Development of a novel expander for enhanced flooded batteries

Government requirements for improved automotive fuel efficiency have driven continuous changes to the automotive industry's electrical subsystem designs. It is well-documented that these changes lead to negative plate battery failure modes. Much work has been done in the industry to improve the negative electrode through use of new additives and battery designs.

EFBs: THE CONTEXT

Today's automotive industry has placed a strong emphasis on improving fuel efficiency to reduce CO2 emissions and meet more stringent regional regulations.

This reduction is primarily achieved by electrification of various components which places additional demands on the battery system. In addition to the typical starting, lighting, and ignition requirements, batteries must now maintain optimal performance with increased electrical loads and regenerative charging.

These changes necessitate improvements to charge acceptance and cycle life while maintaining CCA and reserve capacity performance.

The battery industry's answer to these performance challenges is the enhanced flooded battery (EFB), and key to unlocking the full potential of this new battery design is the use of performance additives. The R&D team at Hammond Group Inc has developed a novel EFB expander and validated its benefits through head-to-head full-scale battery tests and controlled laboratory-scale experiments.

The R&D team comprised: Marvin Ho, Maureen Sherrick, Dave Petersen and Gordon Beckley.

As new materials are introduced, it is necessary to balance the improvement of the targeted characteristics. In this case, the goal is to improve charge acceptance and cycle life while maintaining existing performance characteristics including cold cranking (CCA), reserve capacity (RC), and water consumption (WC).

Unfortunately, many additives cannot achieve this goal without a detrimental effect on the existing performance characteristics.

Research and development of expanders for enhanced flooded batteries (EFBs) has been underway for years. Much of the work has been primarily focused on carbon additives however, there has been some work focusing on organic additives.

Optimizing the selection and loading of both organic and carbon additives is key to enabling improved charge acceptance and cycle life performance without harm to the other performance characteristics (CCA, RC, WC).

Hammond's R&D team has developed a novel expander for enhanced flooded batteries. Controlled experiments in the laboratory have confirmed improved charge acceptance and cycling performance with no loss to other battery performance characteristics versus a Control EFB expander.

Experimental testing

The Control EFB expander was sent to battery manufacturers for qualification in full-scale battery builds. Batteries manufactured with the Control EFB expander were compared to industry and manufacturer standards.

These qualification tests found that charge acceptance (CA) and cycle life were acceptable, but in some instances, the CCA performance and the water consumption (WC) were suboptimal.

Another design iteration was undertaken to improve the CCA and WC while maintaining the performance gains achieved in CA and cycle life. The culmination of this effort is the AE-EFB02 expander which contains a novel combination of organic materials and carbons which were selected from the advanced material screening tool developed by Hammond R&D team.

To compare performance versus the Control EFB expander, negative electrodes were pasted with the following parameters:

Control EFB: 1.45% loading rate versus oxide; paste density: ~4.3 g/cc

AE-EFB02: 1.75% loading rate versus oxide; paste density: ~4.2 g/cc

Paste for both mixes was applied to Ca/Sn alloy book mold cast grids such that the dry cured active material weight was 10.0 grams +/- 0.2 grams (grid dimensions are 2" x 1.5" x 0.054").

Both variables were assembled into cells with group elements of both five plates (3P/2N) and three plates (2P/1N). Control positive electrodes were used for all cells. Cells were formed using a two-shot process and analyzed according to this test matrix. (below).

The relative performance of AE-EFB02 versus Control EFB at the cell level were combined with the Control EFB full-scale battery test results to extrapolate the expected full-scale battery performance for AE-EFB02.

Element grouping	3 Plates (2P/1N)	5 Plates (3P/2N)
Tests performed	Reserve/Crank qDCA High Temperature Float 60˚C	Peukert analysis 17.5% DOD Cycling

Summary of Control EFB test results				
Test	**Criteria**	**Customer 1**	**Customer 2**	**Note**
EN50342-1, 6.1: C20	Specification (60Ah)	Pass	Pass	
EN50342-1, 6.2: CCA	Specification	Acceptable*	Pass	* Acceptable to customer's internal spec
EN50342-1, 6.4: Charge Acceptance	> 20xI20 (A)	Pass	N/A	
EN50342-1, 6.9: Water Consumption	< 3 g/Ah after 42 days	Pass	Acceptable*	* Acceptable to customer's internal spec
EN50342-6, 7.3: DCA	> 0.4 A/Ah	N/A	Pass	
EN50342-6, 7.4: 17.5% DOD Cycle test	> 15 units (1275 cycles)	Pass	N/A	

Table 1: A comparison of two battery manufacturers' testing results versus test specifications.

Full-scale battery testing results

Batteries were built with the Control EFB expander and tested by individual battery manufacturers. Table 1 above shows the summary of test results. As can be seen, the Control EFB expander meets the customers' expected EN50342-1 performance criteria.

Although Control EFB provided good performance in most of tests, the expander is still not robust enough to deliver consistent performance in various battery designs and manufacturing processes. This drove Hammond R&D team to further develop and refine the expander formulation resulting in the novel AE-EFB02 expander.

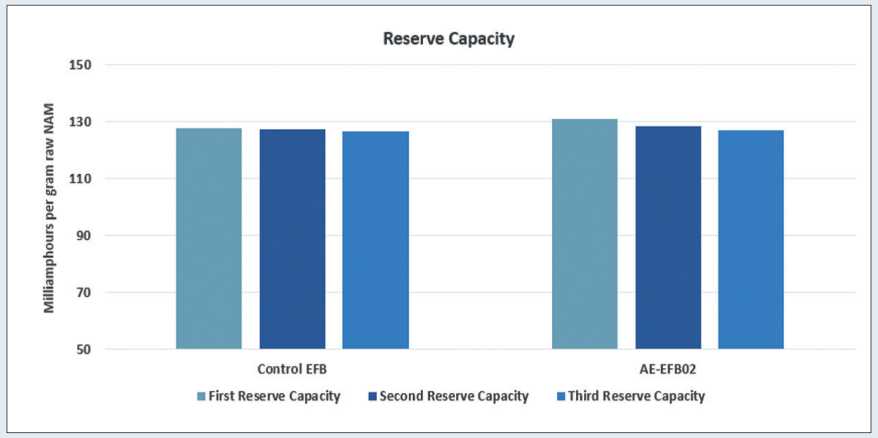

Figure 1: Reserve capacity comparison of Control EFB with EFB02 (Average of 4 cells)

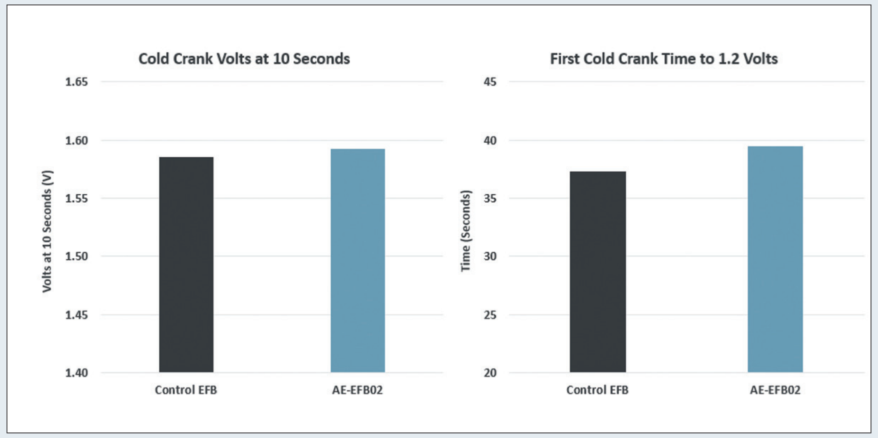

Figure 2: Cold cranking data comparison of Control EFB and AE-EFB02 (average of 4 cells)

Performance results of three-plate cell design

Figures 1 and 2 show the reserve capacity and cold cranking performance of Control EFB versus AE-EFB02. The initial reserve capacity for AE-EFB02 is higher than that of Control EFB. By the third reserve capacity measurement, they become equal. The cold cranking test is run at -18˚C and consists of a discharge of 10 amps (representing ~8C rate) ending at 1.2 volts per cell. AE-EFB02 has marginally higher performance versus the Control EFB in both tests.

BENEFITS

A novel EFB expander (AE-EFB02) developed by Hammond Group was tested and compared with an industry accepted expander (Control EFB). AE-EFB02 demonstrates benefits which improve the performance of EFB batteries in the following areas:

- Superior DCA performance
- Reduced water consumption rate at high temperature
- More stable performance (potential) of the negative electrode during 17.5% DOD cycling

AE-EFB02 expander paves a new pathway for EFB batteries to attain the goals of high DCA and reduced water consumption. AE-EFB02 will further extend the cycle life of EFB batteries if used in combination with positive plates containing life-extending performance additives such as Treated SureCure 140 (4BS crystal seeds).

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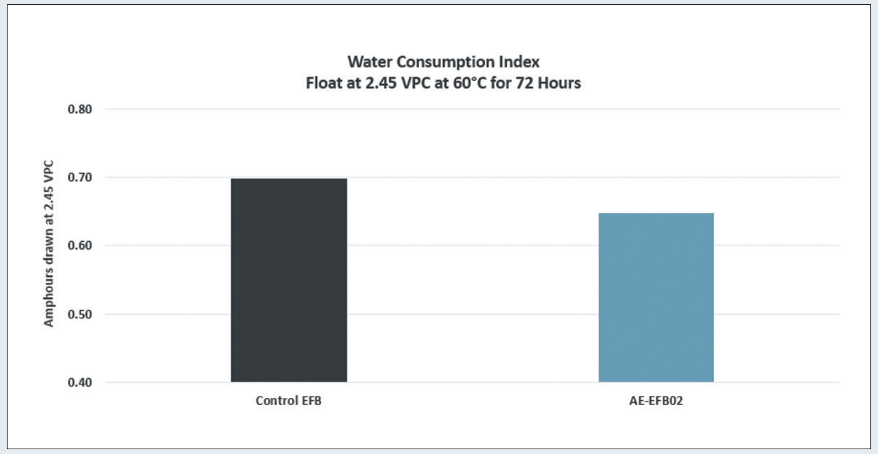

Figure 3: Water consumption index comparison of Control EFB versus AE-EFB02 (average of 4 cells)

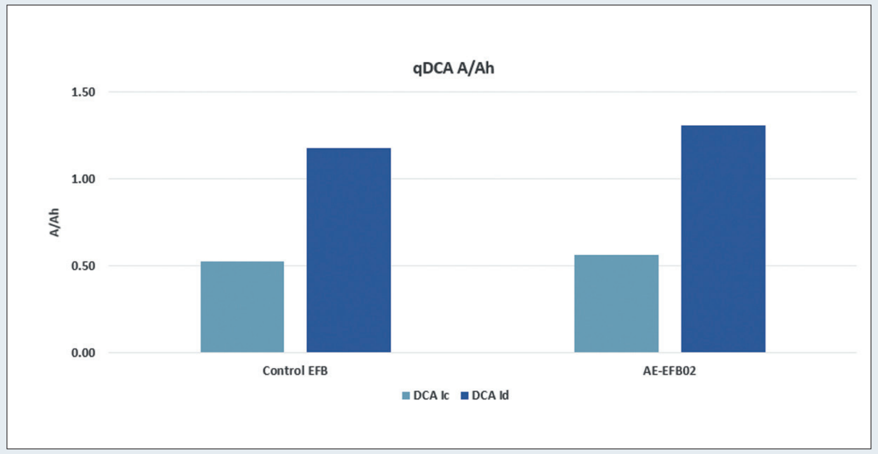

Figure 4: qDCA comparison of Control EFB versus AE-EFB02 (Ic and Id only) with average of 4 cells

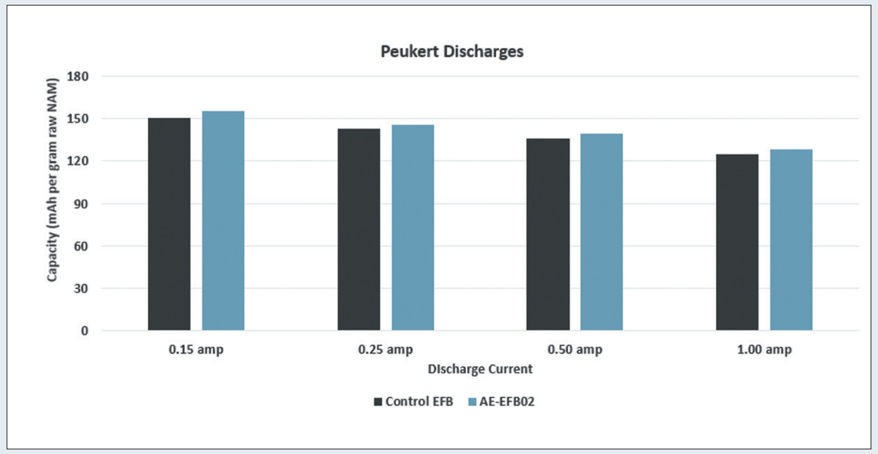

Figure 5: Peukert discharge results of Control EFB versus AE-EFB02

Figure 3 shows the water consumption indicator for both expander formulas. The results for this test are achieved by floating the cell at 2.45 VPC at 60°C for 72 hours. The sum of the amp hours charged during testing is considered to be the water consumption indicator of the cell and is recorded for comparison. The AE-EFB02 achieved a lower water consumption indicator which indicates superior EN50342-1 water consumption performance versus Control EFB.

Figure 4 compares the charge acceptance between variables using EN50342-6, section 7.3. Only Ic and Id analyses were performed in this study. With both formulas, a significant different in charge acceptance is observed depending on if it being compared to discharge history or charge history.

These results meet expectations since the expander variables are designed for superior charge acceptance in EFB applications. The AE-EFB02 variable had higher performance in both categories when compared to Control EFB. Hammond's development of this novel EFB expander with higher DCA performance and lower water consumption opens the door for battery manufacturers to provide improved EFB performance.

Performance results of five-plate cell design

Figure 5 shows the results the Peukert analysis. All cells were discharged using four different rates ranging from 0.15 amps (~20 hours rate) up to 1 amp (~2.5 hours rate). The results are nearly identical for both formulas, showing a slight improvement for the AE-EFB02 variable.

Cycling test (17.5%DOD) was run according to EN50342-6, section 7.4 but adjusted to the cell level. Figure 6 shows the results of the full discharge that is performed every 85 cycles.

The cycling test was stopped at 850 cycles for further investigation. It is evident that AE-EFB02 has a higher capacity through the test until approximately 800 cycles is reached.

Figures 7 and 8 are the half-cell voltages near end of test (850 cycles) during discharge for the negative and positive plates. It is evident that the Control EFB cell was limited by the negative electrode at cycle #838, and AE-EFB02 was limited by the positive electrode at cycle #834.

The health of the negative plates containing AE-EFB02 expander was significantly better than the negative plates containing the Control EFB expander during 17.7% DOD cycling testing.

If AE-EFB02 were to be used in tandem with a positive plate additive such as 4BS crystal seeds, the positive plate life and hence the life of the battery would be significantly improved. ■

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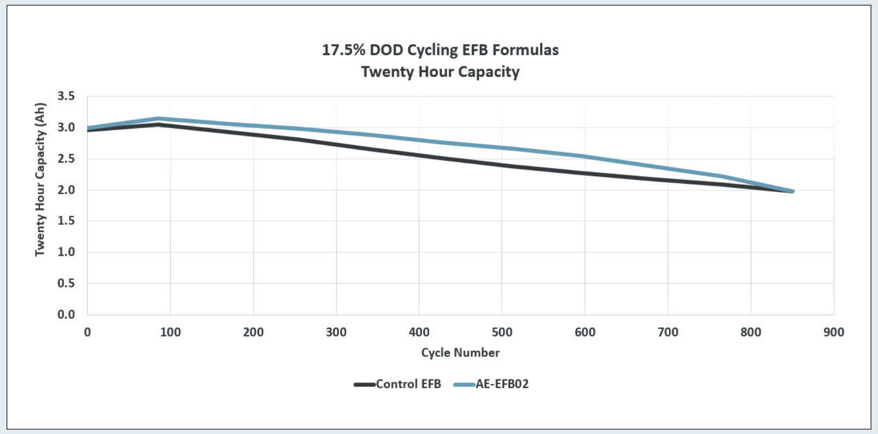

Figure 6: Twenty-hour capacity results for Control EFB versus EFB02 during 17.5% DOD cycling

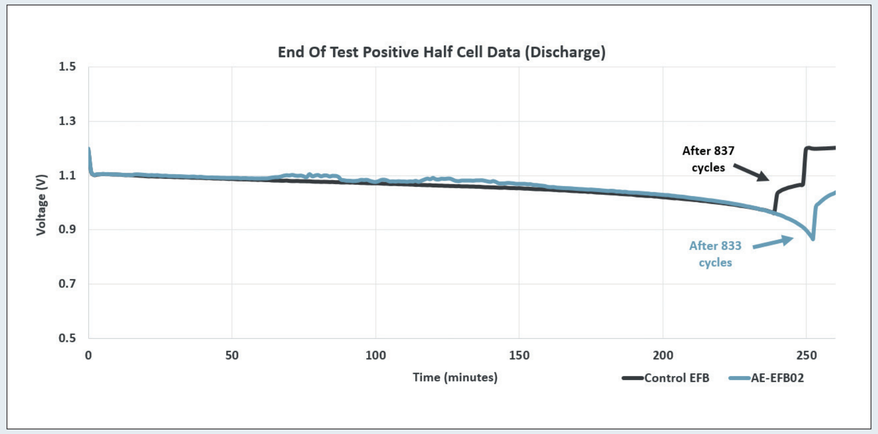

Figure 7: Positive half-cell voltage results for Control EFB versus AE-EFB02 during 17.5% DOD cycling

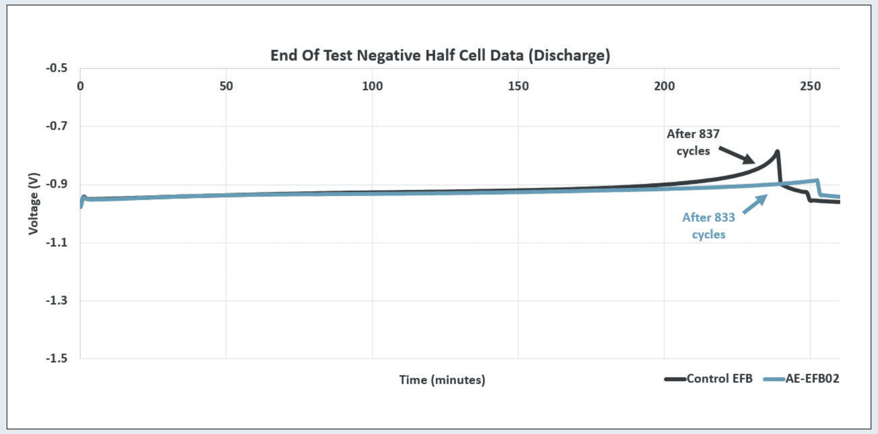

Figure 8: Negative half-cell voltage results for Control EFB versus AE-EFB02 during 17.5% DOD cycling

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Marvin Ho is Hammond's CTO and vice president of research & development responsible for the advancement of lead-acid battery electrochemistry through the development of innovative performance additives and lead oxides.

With over 25 years of experience in energy storage technologies such as fuel cells, nickel based and lead-acid battery systems, he has worked with several leading research institutes including IEEES at the Bulgarian Academy of Sciences and Trinity College in Ireland.

He has held leadership research positions at Trojan Battery Company and China Storage Battery prior to joining Hammond Group Inc.

He earned his PhD in chemical engineering from the University of South Carolina and has published numerous times and holds eight patents.

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For additional information or to request a sample of AE EFB02, please email customerservice@hmndgroup.com.