Renewable Energy 61 (2014) 17–22

Contents lists available at SciVerse ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Potential use of geothermal energy sources for the production of lithium-ion batteries

Gudrun Saevarsdottir*, Pai-chun Tao, Hlynur Stefansson, William Harvey

Reykjavik University, 101 Reykjavik, Iceland

ARTICLE INFO

Article history:
Received 29 December 2011
Accepted 16 April 2012
Available online 2 June 2012

Keywords:
Lithium-ion battery
Geothermal energy
Energy cost
Carbon emission

ABSTRACT

The lithium-ion battery is one of the most promising technologies for energy storage in many recent and emerging applications. However, the cost of lithium-ion batteries limits their penetration in the public market. Energy input is a significant cost driver for lithium batteries due to both the electrical and thermal energy required in the production process. The drying process requires 45–57% of the energy consumption of the production process according to a model presented in this paper. The model is used as a base for quantifying the energy and temperatures at each step, as replacing electric energy with thermal energy is considered. In Iceland, it is possible to use geothermal steam as a thermal resource in the drying process. The most feasible type of dryer and heating method for lithium batteries would be a tray dryer (batch) using a conduction heating method under vacuum operation. Replacing conventional heat sources with heat from geothermal steam in Iceland, we can lower the energy cost to 0.008USD/Ah from 0.13USD/Ah based on average European energy prices. The energy expenditure after 15 years operation could be close to 2% of total expenditure using this renewable resource, down from 12 to 15% in other European countries. According to our profitability model, the internal rate of return of this project will increase from 11% to 23% by replacing the energy source. The impact on carbon emissions amounts to 393.4–215.1 g/Ah lower releases of CO_2 per year, which is only 2–5% of carbon emissions related to battery production using traditional energy sources.

1. Introduction

The exponential growth in the use of portable electronic devices and electric vehicles has created enormous interest in inexpensive, compact, light-weight batteries offering high energy density. Clearly, the lithium-ion battery is one of the most appealing technologies to satisfy this need. It is estimated that the global market for lithium-ion batteries could grow from $877 million in 2010 to $8 billion by 2015 [1]. However, cost limits their penetration in the global market. Energy is a significant cost driver for lithium batteries as both electrical and thermal energy is required in the raw materials processing and battery manufacturing and assembly. As energy use is significant in the process, the sustainability of the energy source influences the overall carbon footprint for the battery production. Iceland offers a number of potential avenues for cost and carbon emissions reductions in the manufacturing process, due to readily available medium grade thermal energy from geothermal or industrial sources, access to inexpensive renewable electricity, and a skilled workforce. The purpose of this paper is to quantify the economic advantages and carbon emission reductions to be gained by locating a lithium iron phosphate ($LiFePO_4$) factory in Iceland close to geothermal heat sources, versus sites in other locations where fossil sources of energy must be used. Furthermore, we will also present the sensitivity of profitability to energy cost.

2. Methodology

The presented work consists of three main tasks: 1) Collection of relevant data and information. 2) Estimation of energy consumption and temperature levels at various steps in the production process and 3) Assessment of profitability and impact on carbon emissions. Firstly, the literature review, including interview data, provides us with information to draw a complete production process map of the lithium iron phosphate battery manufacturing process. Unfortunately, detailed energy consumption data from each step in the lithium battery production is not readily available from factories due to confidentiality reasons in this competitive market. Consequently, we build a theoretical energy consumption model for the drying process based on the thermal properties and moisture content of materials in the batteries, basic physical

* Corresponding author. Tel.: +354 599 6345; fax: +354 599 6201.
E-mail address: gudrunsa@ru.is (G. Saevarsdottir).

0960-1481/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.renene.2012.04.028

formulas and industrial experience. There are some uncertainties in this model, as energy efficiency, and heat loss, are based on educated assumptions. The results from the model are therefore not data from an actual factory, but should be informative none the less. In reality, it could be lower or higher depending on design of industrial equipment components. For the profitability assessment, common standards of estimating the profit of an investment, for example, net present value (NPV) and the internal rate of return (IRR) are applied. Consequently, we build a comprehensive profitability assessment model for building a new lithium iron phosphate battery factory in Iceland. Most cost data are obtained directly from suppliers or publicly available information. The main assumptions are listed in Table 1. In the model, we make several financial assumptions, such as interest rate, capital structure and discount rate of based on current conditions in Iceland. The profitability calculation and Monte Carlo analysis are performed by Microsoft Excel plug in with @Risk5.7.

3. Energy consumption of lithium iron phosphate battery production process

3.1. Energy consumption of entire process

Energy consumption in lithium iron battery production is not openly available information from this emerging industry. Lifecycle analysis of lithium iron battery by Mats Zackrisson and Lars Avellán in 2010 claims that the total energy consumption corresponds to 11.7 kWh electricity and 8.8 kWh of thermal energy from natural gas per kg lithium-ion battery [2]. This corresponds to an energy consumption for 1 Ah battery of approximately 0.68 kWh, assuming that one kg lithium-ion provides 30 Ah capacity of battery. In addition, energy consumption data were obtained from Matti Nuutinen, who reported data from a Chinese lithium iron phosphate battery factory and for European Batteries Oy [3]. In this report, Nuutinen shows that 5000 kW electric power is required to produce 80 MAh battery per year. This equates to energy consumption for producing 1 Ah battery is approximately 0.54 kWh. Based on these sources the energy consumption could range from 0.54 to 0.68 kWh/Ah according to our investigation.

3.2. Production process map

In general, our analysis of the lithium iron battery production process starts with the various raw materials and components from suppliers. The overall process can be divided into two parts: preparation of electrodes and cells assembly. Fig. 1 illustrates the main steps in first part of the production process. In first part, the first step is to mix anode and cathode powders with solvent and binder, coat them on the respective foils, and dry them in the vacuum oven at around 120 °C for 8 h. Traditionally the heat applied at each of the drying steps is obtained by electric heating.

Table 1
Main assumptions of profitability model.

Items	Value
Interest rate of loan	12%
Sale price	1.44 (USD/Ah) with 3% annual decreasing trend
Raw material price	0.69 (USD/Ah) with 2.75% annual decreasing trend
Initial investment	9612 million ISK
Discount rate	15%
Capital structure	70% loan, 30% equity
Exchange rate	156 (ISK/Euro)
	112 (ISK/USD)
Salary for workers	Iceland: 238,000 (ISK/Month)
	Germany: 1944 (€/Month)

However, since the temperature needed in the vacuum oven is relatively low, we might be able to replace electric heating with heat exchangers using geothermal steam as a thermal source. After this drying step the electrode disks would be cut into suitable sizes and compressed thinner by automatic machines. At this stage, the individual electrode is ready for assembly.

Fig. 2 shows the second part, which is to assemble the various components, such as the separators, internal circuits, anodes and cathode altogether. In this step, the electrodes can be stacked and clamped first and put into a metal packing case. Afterwards, the battery cells are placed in the core drying machines. The purpose of this step is to remove the remaining moisture from electrodes completely. This is the most energy intensive step of the whole process. In principle it would seem feasible to accelerate this drying step by increasing the temperature in the oven. However, the melting point of the binder (PVDF) is around 170 °C, so the temperature in the vacuum oven must be kept below 170 °C. As an alternative the process is accelerated by lowering the pressure in the oven in order to efficiently remove the vapor formed. Thereby the boiling point of water and solvent is decreased in order to shorten the drying process. In the end, the moisture content rate in the electrodes is reduced to 500 ppm [4]. After the core drying process, the electrolyte is injected into cell and it is sealed completely. Since the electrodes are very sensitive to moisture, those processes are usually operated in a room, where the humidity is kept at an acceptable level. In principle, the battery pack is ready for use at this stage. However, most producers test their products several times in order to ensure its performance and collect data before shipping the product to consumers.

3.3. Energy consumption of the drying process

Through production analysis, the approximate energy consumption figure has been already addressed in the previous text. But, we need to know the energy consumption of the drying process, if we want to consider alternative energy resources for the drying process. Consequently, we build a theoretical calculation model. It is not perfect, but a reasonable approach to figure out the approximate energy consumption of the drying process. The first step of building an energy consumption model of drying is to collect the weight percentage and thermal properties of component materials. Table 2, shows the physical thermal properties of each material in the lithium iron battery.

The model predicts how much thermal energy we need in order to remove the moisture and NMP from the electrodes. It is accompanied with the increasing temperature of other materials and some heat lost to environmental. The thermal energy consumption of the drying process calculation could be divided into two parts. (1) The energy for increasing the temperature of all component materials. (2) The energy for evaporating the moisture and NMP away from the feedstock. Through the thermal properties and some basic physical formulas, we obtain theoretical results for both parts respectively. And then, we take the empirical energy efficiency of the vacuum dryer into account to get more realistic data. The energy required for heating the materials to the dryer temperature would is 128.62 kJ/kg. The second part is the energy consumption of evaporation. It dominates the energy consumption of drying process. The overall energy consumption of evaporation is 198,197.8 kJ/kg. The key factors in this calculation are the initial weight and outlet weight of moisture because the heat of evaporation of water and solvent dominates as compared to the sensible heat. However, the energy efficiency is not 100%. Based on the literature we assume that the energy efficiency of the vacuum dryer is 0.6 according to the Handbook of Industrial Drying [8]. In this case, the practical energy consumption would be 0.186/