Innovations in Lithium Ion Battery Manufacturing

A Continuous Manufacturing Process Applicable to Nano-scale Materials at a Signficant Cost Reduction

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ABSTRACT

PRIMIX Corporation has developed a continuous processing method for electrode slurry in the manufacturing of lithium ion manufacturing that is able to meet the dispersion requirements of manufacturing nano-scale active material not available with conventional batch mixing methods. This innovative solution not only improves battery performance in many aspects, it can also considerably reduce the costs to manufacture. This paper compares the various advantages the continuous dispersion method offers over batch mixing.

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PRIMIX Corporation has developed a continuous processing method for electrode slurry in the manufacturing of lithium ion manufacturing that is able to meet the dispersion requirements of manufacturing nano-scale active material not available with conventional batch mixing methods. Furthermore, with respect to batch mixing of material, this continuous dispersion method allows for a reduced use of factory floor space, energy, and labor with significant improvements in the reproducibility in quality of slurry and process utilization. This advancement is one solution to the continuing efforts to reduce the cost of lithium ion battery manufacturing.

Lithium ion battery technology continues to advance, especially in key industries demanding high-capacity storage such as applications for automobiles and smart grids. There are two primary drivers behind these advancements--higher performance and lower cost. We have seen significant developments in three major areas, specifically, the use of nano-scale active material; technologies to control particle shape and the greater use of new conductive materials toward lower electrical resistance.

The impact of developments in manufacturing engineering on the performance, reliability, quality and cost is also well understood. One of the most critical processes is the manufacturing of electrode, the dispersion technology of slurry, is the one of the major determinants of the performance, quality and yield of the electrode slurry coated on the metallic foil collector. In order to fully maximize the advantages that new technologies mentioned earlier offer, manufacturing of slurry must move away from conventional batch mixing methods despite our experience with them, and move toward new electrode slurry manufacturing methods. This requires a shift toward manufacturing equipment that allows for precision control over the dispersion of nano-scale particles.

PRIMIX Corporation developed the CDM (Continuous Dispersion Method) process, a continuous dispersion technology that allows for superior dispersion control and high efficiency. Since PRIMIX introduced in 2007, it have helped many corporations both inside and outside of Japan improve their market applications. Results of testing and evaluation of the most advanced materials dispersed using this technology clearly show the advantages over batch mixing. Furthermore, since CDM is a continuous process, a significant improvement in manufacturing efficiency over batch mixing leads to a reduction in cost to manufacture. Following is an explanation the CDM equipment technology, results of dispersion of advanced materials and how costs can be reduced.

I. The CDM Process

Fig. 1 shows a flow of the CDM process.

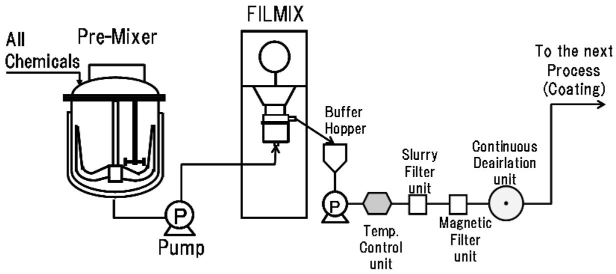


Figure 1: New CDM Process

All materials are fed in order to the pre-mixer where they are mixed for a fixed period of time, then the material is fed to the central mixing unit at a set flow rate with fixed residence time and is mixed in one pass through the FILMIX. At a presentation on the AABC in 2010 in the US, I showed this system with vacuum deaeration using a tank mixer. Since then, we have been successful in developing a continuous deaeration system, feeding the electrode slurry to the next process all continuously, achieving even better efficiency in the manufacturing with this new CDM process.

Next, is a simple overview of the central mixing unit, FILMIX, which is a unique, patented system developed by PRIMIX Corporation.

Fig. 2 shows the FM-252.

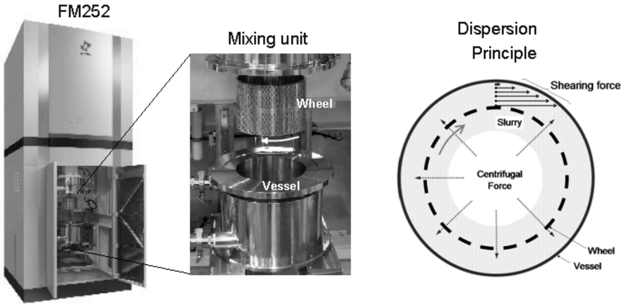


Figure 2: FILMIX outline & Dispersion principle

This unit has the greatest production capacity. The design of the mixing unit is system with an inner wheel that spins at high speed inside a cylindrical container, making it easy to maintain and clean. The dispersion principle involves a dispersion that occurs from the difference in shear force between the fluid material moving at high speed near the spinning wheel and low speed of fluid closer to the stationary wall of the cylinder. The uniform dispersion that achieved from this difference in shear force is ideal for dispersion of electrode slurry. The most prominent characteristic of this method is that it allows for a high level of control over the dispersion.

Fig. 3 shows the distribution of particle diameter for an emulsion of oil, water and surfactant agent with respect to the wheel speed. This data demonstrates that particle size can be controlled by the wheel speed. This unique functionality provides the optimal dispersion for a particular battery material.

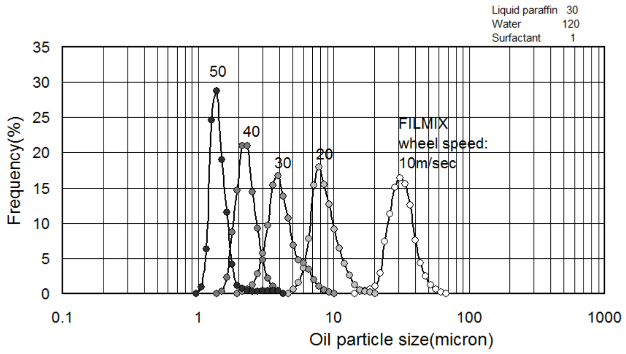


Figure 3: Emulsification with FILMIX(wheel speed vs. particle size distribution)

The second advantage of using shear force in this dispersion method is that the crystalline structure of particles is not damaged as can be seen in Fig. 4. This shows the crystals after mixing of actual active material. This holds true for the wide variety of the new generation of active materials that have a variety of crystal structures.

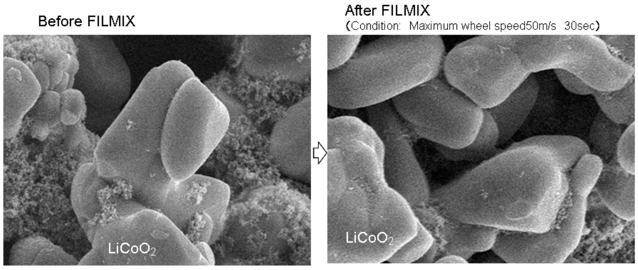


Figure 4: The mixing effect without damage to the crystal

II. Results of Dispersion of Advanced Battery Materials

Let us consider ternary cathode material (NCM) used for high capacity battery applications. The SEM photo in Fig. 5 shows the slurry of cathode NCM with an average particle diameter of D50:10 μm mixed using a FILMIX, then coated and dried. On the right, is the results achieved with a conventional batch mixer. The dispersion achieved with FILMIX shows a favorable distribution of conductive material on the surface of active material particles, contributing to improved electrical resistance. Actual testing on batteries also shows significant improvements in discharging properties as well.

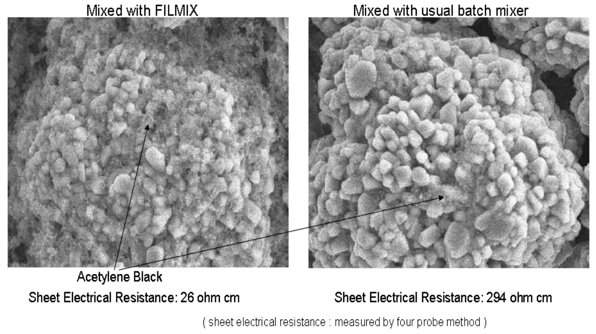


Figure 5:
The difference of conductive material dispersibility with mixers in NCM cathode

Fig. 6 shows a comparison of electrical resistance with respect to amounts of added conductive material in a dried and coated iron phosphate slurry that has been dispersed using both with FILMIX and a batch mixing process. As you can see, it is possible to achieve the same level of conductance using about half of the conductive material when slurry is mixed using a FILMIX. For iron phosphate that has low conductivity, FILMIX allows you to control the amount of added conductive material and improve capacity.

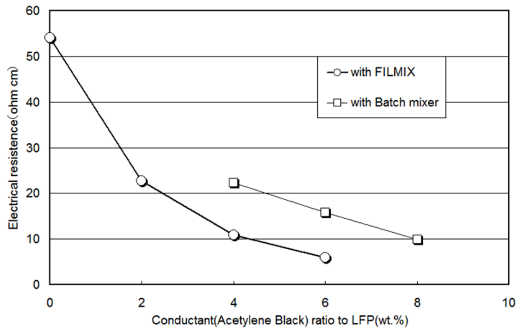


Figure 6:
Sheet electrical resistance to the acetylene black amount ,and mixer effect

Results in Fig. 7 show the electrical resistance of electrode slurry dried film with respect to the wheel speed, which is the determining factor in the level of dispersion. We tested both generally used $LiCoO_2$ and iron phosphate. Acetylene black was used for the conductive material. The graph shows the optimal values of electrical resistance with respect to wheel speed, demonstrating that specific settings impart a high level of control over the dispersion. Use of this method makes it possible to achieve the optimal dispersion conditions of the active and conductive material. Results of testing show that the same holds true for the most advanced conductive materials, such as carbon nanotubes.

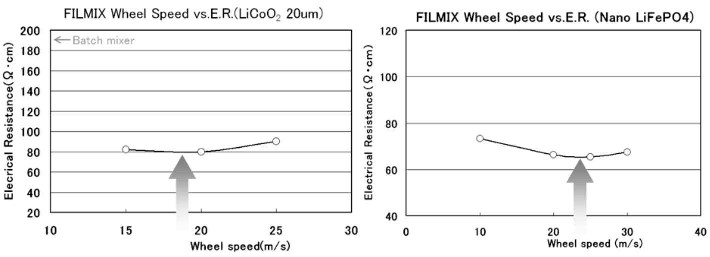


Figure 7: The controllability of FILMIX mixing(Optimization by wheel speed)

Fig. 8 shows the favorable dispersion conditions of carbon nanotubes and a fibrous conductive material such as VGCF using FILMIX. This kind of dispersion of conductive material was impossible to achieve with a batch mixer.

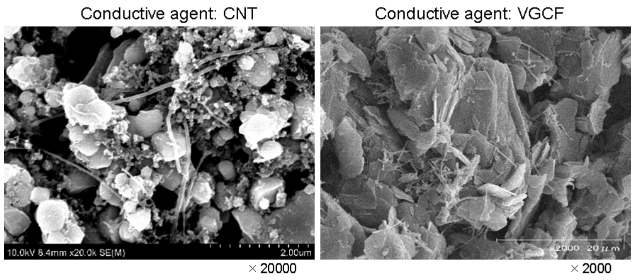


Figure 8: Dispersion of fibrous conductive agent with FILMIX

Next, let us consider how battery properties can be improved through the CDM process. Up to this point, I discussed uniform dispersion of nano-scale battery material using the central unit, FILMIX, and the ability for precise control over the level of dispersion. But it is equally important to examine the performance of the battery.

In this test, we made actual battery prototypes using electrode slurry mixed using a batch mixer and with the FILMIX, the central unit of the CDM process. The active material used was nano-scale iron phosphate. Fig. 9 shows the rate of discharge. In the lower rates of discharge such as in lithium ion batteries used for mobile devices, we see little difference in discharge between the two prototypes. But at higher rates of discharge such as 20 C to 30 C that are required with automotive battery applications, material mixed with FILMIX performs significantly better. These improvements in battery properties are outcomes from a high level of precise control over dispersion that provides superior dispersion of conductive material without any damage to active material particle structure.

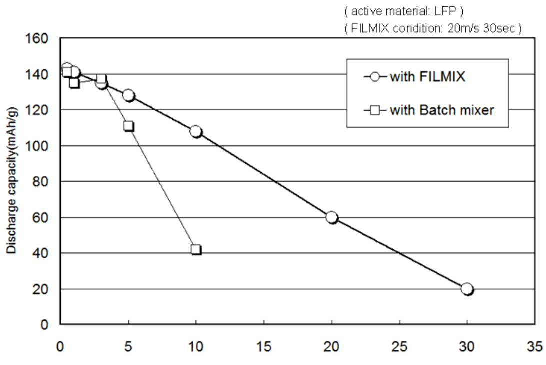


Figure 9:
Large improvement at high rate discharge performance by FILMIX mixing

III. Realizing cost reduction

Obviously the cost of a battery is a function of both the materials and manufacturing process. In this section, I will provide clear evidence of how manufacturing costs can be reduced. Manufacturing costs includes percentage of good product (process yield), process utilization and other costs to manufacture. In order to realize a greater yield, it is crucial to achieve fixed and stable manufacturing conditions.

Fig. 10 shows is data that shows the reproducibility of slurry viscosity using the CDM process, demonstrating a high level of reproducibility in both the NMP cathode and aqueous based anode. This is made possible by the precision control of dispersion imparted by the FILMIX. This ability to achieve stable viscosity over and over again makes the most of the highly precise slit die coating techniques, allowing for improved yield in the manufacturing of electrode material.

Cathode

Run No.	Viscisity (mPa-s)	Temp.(C)
1	5800	25
2	5900	25
3	6100	26
4	6100	26
5	6000	25
6	6100	25
7	6000	26
8	6200	25
9	5900	25
10	6000	26

Materials	Composition
LICoO2	100
Contuctant(AB)	2.08
PVDF(#7208)	2.08

Solid content: 66.5wt%

Anode

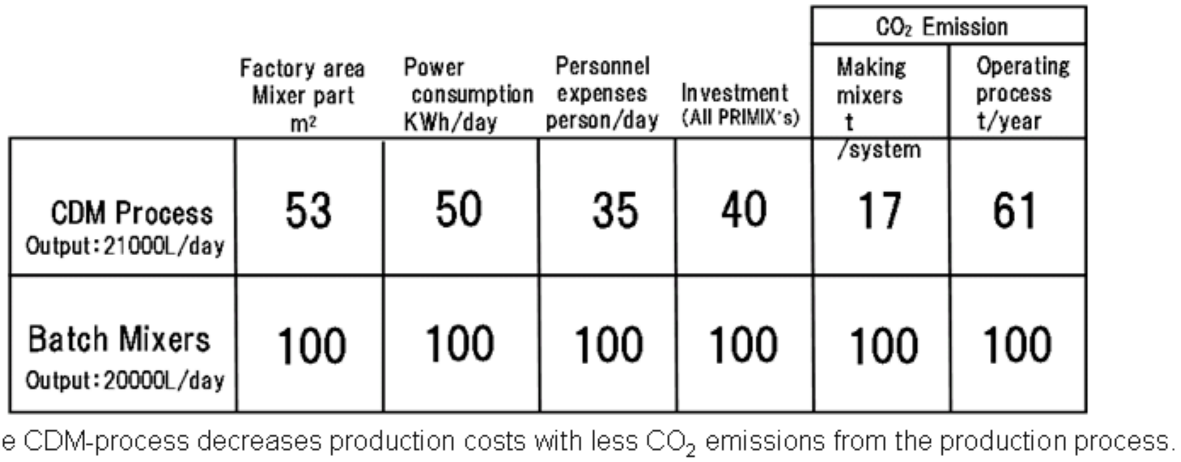
Run No.	Viscosity(mPa-s)	Temp
1	4900	21
2	5200	20
3	5200	21
4	5100	21
5	5000	21
6	5000	21
7	5000	21
8	5000	21
9	5100	21
10	5200	20

Material	Composition
Graphite(MAGD)	100
CMC#2200	1.5%soln.
40%SBR	3.87

Solid content: 40wt%

Fig.10 Reproducibility of slurry Viscosity

Next, let us examine how other manufacturing costs are reduced. Fig. 11 shows the relationship between the cost of CDM process and a batch process per category of costs. The production level considered in this example is 20,000L/day. See the following chart for a comparison.



	Factory area Mixer part m^2	Power consumption KWh/day	Personnel expenses person/day	Investment (All PRIMIX's)	CO_2 Emission Making mixers t/system	CO_2 Emission Operating process t/year
CDM Process Output:21000L/day	53	50	35	40	17	61
Batch Mixers Output:20000L/day	100	100	100	100	100	100

The CDM-process decreases production costs with less CO_2 emissions from the production process.

Fig.11 Comparison of Cost Factors in Slurry Production

Fig. 12 shows how one factor of manufacturing cost, factory floor space devoted to mixing, compares between CDM and a batch mixing process. The CDM process requires about half of the floor space. Although the details will not be explained in depth, the smaller footprint of a continuous process not only contributes to reduced energy consumption, both labor and equipment costs can be drastically reduced.

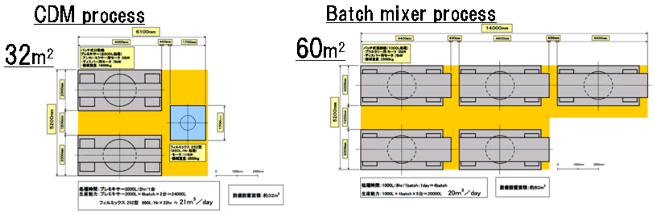


Fig.12 Comparison of mixer area

Fig. 13 shows the equipment and production level available in the CDM process. We are seeing an increase in the installations of the highest capacity line, CDM 252, which meets the maximum production capacity required for manufacture of automotive batteries and large storage batteries. There is an increased demand from the market for manufacturing engineering such as a continuous process that can help reduce costs. As mentioned in this article, the CDM process with the FILMIX at its center, is a powerful lithium ion battery manufacturing technology that can make the most of the newest generation of materials while reducing costs.

CDM Process Line up	Production capacity (L/Hour)	FILMIX model
CDM-252	960	FM252
CDM-220	600	FM220
CDM-156	240	FM156
CDM-125	120	FM125
CDM-80	30	FM80

Figure 13: CDM Process Lineup

More recently, this technology is being increasingly used in the manufacturing of other energy devices that have high market expectations such as fuel cells and capacitors. In addition to the line up in the CDM process, a desktop unit for research and development is also available for the purpose of testing.. The FILMIX and CDM process are making it possible to realize solutions in the many challenges of manufacturing energy devices.