REGENERATION OF ZINC ANODES FOR THE ELECTRIC FUEL® ZINC-AIR REFUELABLE EV BATTERY SYSTEM

Binyamin Koretz
Jonathan R. Goldstein
Electric Fuel Limited
P.O. Box 23073
Jerusalem 91230
Israel
Tel. +972-2-589-0890 Fax +972-2-532-2252
e-mail: info@electric-fuel.com

ABSTRACT

The Electric Fuel Limited (EFL) refuelable zinc-air battery system is currently being tested in a number of electric vehicle demonstration projects, the largest of which is a field test of zinc-air postal vans sponsored chiefly by Deutsche Post AG (the German Post Office).

The zinc-air battery is not recharged electrically, but rather is 'refueled' through a series of mechanical and electrochemical steps that will require a special infrastructure in commercial application. As part of the German Post Office field test program, Electric Fuel designed and constructed a pilot zinc anode regeneration plant in Bremen, Germany. This plant is capable of servicing up to 100 commercial vans per week, which is adequate for the field test vehicle fleet.

This paper will describe the design and operation of each of the areas and devices within the plant.

BACKGROUND

The Electric Fuel zinc-air battery system for electric vehicles comprises three interrelated system elements:

1. the on-board discharge-only zinc-air battery pack;
2. battery exchange and refueling stations for mechanical exchange of zinc anodes; and
3. zinc anode regeneration centers for centralized recycling of the zinc anodes.

The system elements are shown schematically in Figure 1. The battery is discussed in more detail in Harats et al. (1995).

The Electric Fuel Zinc-Air Battery

The cell comprises a central static replaceable anode bed of electrochemically generated zinc particles in a potassium hydroxide solution compacted onto a current collection frame and inserted into a separator envelope, flanked on two sides by the company's high-power air (oxygen reduction) cathodes. Cell capacity to 80% zinc utilization is 250 ampere hours in this design.

During cell discharge, zinc at the anode is consumed by conversion to zinc oxide, and at the cathode, oxygen from the air is electrochemically reduced to hydroxide ions. Nominal discharge voltage at the five hour rate is about 1.15 V per cell.

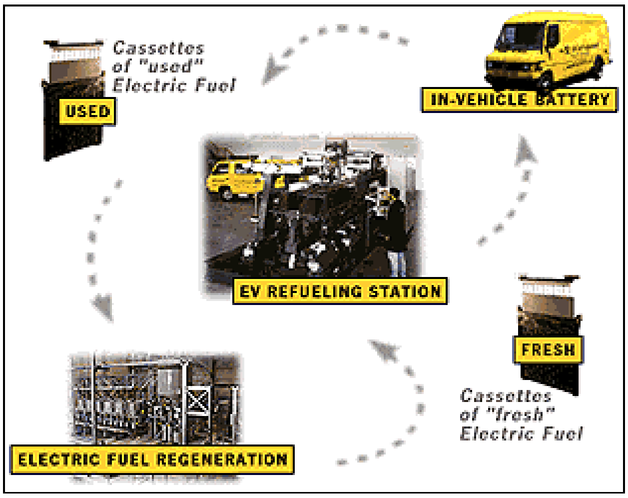

FIGURE 1. THE ELECTRIC FUEL SYSTEM

The EV batteries are built from 6.25 kWh blocks of 22 cells connected in series, with the blocks connected in suitable series and parallel arrangements according to the requirements of the vehicle, motor and controller. The battery contains subsystems for air provision and heat management. As configured for a Mercedes-Benz MB410 4.6-ton Deutsche Post vehicle (>1.5 tons payload), the battery comprises 24 blocks with a deliverable energy content of over 150 kWh, and weight (exclusive of presently unoptimized supporting trays) of 800 kg.

Demonstrated practical specific energy of around 200 Wh/kg in various full size EV batteries of this design, allows vehicle ranges per refueling in excess of 300 km.

The Electric Fuel zinc-air cell is shown in Figure 2.

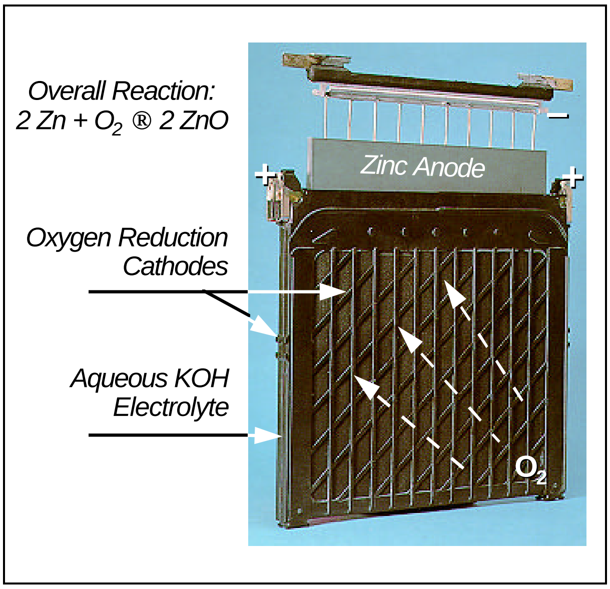

FIGURE 2. THE ZINC-AIR BATTERY CELL

The on-board battery is "refueled" or mechanically recharged by exchanging spent Electric Fuel "cassettes" - the zinc anode including current collector frame and separator envelope - with fresh cassettes. This is accomplished by an automated refueling machine that allows a zinc-air battery powered vehicle to "refuel" in an amount of time comparable to gasoline refueling. The depleted cassettes are electrochemically recharged and mechanically recycled external to the battery.

With commercial implementation, regeneration of the cassettes will take place at centralized facilities serving regional networks of refueling stations. In this way the zinc anode recharging/recycling facility would assume a parallel role in a zinc-air based transportation system to that held by oil refineries in today's fuel distribution system, without the negative environmental impacts of refineries or point-source pollution of conventionally fueled vehicles, especially diesel.

The Regeneration Technology

The regeneration includes the following steps:

a. Disassembly, in which separator bags are removed from the anodes, and the zinc oxide discharge product (along with residual, undischarged zinc) is removed from the current collector frames. Frames and separators are cleaned and reused.

b. Dissolution, in which zinc oxide is dissolved in a KOH solution to form a zincate-rich feed, according to the following equation:

$$ZnO + 2KOH + H_2O = K_2Zn(OH)_4$$

c. Electrowinning, in which the zincate solution is electrolyzed in an electrowinning bath according to the following equation:

$$K_2Zn(OH)_4 = Zn + 2KOH + H_2O + \frac{1}{2}O_2$$

d. Reassembly, in which the electrowon zinc, together with residual (charged) metallic zinc, is compacted in metered quantities onto the current collector frame and the anode is inserted into a separator envelope.

The regeneration process is shown schematically in Figure 3.

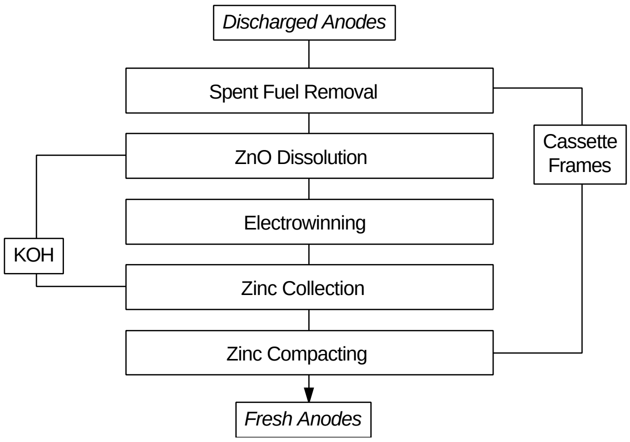

FIGURE 3. REGENERATION PROCESS SCHEMATIC

Previous Pilot Regeneration Plants

Before constructing the Bremen Regeneration Plant, Electric Fuel built two previous pilot regeneration plants, each with regeneration capacity of 10 kg zinc per hour. The first of these pilot plants was constructed in 1994 in Trofarello, near Turin, Italy, for Edison SpA, Electric Fuel's partner and licensee in southern Europe.

The second pilot plant, completed in 1995, was built by Electric Fuel in Bet Shemesh, Israel, a suburb of Jerusalem. This plant serves Electric Fuel's vehicles in Israel, and will also be used for a demonstration program with Israel's national electric company. A photograph of the Bet Shemesh plant is shown in Figure 4.

FIGURE 4. BET SHEMESH PILOT PLANT

THE BREMEN PLANT

The Electric Fuel facility in Bremen was constructed in late 1995 to serve the refueling and regeneration requirements of the Deutsche Post field test. The plant was put into service in 1996.

The Bremen plant consists of both a battery exchange and refueling area and the regeneration plant itself. A logistics block diagram of the Bremen plant is shown in Figure 5.

Battery Exchange and Refueling

The refueling area includes two purpose-built machines: a battery exchange device and an anode exchange device.

Battery Exchange Device. The battery exchange device was designed and built by Webasto AG for the Deutsche Post field test program. The machine is designed to exchange discharged battery trays for recharged batteries in any of the vehicles participating in the field test.

The device performs the exchange in the following steps:

- Vehicle drives onto the device, guided to the proper stopping point
- Locks on the battery trays are opened
- Vehicle is lifted in the air, leaving battery below
- Discharged battery is removed to the side
- Fresh battery is moved in from the side
- Vehicle is lowered onto the battery and locks are closed
- Vehicle drives off

Total battery exchange time is 4 minutes: from the arrival of

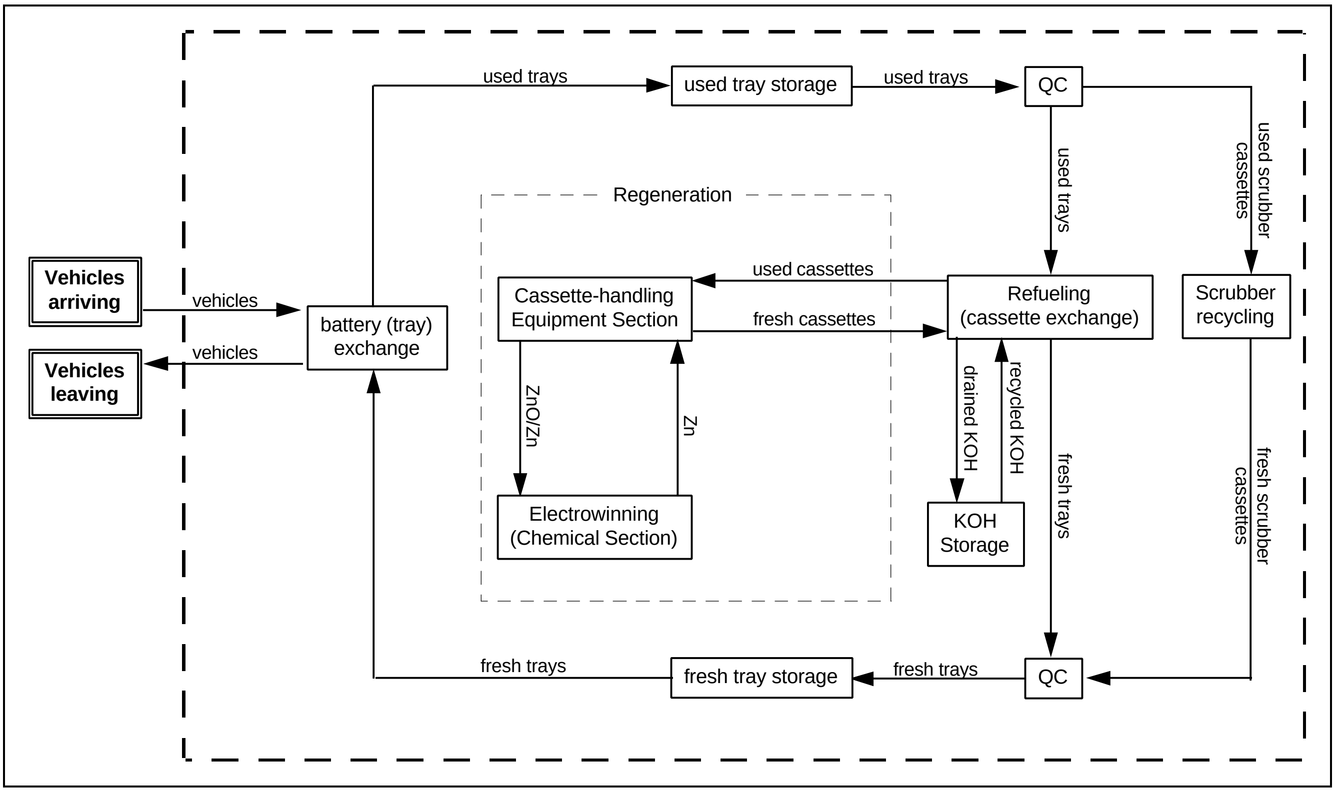

FIGURE 5. BREMEN PLANT - LOGISTICS BLOCK DIAGRAM

the vehicle to the removal of the battery takes 2 minutes, and an additional 2 minutes is required to move the fresh battery in, lower the vehicle, and lock the trays.

The Webasto battery exchange device is shown in Figures 6 and 7.

A forklift is used in the Bremen plant to carry battery trays between the battery exchange device and the refueling machine.

FIGURE 6. OPEL CORSA COMBO AT BATTERY EXCHANGE DEVICE

FIGURE 7. MB410 VAN ON BATTERY EXCHANGE DEVICE

Both incoming and outgoing battery trays are inspected in a quality control area. scrubber cartridges are also tested here and, if necessary, exchanged and sent for recycling.

Refueling Machine. The refueling machine was built by Electric Fuel in Bet Shemesh, Israel, and shipped to Bremen.

This refueling machine was designed to accept an entire battery tray, and to ‘refuel’ each of the battery blocks in turn. Trays removed from the Opel Corsa Combo have 6 blocks of 22 cells each, and trays used in the Mercedes Benz MB410 van have 12 blocks of 22 cells each. Each block is equivalent to 6.25 kWh of battery capacity.

The refueling machine performs the following functions in sequence:

- removal of block cover
- removal of discharged anode cassettes from cells
- removal of KOH electrolyte from cells
- refilling of KOH electrolyte in cells
- insertion of fresh anode cassettes in cells
- replacement of block covers

A photograph of the refueling machine, with an MB410 battery tray being refueling, is shown in Figure 8.

THE REGENERATION PLANT

The regeneration plant consists of an electrochemical section

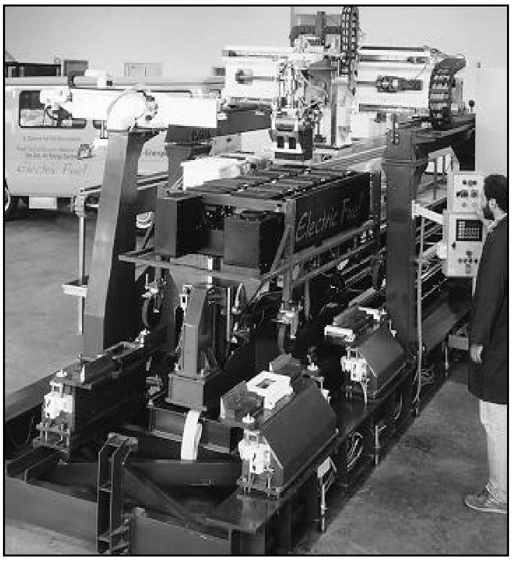

FIGURE 8. REFUELING MACHINE

and a cassette-handling equipment section, also referred to as the manufacturing section. Within the manufacturing section, discharged zinc anodes are disassembled so that the zinc oxide discharge product can be regenerated by electrowinning in the chemical section, and freshly electrowon zinc is assembled into zinc anodes.

Many of the plant functions are automated and controlled through graphical computer screens located in a central control room. Figure 9 is a photograph of the control room in Bremen.

FIGURE 9. BREMEN CONTROL ROOM

The Manufacturing Section

The manufacturing section consists of purpose-built handling equipment designed to perform the mechanical functions associated with the regeneration of the discharged anodes. These functions include disassembly of the discharged anode, reassembly of the fresh anode, and storage and transport of the anodes and anode components.

A view of the manufacturing section is shown in Figure 10.

Anodes removed from the battery by the refueling machine are placed in specially designed boxes that hold 22 anodes, i.e., the number of anodes that are removed from one block. These boxes are used throughout the plant for transport and storage of anodes and anode components in various stages of the process.

An ‘automated warehouse’ stores boxes when needed, and keeps track of the whereabouts of boxes throughout the system.

Discharged Anodes. The first stop for the discharged anodes is the separator removal station, where separators are removed for washing and checking. The separators are later reused for anodes that are completing the regeneration process and are on their way to the refueling machine.

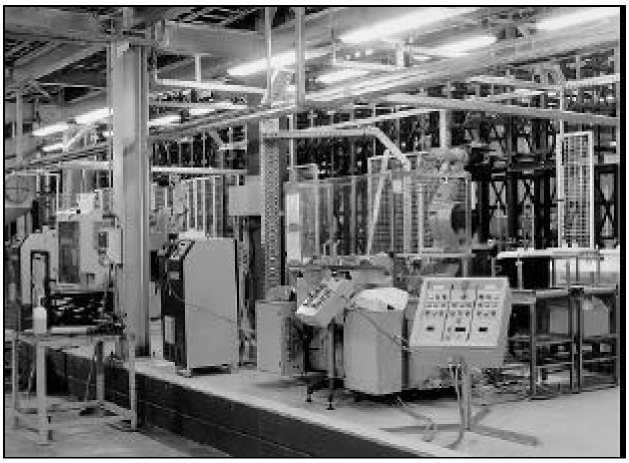

FIGURE 10. VIEW OF MANUFACTURING SECTION

The discharged anodes then make their way along a conveyor to the anode stripping stations, where discharged zinc anodes and residual charged zinc are mechanically removed from the anode frame by an automatic system designed and built by Electric Fuel.

The zinc oxide and zinc are removed via elevators to the chemical section on the second level of the plant; the stripped current collector frames are checked and sent to the anode compaction press, where they will be reused in fresh zinc anodes.

Regenerated Anodes. Electrowon zinc from the chemical section (see below) is conveyed to the anode compaction area through pipes extending down from the second level.

The zinc first passes through a dosing system, which meters our a pre-determined quantity of regenerated zinc. The dosing of zinc is a sophisticated process which has to measure out a given mass of solid within a three-phase admixture consisting of zinc, aqueous KOH, and minute amounts of gaseous hydrogen.

The metered amount of regenerated zinc is then compacted onto the anode frame in an anode press. The unique characteristics of the Electric Fuel zinc allow zinc particles to be compacted into a robust plate that is both solid and porous, without the use of any chemical binders.

The pressed zinc anodes are conveyed to a station where the separators are replaced, and they are then brought either to the refueling machine or to storage in the automated warehouse, to await later use whenever a battery needs refueling.

The Chemical Section

In the chemical section, dendritic zinc is produced in 24 alkaline electrowinning cells arranged in two parallel strings of 12 series-connected electrowinning cells each. Each string can produce about 50 kg of zinc metal per hour. Total plant capacity is therefore 100 kg/hour, which is sufficient for the more than 60 commercial vehicles planned to operate from the plant.

A photograph of one string is shown in Figure 11.

Each string contains:

- AC-DC rectifier
- zinc mixing and dissolution tanks
- electrowinning cells
- buffer tanks

The feedstock is a zincate-rich aqueous KOH solution, wherein the zincate level is replenished by the addition and dissolution of zinc oxide. The zinc oxide is typically from partially discharged zinc anodes removed from a zinc-air electric vehicle traction battery. During plant start-up or periods of ramping up regeneration capacity, commercial zinc oxide is used.

Additional details concerning the operating parameters of the Electric Fuel electrowinning process are discussed in Goldstein et al. (1995). Projections on refueling and regeneration system cost and energy efficiency are presented in Koretz et al. (1995).

Electrowon zinc, periodically scraped from the surfaces of the cathodes in the electrowinning cells, is collected from the baths, homogenized, and conveyed to the dosing system in the manufacturing section.

NEXT STEPS

Vattenfall AB, the largest power producer in Scandinavia and Electric Fuel's strategic partner in that region, is planning to construct a 250 kg/hour plant in Stockholm. This plant is expected to come on-line by late 1998 and will be capable of supporting a fleet of 150 electric vehicles.

REFERENCES

Goldstein, J. R., Gektin, I., and Koretz, B., 1995, "Electric Fuel™ Zinc-Air Battery Regeneration Technology," *Proceedings, The 1995 Annual Meeting of the Applied Electrochemistry Division of the German Chemical Society,* Duisburg, Germany.

Harats, Y., Koretz, B., Goldstein, J.R. and Korall, M., 1995, "The Electric Fuel™ System Solution for an Electric Vehicle," *Proceedings, Batterien und Batteriemanagement Conference,* Essen, Germany.

Koretz, B., Harats, Y., and Goldstein, J. R., 1995, "Operational Aspects of the Electric Fuel™ Zinc-Air Battery System for EV's," *Proceedings, 12th Seminar on Primary and Secondary Battery Technology and Application,* Deerfield Beach, Florida, USA.

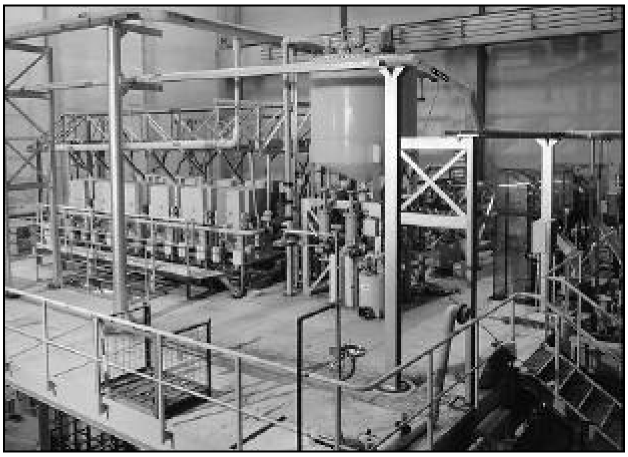

FIGURE 11. ELECTROWINNING STRING