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TECHNICAL REPORT

Dry Rooms: Why They Are Needed and a Review of the Complex Issues Associated With Building Them - Particularly the Large Ones Required to Mass Produce Lithium Batteries

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Abstract
Dry rooms are not "clean rooms" or "environmental chambers " While constant temperature and low particulate counts may be a requirement, controlling the humidity levels necessary to meet the demands of today rapidly growing Lithium ion technology and tomorrow's future technology present unique problems and skills which are currently in limited supply. To complicate matters, failure to control the humidity can result in loss of quality, lower manufacturing capacity, energy inefficiencies, and possibly catastrophic failures and personnel injuries. Lithium battery manufacturing processes require low humidity conditions not unlike those found on the Moon or Mars. Designing and delivering a facility to build large format batteries requires suppliers with special skills acquired from years of experience with very low dew point installations.

Manufacturing lithium ion batteries is a complicated technical process that has many challenges - not the least of which is the requirement for all processing of the lithium electrodes to be done under very low humidity conditions - typically below 1% RH or lower (- 35°C or -40°C dew point) and must also be a low particulate environment. On the other hand, clean rooms (like those used in the semiconductor industry) arc actually designed to leak, so that the positive internal pressure prevents any particle intrusion into the space. These environments are typically controlled to humidity levels that are at least 50 times more humid than a typical dry room. To better control the humidity in the processing areas, dry rooms (a hermetically sealed environment that maintains very low humidity levels and provides particle filtration) were developed that allowed manufacturing to take place in an almost absolute dry environment. For high volume Lithium ion battery manufacturers, the dry room is likely the most expensive single piece of 'equipment' they will ever design or install.

A handful of companies became very specialized in dry room design, materials technology and the supporting dehumidification equipment, controls and air distribution systems. As with any developing technology there were mistakes made and a steep learning curve in defining and then executing the design details. Working with lithium, mistakes can be costly, and several of the early manufacturing plants were badly damaged or destroyed by violent lithium reactions caused from loss of moisture control in the working space (SAFE HANDLING OF LITHIUM METAL by ESPI http://www.esp.i-metals.comltechffech%20Lithium%20Metal%20Handling.htm). Depending on the battery chemistry used, elemental lithium can be present and will react violently when exposed to even very small amounts of moisture (so low that it requires special instrumentation to even measure it), the consequences of not managing moisture can be devastating - including the potential to destroy the facility and its contents.

More prevalent than the "meltdowns" were battery quality issues caused by dry rooms and HVAC systems that could not maintain the consistent and precise environmental conditions that are required to assure a high quality manufacturing process. Even slight variations in the humidity levels during the manufacturing process can affect the cycle life of the lithium cells and the maximum storage capacity over time. Early dry room providers learned how to design and install a manufacturing environment that was safe, reliable and consistent. These early systems, though small, consumed prodigious amounts of energy as the tradeoff to maintain the very critical environmental conditions. With time and experience the dry room providers have been able to reduce energy consumption by over 30% with new proprietary dehumidification and room systems that are available today, options for regeneration of the desiccant, and by energy efficient dry room designs.

The demand for lithium battery manufacturing facilities has experienced a tenfold increase during the last eighteen months as a result of the convergence of several factors; fossil fuel price pressures, renewable energy growth, electric and hybrid autos and the proliferation of military field electronics. Availability of stimulus funding from the U.S. government has also prompted a number of start-ups and joint ventures all launching at nearly the same time, competing for this new and expanding market sector. This has resulted in the need for many new high-volume lithium ion battery manufacturing facilities with increased time and cost pressures to get these facilities operating quickly and efficiently. The lithium battery industry is highly cost competitive. Since the dry room is a large up-front investment for the owner, there seems to be a growing tendency for some new suppliers to offer their dry room product at significantly lower costs, in order to win contracts. The experienced dry room suppliers have avoided projects where time constraints, cost pressure or other facility design issues could cause the design and construction of the dry rooms to be compromised, and thus would not allow them to guarantee their dry room performance over the long term. Due to the surge in demand for production of large, high volume facilities, some new players have entered the dry room marketplace that have abundant experience in clean rooms, environmental rooms or HVAC systems but have little or no direct dry room design and construction experience. Some have reallocated the resources that used to design semiconductor clean rooms (which is a declining market) to try to penetrate the growing dry room market. They face a steep learning curve, similar to what the now experienced dry room providers faced when they entered the market 20+ years ago. However, unlike their predecessors, mistakes made now would have a much more profound negative impact as the size of the planned facilities are significantly larger and the amount of product affected by a single event is far greater. Mistakes in design or installation in turn can create major problems for the owners of the facilities, including poor battery quality, reduced capacity, production downtime, energy inefficiency and even potential catastrophic losses.

The costs for mistakes and poor performance are much greater now because the lithium ion battery manufacturing plants being built today are very large with very high levels of production. These are not pilot projects but true high volume manufacturing facilities that are semi or fully automated where even a slight problem with the dry room performance will have a significant impact on the quality and quantity of batteries manufactured.

Therefore a number of important and critical requirements need to be considered when selecting supplier(s) to deliver your successful dry room project:

• Start with an experienced supplier who has the ability to design and build a large, high volume dry room(s) to meet your required specifications. The prime supplier would also be able to help you to understand the cost -benefit options for incremental performance points.

• Insure that the dry room supplier guarantees the performance of the entire dry room as a system, including the walls, ceilings, floor coatings, doors, HVAC, lighting, controls and all external penetrations.

• Select materials and wall and ceiling construction that will integrate well and will satisfy local authority approval as well as fire rating, look and feel, etc.

• Build in a level of redundancy with a practical approach to its application. For example, some amount of redundancy is necessary to allow performance of routine maintenance on the dehumidification systems, particularly if the operations are

24/7 or if there is a significant loss of power that could impact a large volume of production. Separating the dehumidification system from the airborne particle filtration system might be a more effective approach that allows redundancy and a simpler path to upgrade for future needs.

• Instrumentation systems are just as critical and should integrate all the control and monitoring functions of your dry room into a single package that is reliable, accurate and provides important information to the operators of the dry room.

• Maximizing energy efficiency will significantly reduce the long-term operating costs of the dry room and your entire facility. Dry-room providers should be required to provide a detailed energy analysis for the dry room(s) as part of their package as well as offer equipment options, such as multi-mode HVAC system controls.

• Consider constructability, logistics planning and supplier's track record with difficult or unique installations. The successful vendor should be able to demonstrate to the owner via shop drawings, submittals, project schedules, risk management plans and experienced on-site installers that have "been there, done that" before. Field installation is not the time to "figure out how to do it".

• Develop a long-term preventative maintenance plan that addresses the critical nature of the dry room systems and will ensure continued functionality at design conditions for its entire life.

Additionally, several critical parameters need to be defined when specifying a dry room:

• Process requirements: temperature, dew point, particles, exhaust, chemicals, ESD, future needs.

• People load and shift timing: access/egress, material, equipment movement, level of automation, shift times/breaks.

• Machine loads: heat, exhaust, chemicals, noise levels, automation, penetrations for utilities.

• Energy consumption: HVAC, lighting, utility costs, variety of available utilities (electricity, gas, chilled water, steam).

• Recovery requirements after an event: redundancy, backup power, chilled water.

• Controls integration (dehumidifier, refrigeration, air handling, and building automation).

• Cost of malfunction or downtime: training, preventive maintenance, field service.

• Building integrity: occupancy class, floor condition, ceiling loads, existing utilities, grounding.

• External environment: climate, local codes, seismic zone, access to various utility providers.

• Managing change: tighter specs, lower operating expenses, modular design.

• Integrated design and delivery: including spec validation, commissioning, formal acceptance validation, training, field service and services after the sale.

In summary, high volume lithium ion battery manufacturing requires one of the most critically controlled process environments in order to be successful. The learning curve is very steep and mistakes can be costly in terms of product quality, productivity and energy costs, and can result in severe damage to the equipment and injuries to workers. A wise course is to work with dry room providers who will include all of the necessary services and will also provide the support, training and track record of long-term success in not only the design, but the full integration, delivery and ongoing support of your largest equipment investment.