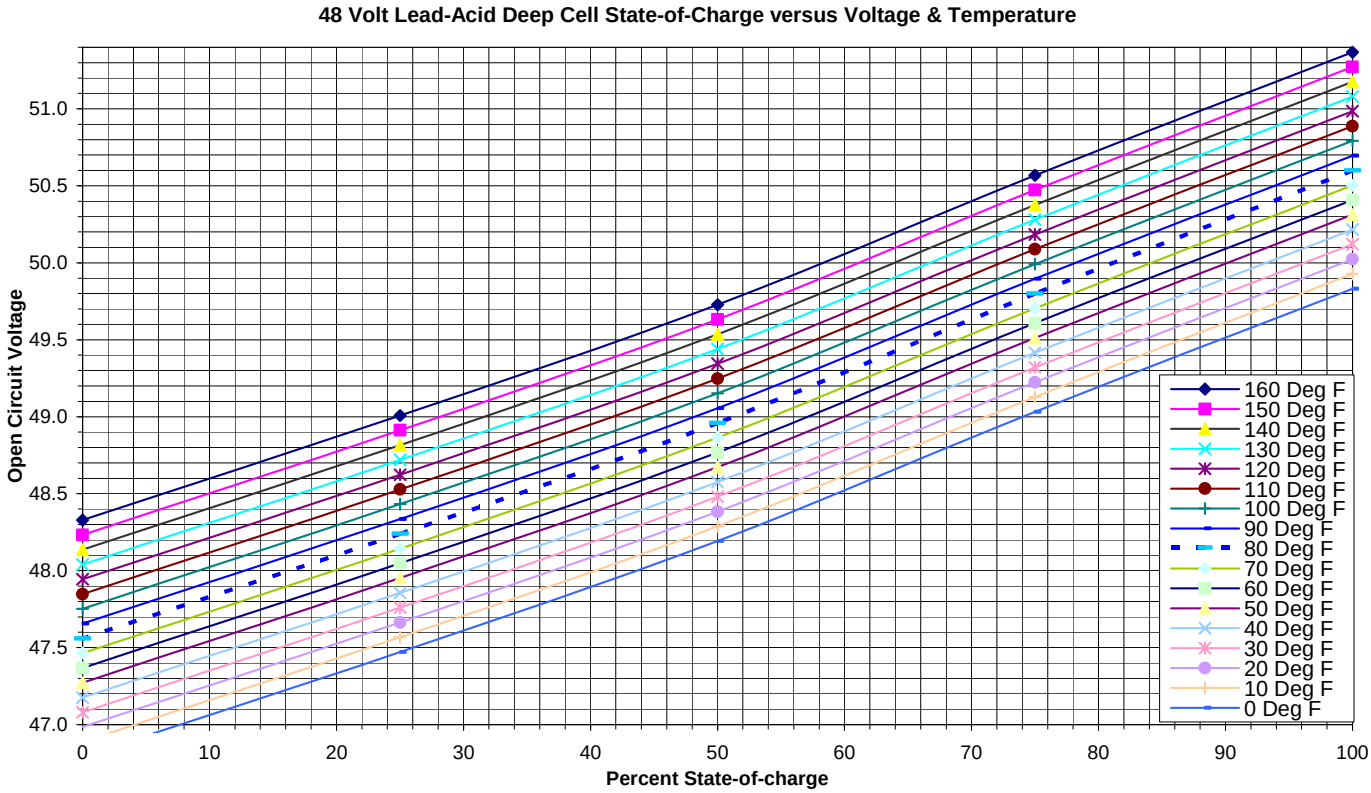
48 Volt Lead-Acid Deep Cell State-of-Charge versus Voltage & Temperature
Open Circuit Voltage
51.0
50.5
50.0
49.5
49.0
48.5
48.0
47.5
47.0
0
10
20
30
40
50
60
70
80
90
100
Percent State-of-charge
160 Deg F
150 Deg F
140 Deg F
130 Deg F
120 Deg F
110 Deg F
100 Deg F
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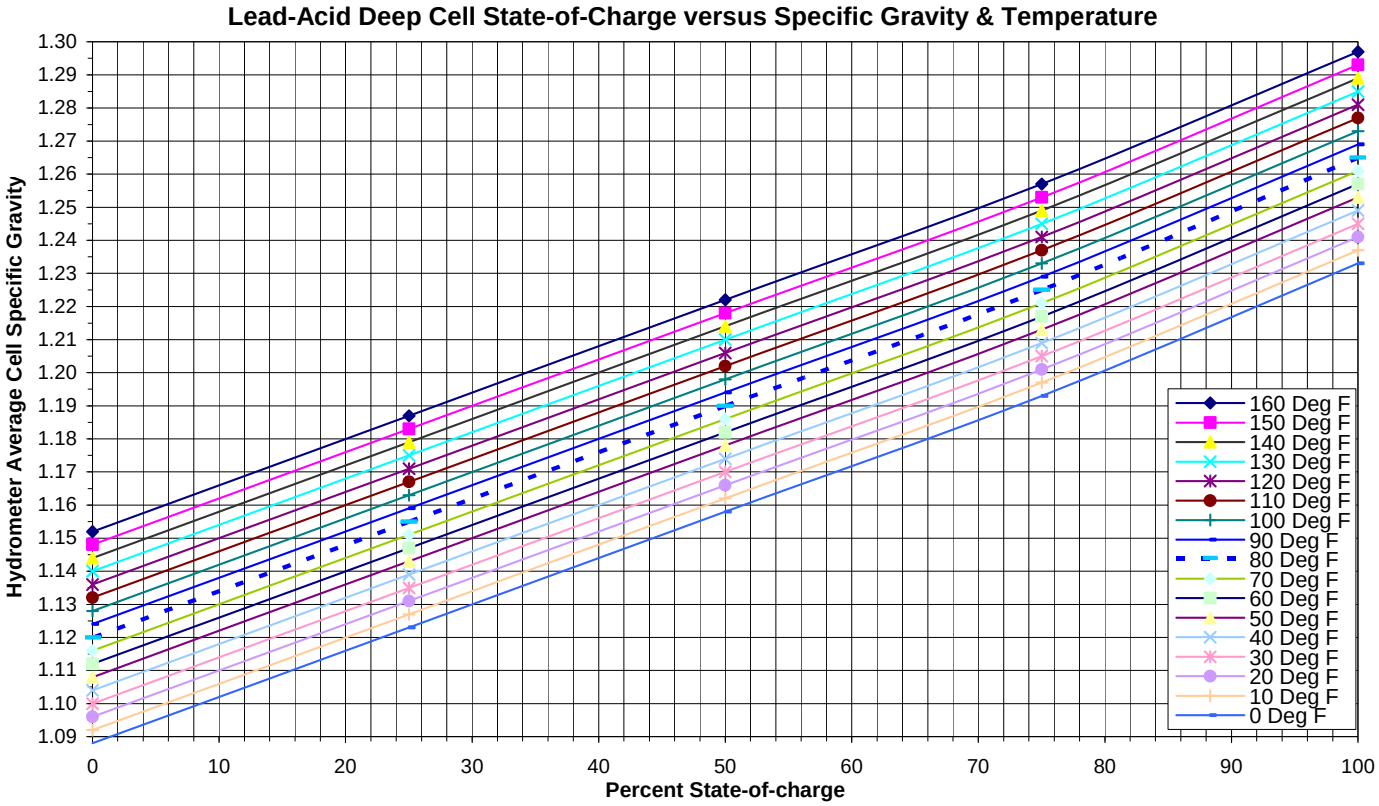
50 Deg F
40 Deg F
30 Deg F
20 Deg F
10 Deg F
0 Deg F


Lead-Acid Deep Cell State-of-Charge versus Specific Gravity & Temperature
Hydrometer Average Cell Specific Gravity
Percent State-of-charge
160 Deg F
150 Deg F
140 Deg F
130 Deg F
120 Deg F
110 Deg F
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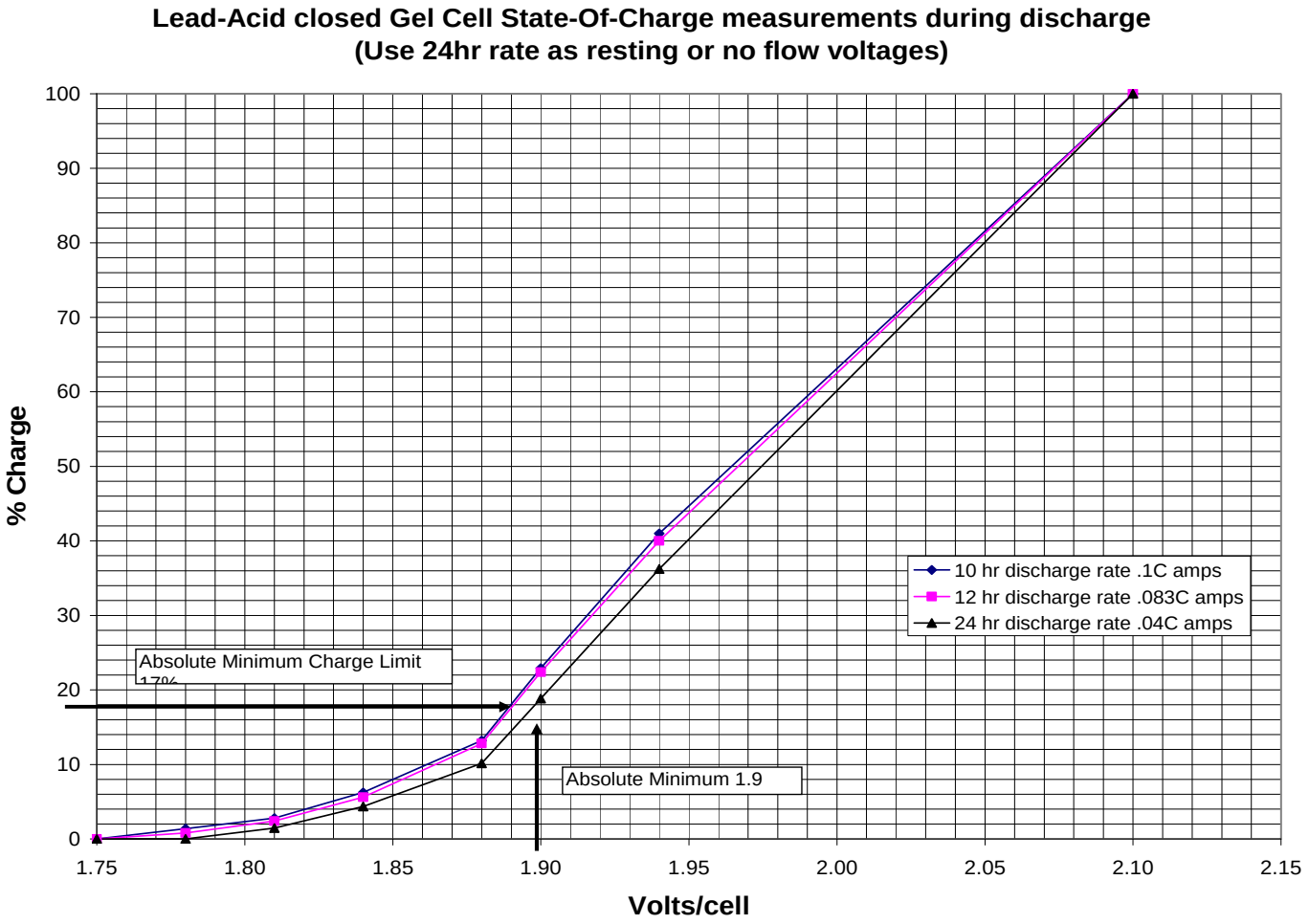
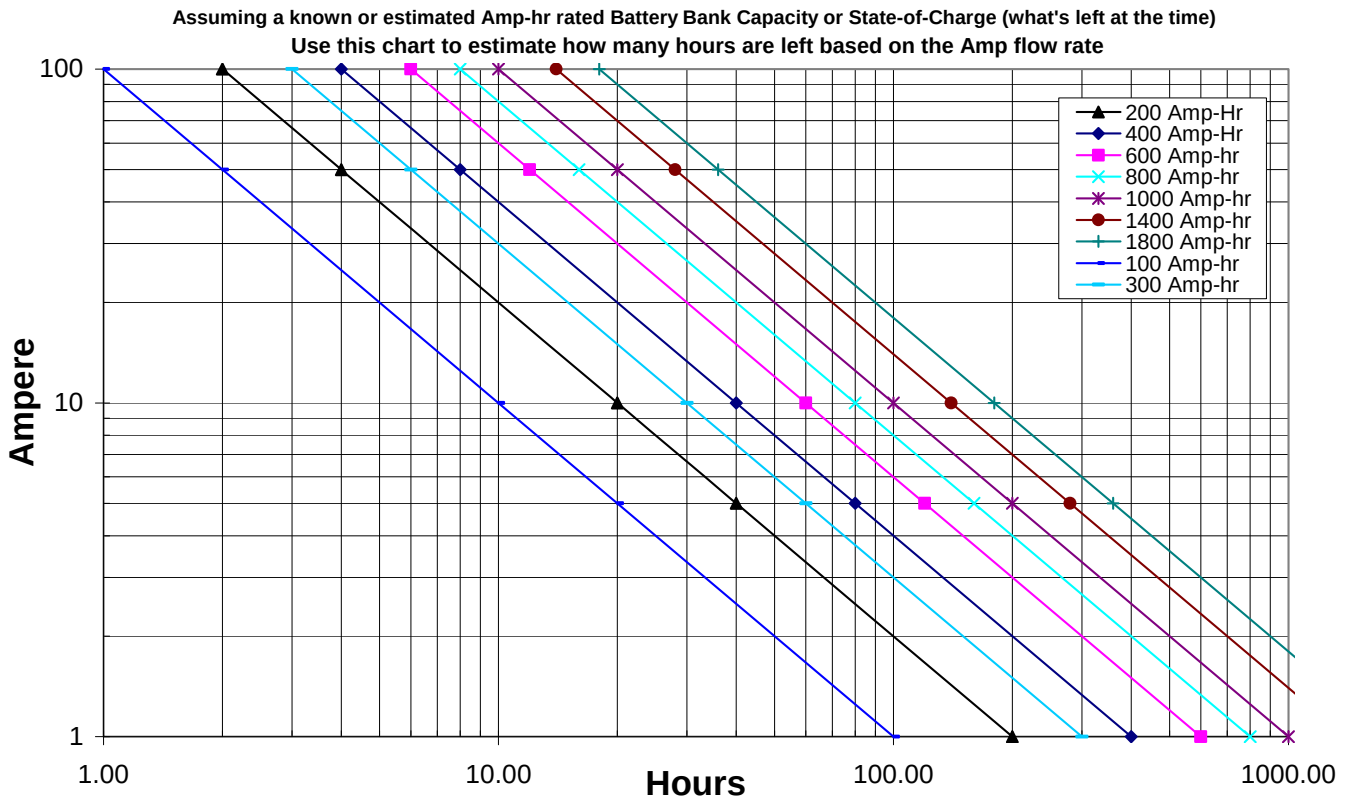
50 Deg F
40 Deg F
30 Deg F
20 Deg F
10 Deg F
0 Deg F


Lead-Acid closed Gel Cell State-Of-Charge measurements during discharge
(Use 24hr rate as resting or no flow voltages)
% Charge
Volts/cell
10 hr discharge rate .1C amps
12 hr discharge rate .083C amps
24 hr discharge rate .04C amps
Absolute Minimum Charge Limit
Absolute Minimum 1.9



Print these out along with the instructions and have available when you need to do the measurements. A good idea would be to laminate it and keep it with your batteries.

3. HOW DO I TEST A BATTERY?

There are six simple steps in testing a deep cycle battery: inspect, recharge, remove surface charge, measure the state-of-charge, load test, and recharge. If you have a non-sealed battery, it is highly recommended that you use a good quality temperature compensated hydrometer; these can be purchased at an auto parts store for between $5 and $20. A hydrometer is a float type device used to determine the state-of-charge by measuring the specific gravity of the electrolyte in each cell. It is a very accurate way of determining a battery's state-of-charge and its weak or dead cells. To troubleshoot charging or electrical systems or if you have a sealed battery, you will need a digital voltmeter with 0.5% or better accuracy. A digital voltmeter can be purchased at an electronics store like Radio Shack for between $20 and $200. Analog voltmeters are not accurate enough to measure the millivolt differences of a battery's state-of-charge or the output of the charging system. The purchase of a battery load tester is optional; if you use a golf cart or electric trolling motor every day, buy one. A more accurate way of testing the capacity of a lead acid battery is by using a conductance tester, such as a Midtronics.

3.1. INSPECT

Visually inspect for obvious problems. For example, is there a loose or broken alternator belt, electrolyte levels below the top of the plates, corroded or swollen cables, corroded terminal clamps, dirty or wet battery top, loose hold-down clamps, loose cable terminals, or leaking or damaged battery case? If the electrolyte levels are low in non-sealed batteries, allow the battery to cool and add distilled water to the level indicated by the battery manufacturer. If this is not indicated, use 1/4 inch (7 mm) below the bottom of the plastic filler tube (vent wells). The plates need to be covered at all times. Avoid overfilling, especially in hot climates, because heat will cause the electrolyte to expand and overflow.

3.2. RECHARGE

Recharge the battery to 100% state-of-charge. If the battery has a difference of .03 specific gravity reading between the lowest and highest cell, then you should equalize it. (Please see Section 6.)

3.3. REMOVE SURFACE CHARGE

Surface charge is the uneven mixture of sulfuric acid and water within the surface of the plates as a result of charging or discharging. It will make a weak battery appear good or a good battery appear bad. You need to eliminate the surface charge by one of the following methods:

3.3.1. Allow the battery to sit for four to twelve hours to allow for the surface charge to dissipate.

3.3.2. Apply a load that is 33% of the ampere-hour capacity for five minutes and wait five to ten minutes.

3.3.3. With a battery load tester, apply a load of at least one half the battery's CCA rating for 15 seconds and wait five to ten minutes.

3.4. MEASURE THE STATE-OF-CHARGE

If the battery's electrolyte is above 110° F (43.3° C), allow it to cool. To determine the battery's state-of-charge with the battery's electrolyte temperature at 80° F (26.7° C), use the following table. The table assumes that a 1.265 specific gravity reading is a fully charged, wet, lead acid battery. For other electrolyte temperatures, use the Temperature Compensation table below to adjust the Open Circuit Voltage or Specific Gravity readings. The Open Circuit Voltage will vary for gel cell and AGM type batteries, so check the manufacturer's specifications.

TEMPERATURE COMPENSATION:

Electrolyte temperature compensation, depending on the battery manufacturer's recommendations, will vary. If you are using a non-temperature compensated

HYDROMETER, make the adjustments indicated in the table above. For example, at 30° F (-1.1° C), the specific gravity reading would be 1.245 for a 100% State-of-Charge. At 100° F (37.8° C), the specific gravity would be 1.273 for 100% State-of-Charge. This is why using a temperature compensated hydrometer is highly recommended and more accurate than other means. If you are using a DIGITAL VOLTMETER, make the adjustments indicated in the table above. For example, at 30° F (-1.1° C), the voltage reading would be 12.53 for a 100% State-of-Charge. At 100° F (37.8° C), the voltage would be 12.698 for 100% State-of-Charge. For non-sealed batteries, check the specific gravity in each cell with a hydrometer and average the readings. For sealed batteries, measure the Open Circuit Voltage across the battery terminals with an accurate digital voltmeter. This is the only way you can determine the State-of-Charge. Some batteries have a built-in hydrometer, which only measures the State-of-Charge in one of its six cells. If the built-in indicator is clear or light yellow, then the battery has a low electrolyte level and should be refilled and recharged before proceeding. If sealed, the battery is toast and should be replaced. If the State-of-Charge is below 75% using either the specific gravity or voltage test or the built-in hydrometer indicates bad (usually dark), then the battery needs to be recharged before proceeding. You should replace the battery, if one or more of the following conditions occur:

3.4.1. If there is a .05 (sometimes expressed as 50 points) or more difference in the specific gravity reading between the highest and lowest cell, you have a weak or dead cell(s). If you are really lucky, applying an EQUALIZING charge may correct this condition. (Please see Section 6.)

3.4.2. If the battery will not recharge to a 75% or more state-of-charge level or if the built-in hydrometer still does not indicate good (usually green, which is 65% state-of-charge or better). If you know that a battery has spilled or bubbled over and the electrolyte has been replaced with water, you can replace the old electrolyte with new electrolyte and go back to Step 3.2 above. Battery electrolyte is a mixture of 25% sulfuric acid and distilled water. It is cheaper to replace the electrolyte than to buy a new battery.

3.4.3. If digital voltmeter indicates 0 volts, you have an open cell.

3.4.4. If the digital voltmeter indicates 10.45 to 10.65 volts, you probably have a shorted cell or a severely discharged battery. A shorted cell is caused by plates touching, sediment (mud) build-up or treeing between the plates.

3.5. LOAD TEST

If the battery is fully charged or has a good built-in hydrometer indication, then you can test the capacity of the battery by applying a known load and measuring the time it take to discharge the battery until 20% capacity is remaining. Normally a discharge rate that will discharge a battery in 20 hours can be used. For example, if you have an 80-ampere-hour rated battery, then a load of four amps would discharge the battery in approximately 20 hours (or 16 hours down to the 20% level). New batteries can take up to 50 charge/discharge cycles

before they reach their rated capacity. Depending on your application, batteries with 80% or less of their original capacity are considered to be bad.

3.6. RECHARGE

If the battery passes the load test, you should recharge it as soon as possible to restore it to peak performance and to prevent lead sulfation.

11. HOW LONG WILL A DEEP CYCLE BATTERY LAST ON A SINGLE CHARGE?

Discharging, like charging, depends on a number of factors such as: the initial state-of-charge, depth-of-discharge, age, capacity of the battery, load and temperature. For a fully charged battery at 70° F (21.1° C), the ampere-hour rating divided by the load in amps will provide the estimated life of that cycle. For example, a new, 72-ampere-hour battery with a 10-amp load should last approximately 7.2 hours. As the battery ages, the capacity is reduced.

12. HOW CAN I REVIVE A SULFATED BATTERY?

Lead sulfation occurs when a lead sulfate compound is deposited on the lead electrodes of a storage battery; this is a problem if the lead sulfate compound cannot be converted back into charged material and is created when discharged batteries stand for a long time. When the state-of-charge drops below 80%, the plates become coated with a hard and dense layer of lead sulfate, which fill up the pores. The positive plates will be light brown and the negative plates will be dull off-white. Over time, the battery loses capacity and cannot be recharged.

12.1. Light Sulfation

Apply a constant current from one to two amps for 48 to 120 hours at 14.4 VDC, depending on the electrolyte temperature and capacity of the battery. Cycle (discharge to 50% and recharge) the battery a couple of times and test capacity. You might have to increase the voltage in order to break down the hard lead sulfate crystals. If the battery gets above 110° F (43.3° C) then stop charging and allow the battery to cool down before continuing.

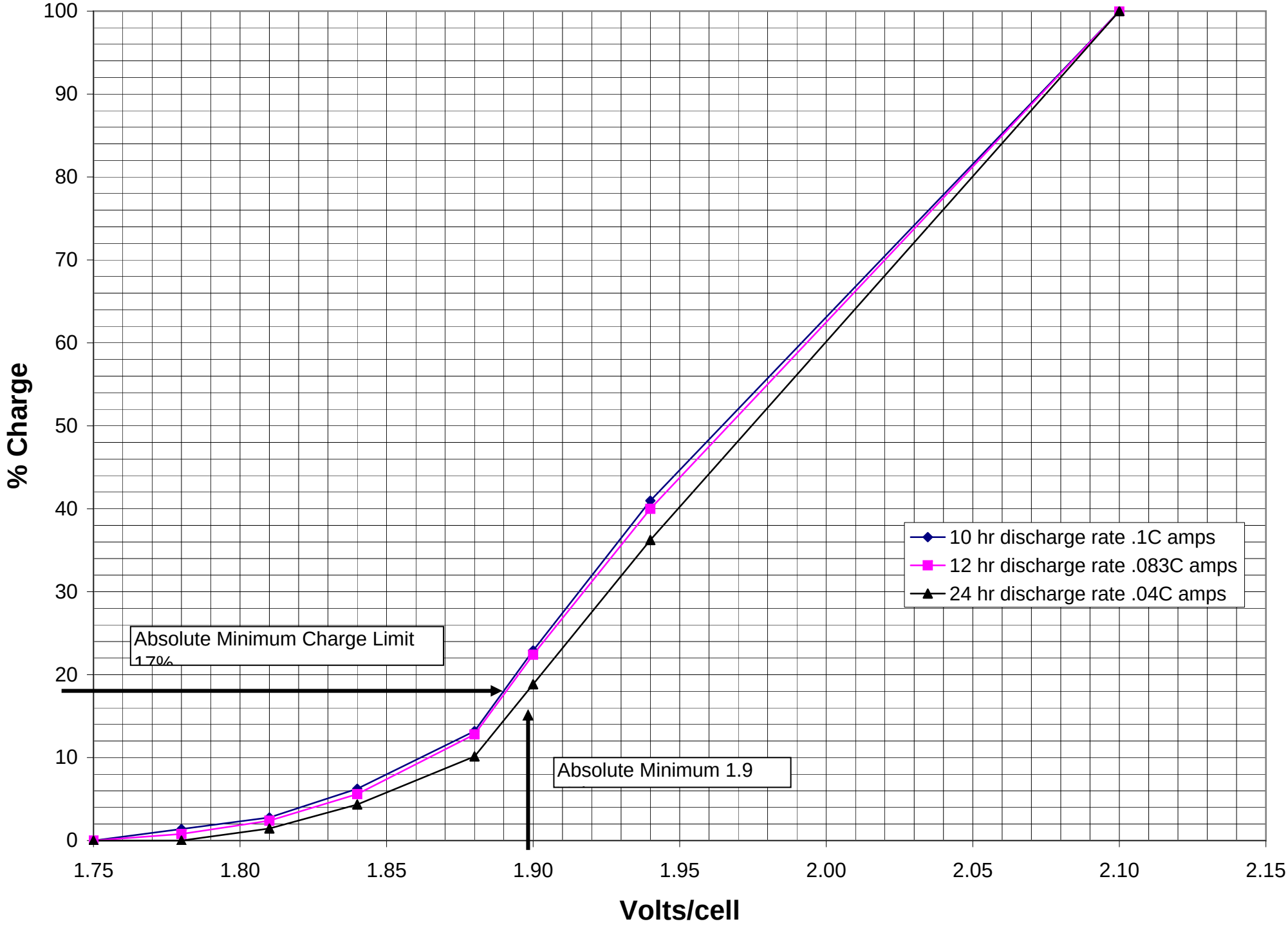
12.2. Heavy Sulfation

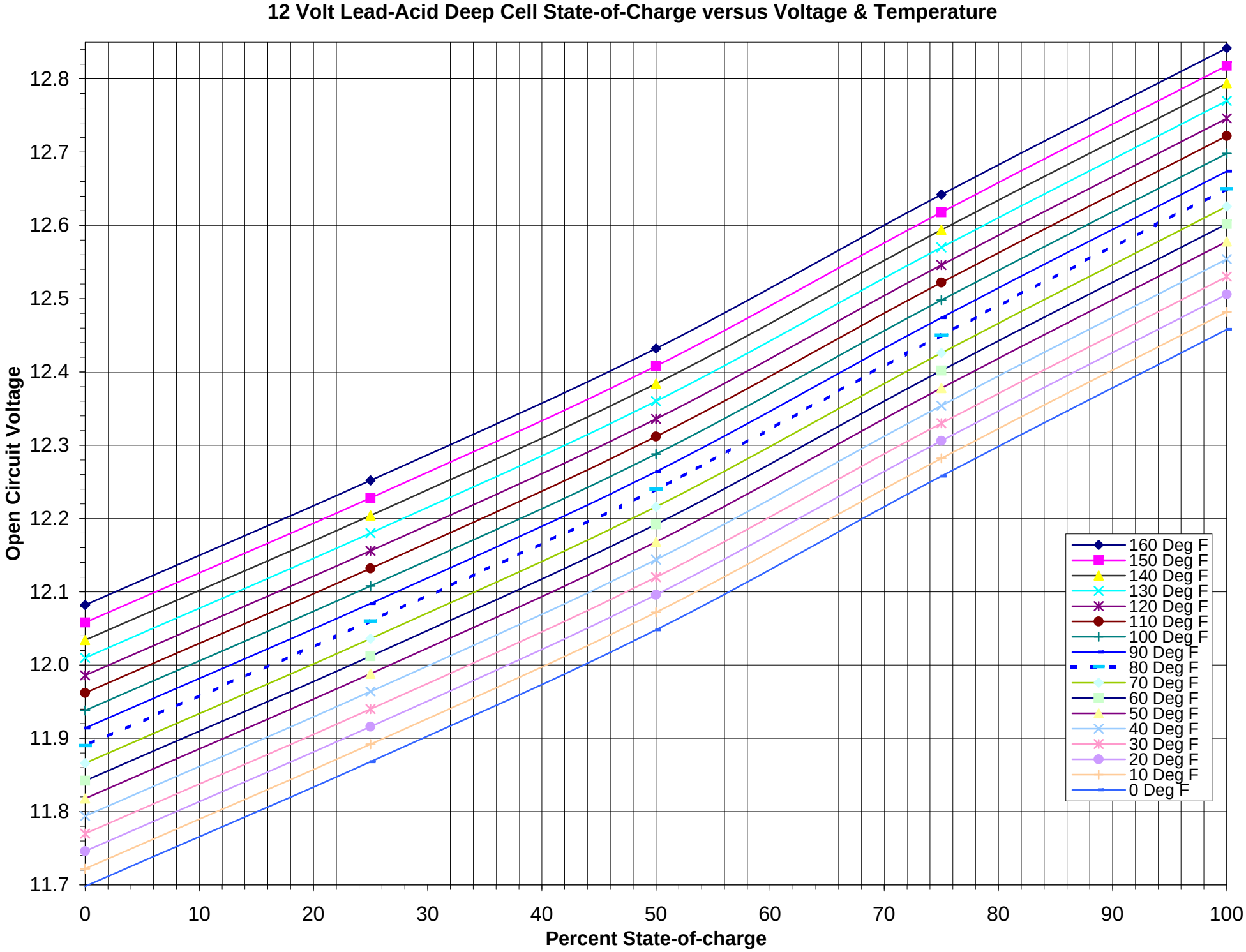
Replace the electrolyte with distilled water, let stand for one hour, apply a constant current of four amps at 13.8 VDC until there is no additional rise in specific gravity. Remove the old electrolyte, wash the sediment out, replace with fresh electrolyte, and recharge. If the specific gravity exceeds 1.300, then remove the old electrolyte, wash the sediment out, and start over with distilled water. If the battery electrolyte rises above 110° F (43.3° C), then stop charging and allow the battery to cool down before continuing. Cycle (discharge to 50% and recharge) the battery a couple of times and test capacity. The sulfate crystals are more soluble in distilled water than in electrolyte. As they are dissolved, the sulfate is converted back into sulfuric acid and the specific gravity rises. These techniques will only work with some batteries.

13. HOW CAN I REDUCE RECHARGING TIME?

To reduce the amount of time that your charger is running, only recharge the battery to 90% state-of-charge at the amp hour rate not exceeding the number of ampere-hours that need to be replaced. For example, if you have consumed 50-ampere-hours from a 100-amp hour battery, then you do not want to recharge it at rate any greater than 40 amps in one hour. At a 10-amp, charging rate, it should take approximately 4.3 hours to get to a 90% state-of-charge. Please note that it will take almost the same amount of time, at a reduced current, to recharge the battery the remaining 10% to bring it to 100% state-of-charge as it took to recharge it originally from the 50% to the 90% level. If you recharge to the 90% state-of-charge level, you should charge to 100% at least every 10^{th} cycle.

Lead-Acid closed Gel Cell State-Of-Charge measurements during discharge
(Use 24hr rate as resting or no flow voltages)




12 Volt Lead-Acid Deep Cell State-of-Charge versus Voltage & Temperature
Open Circuit Voltage
12.8
12.7
12.6
12.5
12.4
12.3
12.2
12.1
12.0
11.9
11.8
11.7
0
10
20
30
40
50
60
70
80
90
100
Percent State-of-charge
160 Deg F
150 Deg F
140 Deg F
130 Deg F
120 Deg F
110 Deg F
100 Deg F
90 Deg F
80 Deg F
70 Deg F
60 Deg F
50 Deg F
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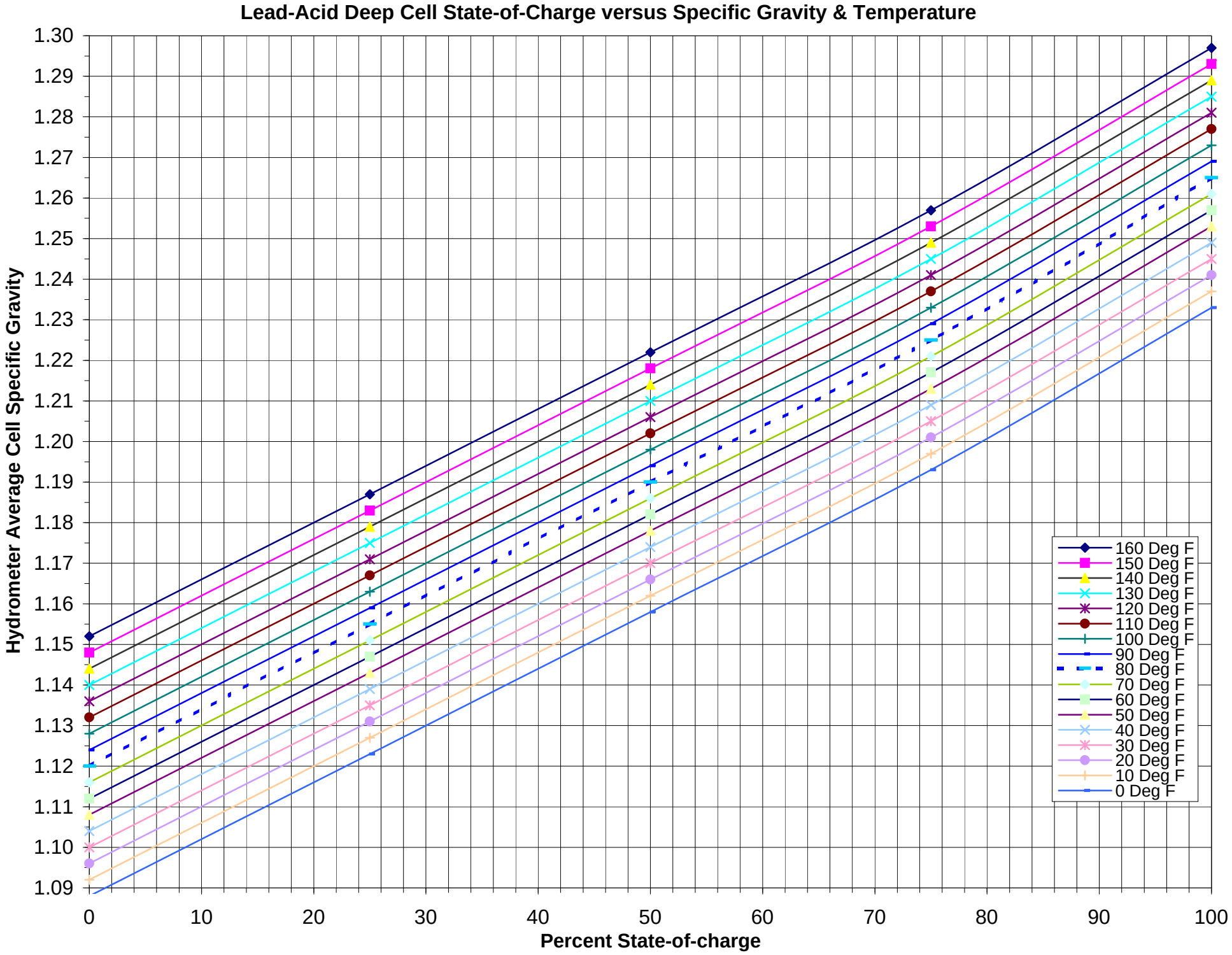
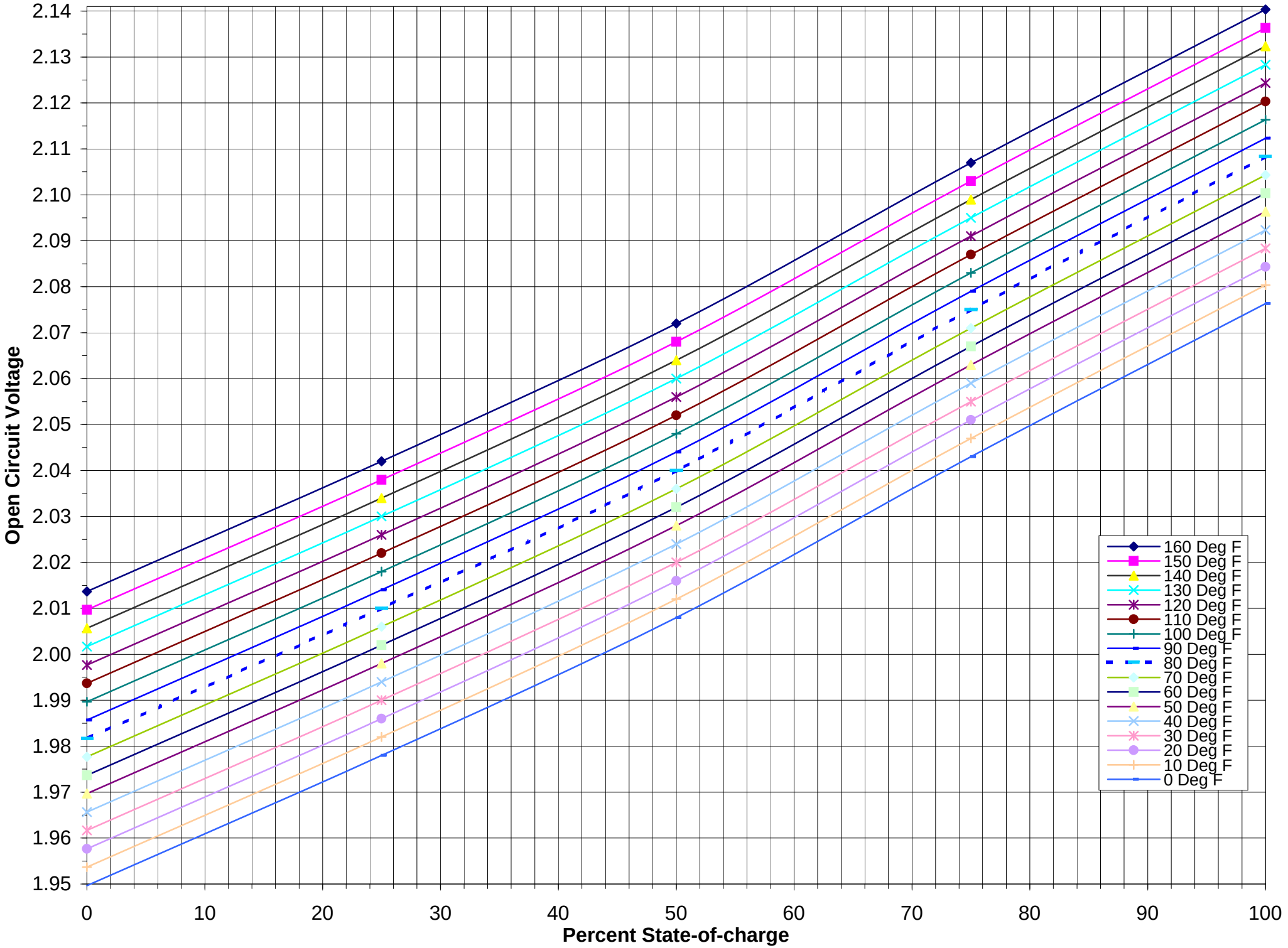
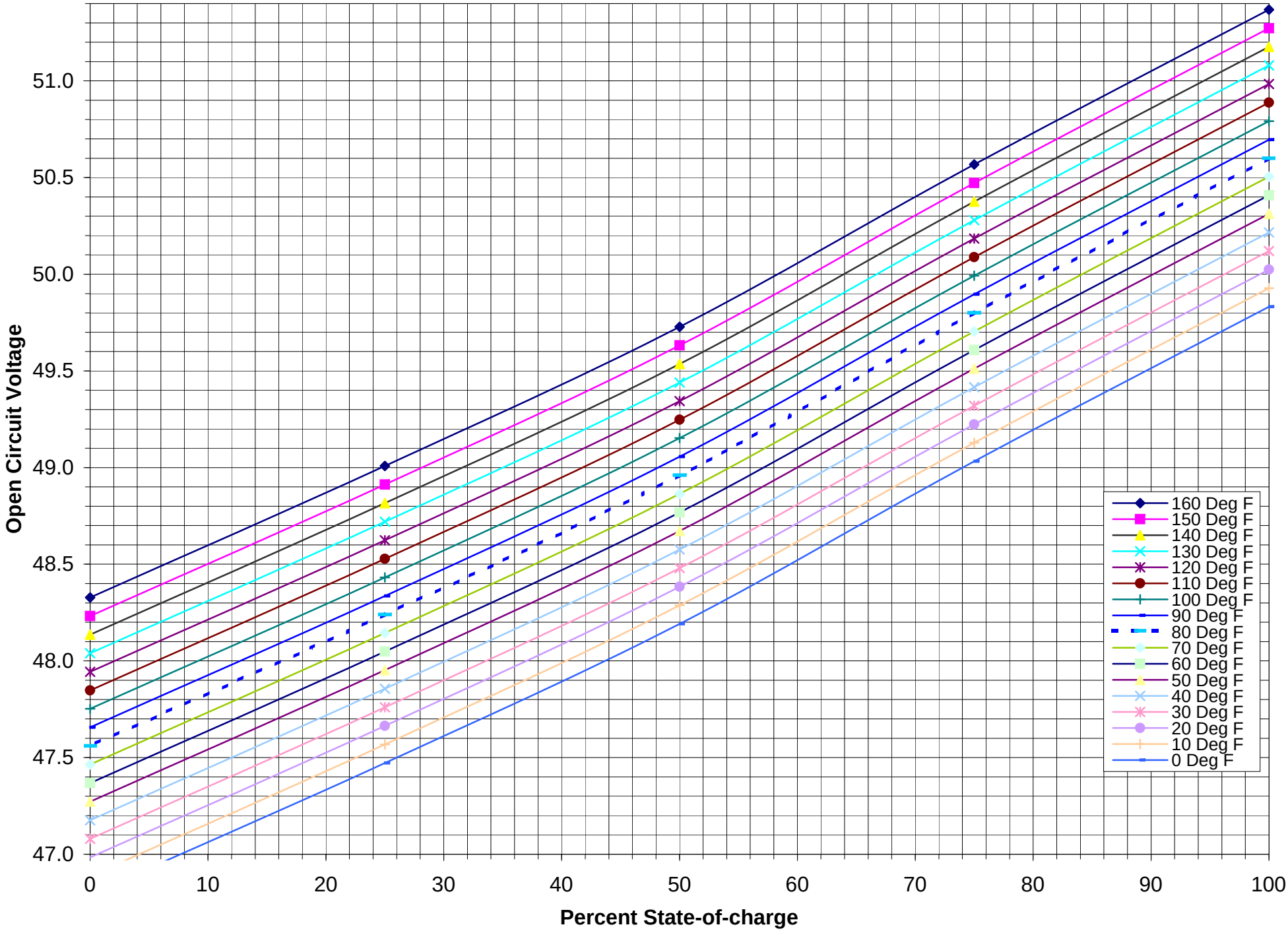

Lead-Acid Deep Cell State-of-Charge versus Specific Gravity & Temperature
Hydrometer Average Cell Specific Gravity
1.30
1.29
1.28
1.27
1.26
1.25
1.24
1.23
1.22
1.21
1.20
1.19
1.18
1.17
1.16
1.15
1.14
1.13
1.12
1.11
1.10
1.09
0
10
20
30
40
50
60
70
80
90
100
Percent State-of-charge
160 Deg F
150 Deg F
140 Deg F
130 Deg F
120 Deg F
110 Deg F
100 Deg F
90 Deg F
80 Deg F
70 Deg F
60 Deg F
50 Deg F
40 Deg F
30 Deg F
20 Deg F
10 Deg F
0 Deg F

One 2 Volt Lead-Acid Cell State-of-Charge versus Voltage & Temperature




48 Volt Lead-Acid Deep Cell State-of-Charge versus Voltage & Temperature
Open Circuit Voltage
51.0
50.5
50.0
49.5
49.0
48.5
48.0
47.5
47.0
0
10
20
30
40
50
60
70
80
90
100
Percent State-of-charge
160 Deg F
150 Deg F
140 Deg F
130 Deg F
120 Deg F
110 Deg F
100 Deg F
90 Deg F
80 Deg F
70 Deg F
60 Deg F
50 Deg F
40 Deg F
30 Deg F
20 Deg F
10 Deg F
0 Deg F

Assuming a known or estimated Amp-hr rated Battery Bank Capacity or State-of-Charge (what's left at the time)

Use this chart to estimate how many hours are left based on the Amp flow rate