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Study of a dry room in a battery manufacturing plant using a process model

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HIGHLIGHTS

- The energy demand and cost of a dry room has been studied with the help of a process model.
- A heat exchanger in the desiccant regeneration loop significantly reduces the energy demand.
- Moisture is easier to remove from make-up air than from the larger volume of air going to the dry room.

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ABSTRACT

The manufacture of lithium ion batteries requires some processing steps to be carried out in a dry room, where the moisture content should remain below 100 parts per million. The design and operation of such a dry room adds to the cost of the battery. This paper studied the humidity management of the air to and from the dry room to understand the impact of design and operating parameters on the energy demand and the cost contribution towards the battery manufacturing cost. The study was conducted with the help of a process model for a dry room with a volume of 16,000 cubic meters. For a defined base case scenario it was found that the dry room operation has an energy demand of approximately 400 kW. The paper explores some tradeoffs in design and operating parameters by looking at the humidity reduction by quenching the make-up air vs. at the desiccant wheel, and the impact of the heat recovery from the desiccant regeneration cycle.

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1. Introduction

Increasing demand for lithium ion batteries (LIB) [1] and the resultant demand for reliable dry rooms [2] have spurred numerous suppliers offering dry room technologies. The trend is toward larger manufacturing plants to benefit from economies of scale [3]. These plants seek to squeeze out inefficiencies and cost factors. The dry room represents a step in the manufacturing process where the energy demand is very high because of the large volume of air that needs to be temperature controlled and dried.

At present, the dry room is an essential part of the manufacturing plant for lithium ion batteries [4–6]. Here the cells are filled with the electrolyte which is very sensitive to moisture (e.g., lithium hexafluoride reacts with water) and sealed in an environment with moisture concentrations below 100 parts per million by volume (ppmv). Small variations in the moisture content can affect the capacity and/or the cycle life of the cells produced [7].

The dry room environment is maintained by designing a leak-proof contained volume, where the incoming air contains very low moisture content (say 15 ppm or 0.066 grains per pound (gpp)), such that the exit gas does not exceed the specified upper limit (say 100 parts per million volume (ppmv) or 0.44 gpp). The air flow rate through the dry room is controlled with sensors to maintain the exit gas at a moisture content of 100 ppm or less. Management of ventilation through a combination of vent placement and air flows ensures rapid resolution of any occasional spikes in moisture at key spots in the room [8]. The room enclosure is kept leak-proof which includes use of a vapor barrier seal on the concrete floor followed by an epoxy finish coat. Some key parameters in the design of the dry room include the volume of the room, the allowable moisture

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Abbreviations: COP, Coefficient of Performance; gpp, grains per lb; kW, kilowatt; LIB, Lithium ion batteries; NG, Natural gas; PHEV, Plug-in Hybrid Electric Vehicle; ppmv, Parts per million by volume; RH, Relative Humidity; scfm, Standard cubic foot per minute.

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concentration, and the amount of moisture released from the materials entering and personnel working in the room [9].

The objective of this paper is to estimate the energy consumption and the cost contribution to the battery manufacturing plant from operating a dry room. A generic system diagram has been proposed to enable a reasonable estimate of the cost and energy demand of operating a dry room.

2. Dry room process model

This study was conducted for a dry room in a battery manufacturing plant that will produce 100,000 packs of automotive lithium ion batteries (LIB). The plant equipment is amortized over 6 years. The dry room is assumed to have a volume of 16,000 m^3.

Fig. 1 is a schematic of the management of the air supply for the dry room, including some assumptions, input parameters, and calculated results for a base case system. The make-up air at 33 °C, 50% relative humidity (RH) or 2.5 vol% moisture, is pre-cooled to 9 °C to drop out some of the moisture and then blended with the return air from the dry room. The combined stream emerges at a temperature of 24 °C and a moisture content of 0.07 vol% (3 gpp). This stream is filtered and cooled down to 10 °C, and then split with 95% going towards the dry room (A7-A10), the balance (purge stream) to be eventually discharged (B7–B14) from the system. A low purge rate (5%) is advantageous in that it lowers the heating and cooling loads in the system, and is discussed in Section 3.5. The dry-room stream is passed through a desiccant wheel where the moisture content is reduced to 15 ppmv (0.066 gpp). This gas is then heated or cooled as needed such that the dry room exit air is at 25 °C. For this base case scenario, the dry room inlet temperature is 14 °C. Within the dry room the air picks up moisture from the personnel, from the negative electrodes that come in with moisture content, and the opening of the airlock doors. The air flow rate and its inlet temperature are calculated such that the return air is at 25 °C and with a moisture content of 100 ppmv (0.44 gpp), or less. For the base case set of conditions, the inlet air is at 14 °C and the air flow rate is 20 $m^3\ s^{-1}$ (41,000 $ft^3\ min^{-1}$). This air flow rate corresponds to a residence time of 13.6 min within the dry room.

The desiccant wheel is regenerated by passing the discharge air stream heated to 146 °C. The discharge air stream flows multiple times through the desiccant wheel to heat and cool the desiccant wheel and to allow for recovery of some of the sensible heat, as shown in the figure. Table 1 lists the assumptions and input parameters used in calculating the results shown in Fig. 1.

3. Results and discussion

With the dry room inlet and exit air streams stipulated to contain 15 ppm (0.066 gpp) and 100 ppm (0.44 gpp) of moisture, respectively, the air flow needed through the dry room is calculated to be 19.6 $m^3\ s^{-1}$ (41,600 $ft^3\ min^{-1}$). This flow represents a residence time or volumetric air turnover every 13.6 min. With the heat generated in the dry room assumed to be 250 kW, the inlet air temperature needs to be at 14 °C to ensure that the air leaving the dry room is at the specified 25 °C.

Table 2 shows the heating and cooling loads for the steps in the process. The largest cooling load of 426 kW is at the Cool station (A5-A6). The combined cooling load at three stations (Pre-Cool, Cool, and Post-Cool) is 483 kW. Assuming a coefficient of performance of 3.5, the electric power needed for the heat removal is 138 kW. A heating load of 30 kW is needed to regenerate the desiccant wheel. Electric power is needed for the blowers (167 kW) and refrigeration (138 kW), adding up to 305 kW. The thermal energy requirements are at Post-Heat (63 kW) and for the discharge air heating for zeolite wheel regeneration (30 kW). The total energy requirement for the operation (the sum of the thermal and electrical) is 398 kW. If we consider that the electric power from the grid is generated from natural gas (NG) with an efficiency of 40%, then the energy required for the system becomes ((138 + 167)/0.4 + 93 =) 856 kW. Using the EPA greenhouse gas equivalencies calculator [10], the greenhouse gas emissions from the generation of the thermal and energy usage for the dry room air management converts to 5.4 MT of CO_2 Equivalent. These estimates

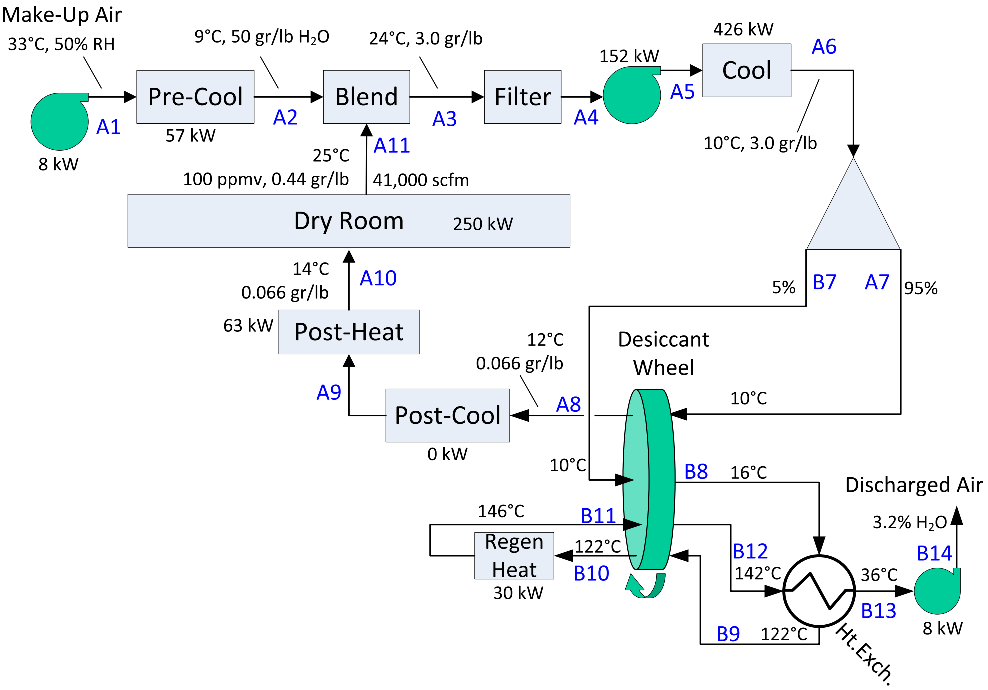

Fig. 1. Schematic of the air management for the Dry Room.

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