1. Batteries - Energy Storage Systems

1.1. Basics - How batteries work

Batteries are chemical storage systems of electrical energy. There are batteries, which are designed to be used once and discarded when they are exhausted (primary batteries) and rechargeable batteries, which are designed to be recharged and used multiple times (secondary, or sometimes also called accumulators). The principle is the same for both types with the only difference that in primary batteries the electrochemical reaction is not reversible.

The principle is based on the different standard potential (*redox potential*) of the individual metals and their compounds.

In figure 1.1 the principle is shown by a simple example: a copper-zinc batterie. In the example in one compartment of the system, an electrode of zinc is immersed into a solution of zinc sulfate and in the other compartment an electrode of copper is immersed into a solution of copper sulfate. Both compartments are connected by a so-called salt bridge, which contains movable ions, which are not taking part in the reactions, but maintain the flow of the ions to balance the electron charges. As an alternative also a membrane is used which allows (mainly) the movement of other ions than zinc and copper for balancing the charges.

As zinc is much more ignoble (has a more negative standard potential) than copper (has a more positive *standard potential*), the pressure to go into solution for zinc is higher than for copper. If both compartments would not be separated either by a membrane or by a salt bridge and the electrolytes of copper and zinc would be mixed, we would only have corrosion of zinc by the deposition of copper instead of a electrochemical cell and instead of electrical energy, thermal energy would be delivered. But with the separation and the connection by a salt bridge or a membrane we have a electrolytical cell which can deliver a cell voltage between the compartments. If we have one molar solutions (about 56 g/l zinc and 63 g/l copper) this cell would theoretical supply a voltage of 1.1

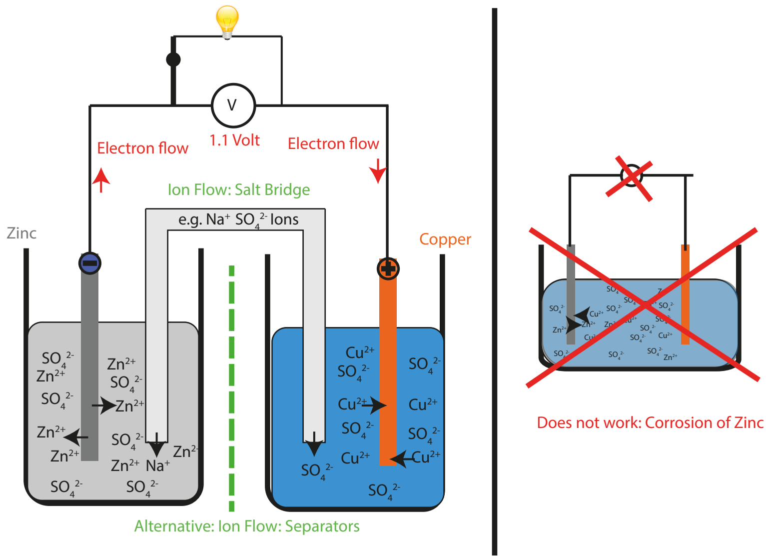

Figure 1.1.: Working Principle of Batteries

V which is the difference of the standard potentials of zinc (-0.76 Volt) and copper (0.34 Volt).

If we now connect a consumer of electrical energy like a lamp, electrons are flowing from the zinc to the the copper and and switching on the light. As in this process electrons move, the charges have to be balanced. This can be done by the salt bridge, where ions like sodium ions and sulfate ions flow from a salt bridge or through a membrane. The salt bridge should have a high ionic conductivity, which is different from the normal electrical conductivity as there are moving ions in an electrolyte instead of electrons in a electrical conductor.

If in our example, if the zinc electrode is dissolved totally, then the batterie is exhausted.

In the practical usage of battery system some key figures are important:

- The **voltage** (measured in Volt) depends on the differences of the normal potential between the electrodes. The more ignoble the anode and the more noble the cathode is, the higher is the voltage *(redox potential)*. Alkali metals like lithium have a strong negative standard potential and can supply a high voltage. There are also systems, which do not contain active metal, but its compounds with different oxidation states, which

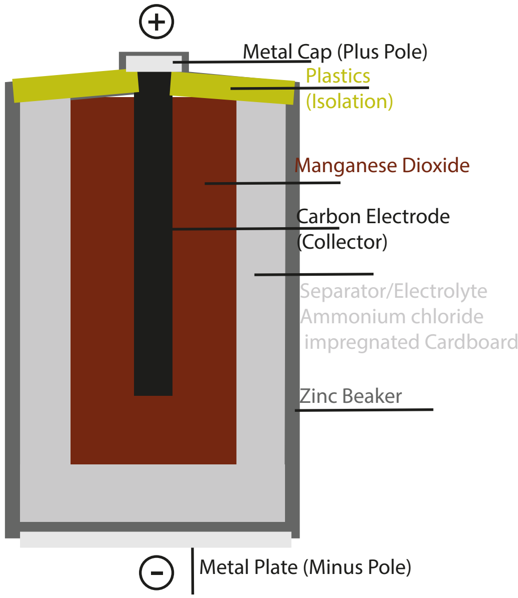

Figure 1.3.: Principle of a Zinc Carbon Battery

1.2. Zinc Carbon Batteries

Zinc carbon batteries have been the first batteries which have got big commercial use. By 1876, the wet Leclanché cell was made with a compressed block of manganese dioxide. In 1886, Carl Gassner patented a "dry" version by using a zinc cup as the anode and a paste of plaster of Paris (and later, wheat flour) to jellify the electrolyte and to immobilize it. The zinc-carbon cell is one of the primary elements because, unlike accumulators or secondary cells, it is not rechargeable. It was widely used in various sizes until the 1970s, but has since then been largely displaced by the technically better and more leak-proof alkali-manganese cells. Nevertheless, today they still have a market of 15-20% especially used for applications, which do not need high currents. Zinc–carbon batteries are a reliable source of power for appliances that consume little energy, like remote controls for television, clocks, smoke detectors. It delivers an energy density of 30-40 Wh/kg

A zinc–carbon battery (see figure 1.3) is a dry cell, that provides direct electric current from the electrochemical reaction between zinc and manganese dioxide (MnO_2). It produces a voltage of about 1.5 volts. It is a primary cell, which where in reality no free lithium atoms are in the graphite structure to be oxidized, but they are stabilized as lithium ions within a graphite structure

$$\text{at the cathode (very simplified !!): } MnO_2 + Li^+ + e^- \longrightarrow LiMnO_2,$$

$$\text{as a total reaction: } MnO_2 + Li \longrightarrow LiMnO_2$$

For a better understanding of these reactions the equations have been much more simplified, as on the one hand it is not atomic lithium which reacts, but it is the negative charged graphite structure which contains lithium ions, which gives its electrons and on the other hand, it is not the pure manganese dioxide which is reduced to from +4 to +3, but a layer structure of the oxide with lithium ions. But at the end, it is similar to the nickel (III) in NiMH battery the reduction of a metal ion, which exist in two oxidation states and is reduced from the higher oxidation state to the lower oxidation state during discharging.

Commercially available single cells of lithium-ion accumulators are usually produced in cylindrical form, as single cells assembled with a special housing. But as the lithium ion batteries can be taken into nearly each form, they are often adopted to the the space requirements of the special apparatus. Lithium batteries loses some energy during recharges and storage. But after several years - or about 1000-2000 cycles of charging and discharging- they have still 80% of its energy density, and can be used e.g. for stationary storage for renewable energies.

Lithium ion batteries play - at least today - the most important role for storing renewable energy.

There are also non rechargeable lithium batteries (in contrast to lithium ion batteries), which are normally very small ones like in button cells. See figure 1.8, button cell in the middle.

Non-Ferrous Metals in Lithium Ion Cells:
Lithium, Cobalt, Manganese, Nickel, Aluminium, Titanium

1.8. Lead Acid Battery

The lead acid battery works with lead metal on the anode and with lead dioxide at the cathode. As electrodes for collecting the current on both side, alloyed lead sheets are used. It is rechargeable and therefore it counts to the secondary batteries.

2. Non-Ferrous Metals for Renewable Electrical Energy

The use of non-ferrous metals is essential for the production of renewable energies. The main technologies are solar energy, which can be used both for electrical as thermal energy in heat absorption systems, and wind power systems both on shore or off shore. Non-ferrous metals are notonly necessary in the direct production process, but they are necessary for the transformation and distribution of electrical energy. As single renewable energy plants have mostly smaller capacities than nuclear or coal power plants, renewable energy needs much more electrical lines. Furthermore, locations which are a good location for renewable energy are not always the same location, where the main consumption takes place. Therefore more copper is needed for underground lines or aluminium for overhead lines. Furthermore, energy storage systems like rechargeable batteries are needed, as renewable energy is not always available over the year and the day.

2.1. Solar Energy (Photovoltaics)

Solar energy (Photovoltaic, PV) need the most simple installation of renewable energy, as it only needs certain area to put solar modules on it. Therefore, it is not only used in big solar power plants, but also on single houses, or even balconies. Micro modules can also be used for the power supply of electronic devices. There are two different systems in use: solar cells with different forms of silicon and thin layer cells, where different special semiconductors act as the active layer. Silicon wafer based PV technology accounts for about 95% of the total production in 2020, whereas thin layer technology only accounts for 5% - used mainly in big solar farms. The unit as a measure of the energy production of a solar module is kWp (kilo Watt peak) , that means the amount of electrical power, which is produced by optimal and standardized energy und direction of sunlight. If one calculates the “harvest” over one year as a rule of thumb 1 kWp gives 800-1200 kWh in one year depending on the region. More than 92% of all photovoltaic modules are produced in Asia, mainly in China.

to the strength and direction of the wind. Modern wind turbines operate on the principle of lift, similar to airplanes or helicopters. Upwind creates a torque and a rotational motion. The resulting energy is transferred to a generator, which converts it into electricity, similar to a bicycle dynamo. As the wind strength changes, the rotor blades can adjust - preventing them from rotating too quickly. The nacelle and the rotor are flexible. They turn to the wind like a sunflower to the sun. So the wind turbine always works, no matter which way the wind blows. The higher the wind turbine and the greater the wind speed, the higher the electricity yield.

Figure 2.3.: Copper in a Generator of a big Windturbine (Source: Enercon, www.enercon.de)

The electricity is produced by converting mechanical energy into electrical energy by electromagnetic induction. Beside copper as the conductor, magnets are the most important parts in the generation of power from wind. There are two systems. Some utility scale wind-turbine designs use induction generators to produce electricity. Induction generators use electromagnets designed into a rotor assembly to create a magnetic field. These electromagnets - made from coils of copper - take a small amount of current from the power system to generate a magnetic field in the rotor, which is then rotated within the generator near stationary coils of wire. This rotating magnetic field induces a large current in the stationary coils of wire. This design typically requires slip rings to power the electromagnets and a gearbox to convert the low rotational speed of a turbine shaft to the higher speeds that induction generators require in order to produce electricity. These gearboxes can be massive, typically weighing between 15 and 80 tons. As the wind does not blow all the time, the electricity

3. Non-Ferrous Metals in Renewable Thermal Energy

Solar thermal energy (STE) is a well-developed, reliable technology, to use solar energy to generate heat. Solar thermal energy converts solar radiation into heat. There are two different technologies using solar thermic energy. The one, which is used already since more than 20 years, is the warming of water in private homes, and public and industrial buildings to heat water by sun collectors for low temperature heating system and hot water. In the other system (CSP = Concentrated Solar Power) solar towers in which individual flat mirrors track the sun, so that the light at the top of a tower is concentrated on the actual absorber. Very high temperatures of more than 1,000 °C can be generated by this process. Air, oils or liquid sodium are used as the heat transfer medium.

3.1. Low Temperature Systems

There are two different systems for the recovering of heat or solar energy in low temperature systems. The flat plate solar thermal collector and the vacuum tube collector.

The flat plate solar thermal collectors consist of a casing, a transparent cover, thermal insulation material, an absorber plate, and tubes. The transparent cover produces the greenhouse effect above the absorber plate, allowing the majority of the solar radiation passing through. The absorber plate produces the energy conversion from solar radiation to internal energy in a fluid. It is usually made mainly from copper strip of about 0.1 to 0.5 mm thickness or more seldom of aluminum. To absorb the light, the surface is painted black - sometimes with an enamel layer - or more efficiently covered with an other dark material with a very high solar energy absorption rate, like chromium oxide or titanium nitride. This high efficient absorber material is made by continuous *sputterin*g in a vacuum system on copper strip with a width of more than 1,000 mm. The most common layer today is a sputtered chromium/tin coating with a blue appearance. A copper tube system is used to carry the energy out titanium, zirconium and/or others. Iron based alloys are cheaper, but can be used only at medium temperature at temperatures until about 700°C. Superalloys are often strengthened by the incorporation of borides or carbides. They are mostly resistant against scaling and creeping at high temperatures..

They can be produced either by melting metals or by powder metallurgy.

Non-Ferrous Metals in Saving Thermal Energy:

Copper, Aluminium, Silver (Thermal Conductivity)

Molybdenum, Chromium, Nickel, Cobalt, Tantalum, Rhenium, Platinum Metals and others (High Temperature Resistance)

4.2. Non-Ferrous Metals in Saving Electrical Energy

There are a lot applications, where non-ferrous metals can save electric energy or minimize the losses of electric energy. In many cases energy also can be saved by regulating and controlling using of electronic components. Examples are controlling temperatures, pressure, energy consumption. This is only possible if there are sensors which can measure the the physical factors. Sensors often also contain compounds or alloy of non-ferrous metals. As there are many applications , where non-ferrous metals are important for saving electrical energy, in this chapter only some examples are described. In each electrical application copper and/or aluminium are used.

Non-Ferrous Metals in all Electric and Electronic Applications:

Copper, Aluminium (Conductor), different Non Ferrous Metals and Semimetals (Sensors)

Heat Pumps A heat pump is a device used to warm the interior of a building or heat domestic hot water by transferring thermal energy from a cooler space to a warmer space, working like an inverted refrigerator. This is achieved by an outer circuit with a a heat exchanger, made of copper or aluminium, which exchanges the heat from outside air, water or ground. Whereas in the external circuit water with an anti-freezing agent is used, in the internal circuit media like ammonia or fluorinated hydrocarbons are used, which can easily be compressed and liquified. During the compression, heat is released, which is used for heating. After the heat is transferred to the heating system, the

5. Non-Ferrous Metals in Saving Resources

Often pure metals are not very resistant against corrosion and have a low strength. Therefore, other elements are incorporated into the base metals to improve strength and corrosion resistance. Beside paint coating - which does often not have an unlimited lifetime to prevent corrosion and wear, also sometimes metals are coated with other metals. Alloying or coating metals with other metals is a big contribution to the sustainable development, as the corrosion prevention prolongs the life of constructions and saves material. Higher strength of metals also save material as thinner elements in a construction means less material input. Therefore alloying metals with other non-ferrous metals is a substantial contribution of non-ferrous metals to the sustainable development.

5.1. Non-Ferrous Metals against Corrosion and Wear

5.1.1. Alloying Base Metals against Corrosion

Iron and Steel Iron is the most widely used of all the metals, accounting for over 90% of worldwide metal production. But iron is corrosion sensitive. To convert iron into to steel, a few tenths of a percent of carbon are necessary to improve strength, but it remains corrosion sensitive. The reason for the corrosion of steel is a reaction with moist air. In contrast to e.g. aluminium, iron oxides do not form a dense layer on the surface, as the resulting iron oxide surface layer is porous and fragile. In addition, as iron oxide occupies a larger volume than the original steel, this layer expands and tends to flake and fall away, exposing the underlying steel to further attack of moist air. Therefore, to prevent oxidation, metals are added, which form a dense oxide layer on the surface of steel. For producing stainless steel at least 11% chromium and other non-ferrous metals like nickel, niobium, titanium, molybdenum and/or others