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SCIENCE DIRECT®
Journal of Power Sources 154 (2006) 545–549
JOURNAL OF POWER SOURCES
www.elsevier.com/locate/jpowsour

Short communication

Temperature behaviour: Comparison for nine storage technologies Results from the INVESTIRE Network

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Available online 7 December 2005

Abstract

Within the INVESTIRE Thematic Network, 33 partners worked together in order to compare nine storage technologies for renewable energy applications. For this purpose, storage technology reports were written that presented the state of the art of

- lead-acid batteries;
- lithium batteries;
- double-layer capacitors;
- nickel-based batteries;
- flywheel;
- redox flow battery;
- compressed air;
- hydrogen-based energy storage;
- metal/air systems, e.g. Zn/O_2.

The technology reports include detailed consideration of the technical characteristics, including thermal behaviour. Parallel tasks defined categories of storage requirements and technical criteria in renewable energy applications and conducted a detailed analysis of the economic and environmental aspects.

This paper summarises the technology reports to show the differences of behaviour between the storage technologies, with particular focus on the thermal performance according to environmental and other operational conditions. The thermal characteristics of each technology are considered in the context of the storage requirements in various renewable energy applications.

Keywords: Renewable energies; Thermal behaviour; Storage technologies

1. Introduction

Renewable energies are by nature intermittent. It is, therefore, necessary to use an electricity storage device in stand alone applications for balancing load and power supply. In addition, applications where the cost efficiency of these renewable ener-

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✠ Unfortunately, Dr. Bernd Willer of ISET in Kassel died shortly after the end of the INVESTIRE Project. The authors and the whole consortium express here their sadness at the loss of a positive, competent and open-minded colleague.

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doi:10.1016/j.jpowsour.2005.10.054

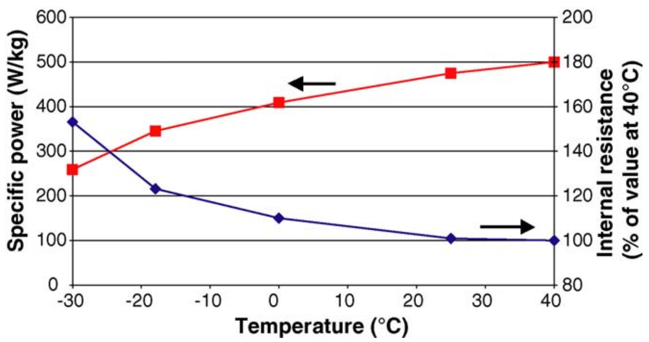

Fig. 1. High-power VRLA orbital batteries internal resistance/specific power vs. temperature.

gies is most evident are in remote areas and very often, remote areas have an environment with extreme temperature. Therefore, when studying storage technologies for applications in relation to electricity from renewable sources, the topic of the thermal behaviour is crucial.

2. Thermal behaviour of the nine technologies as addressed within INVESTIRE

2.1. Lead-acid batteries [1]

Lead-acid systems are very tolerant with the temperature. The usual operating temperature range for industrial lead-acid batteries is from −20 °C to 45 °C. In some cases, the battery can be designed for −30 °C or lower. In some other cases, the batteries can be used at higher temperature. It means that the temperature tolerance can be considered to be −30 °C/+60 °C.

Fig. 1 presents the performance (internal resistance and specific power) related to the Orbital batteries for a wide range of temperatures (from −30 °C to 40 °C).

High temperatures increase the performances without charge problems but decrease the life of the battery. Namely, as temperature increases, the kinetic of the electrochemical reactions is improved and the mobility of species as well. As a result, the energy that can be discharged from a battery increases as ambient temperature increases. This fact is illustrated in Fig. 2.

But the kinetics of the parasitic reactions are favoured as well by the temperature increase. Therefore, electrolysis of the water contained in the electrolyte proceeds easier and corrosion is accelerated as well. Recent studies performed at GENEC on stationary batteries in floating conditions show that increasing the operation temperature from 25 °C to 55 °C leads to a four times faster growth of the corrosion layer (see Fig. 3). The results presented in the figure were performed on batteries received at the laboratory after 8 years of service life in a power plant [2] that were put under floating conditions at two different temperatures. The corrosion layer thickness at year zero was measured form a new battery.

Fig. 4 shows the dependence of the service life on the operating temperature, while Fig. 5 shows the evolution the self-

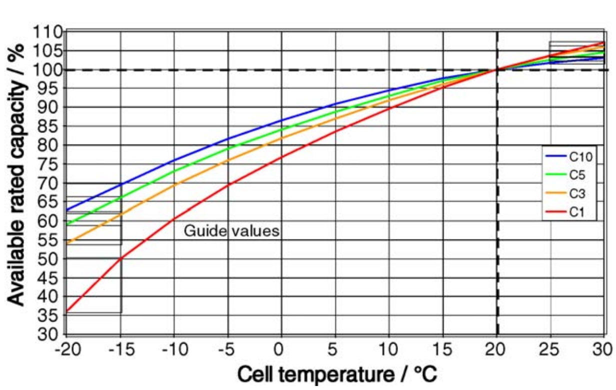

Fig. 2. Temperature impact on capacity (EXIDE document).

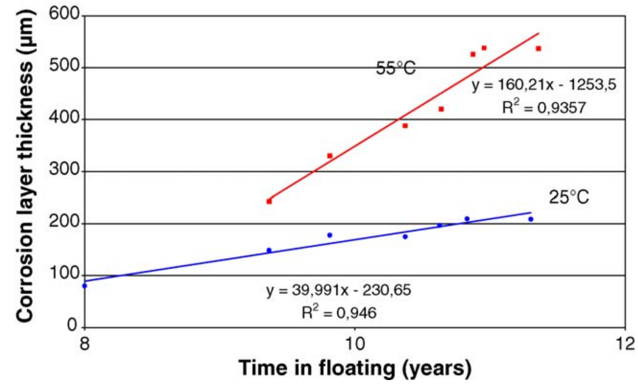

Fig. 3. Corrosion layer thickness evolution depending on floating time at different temperatures.

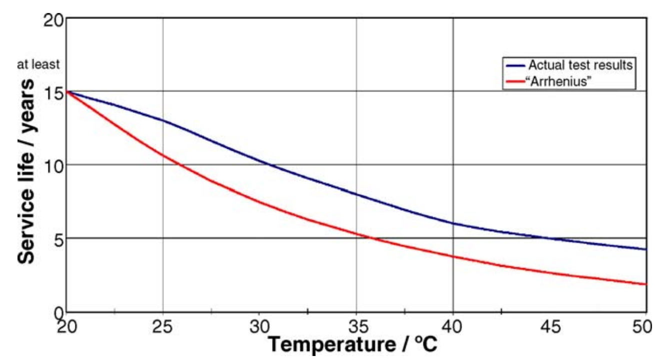

Fig. 4. Service life as a function of the temperature (Sonnenschein-EXIDE document).

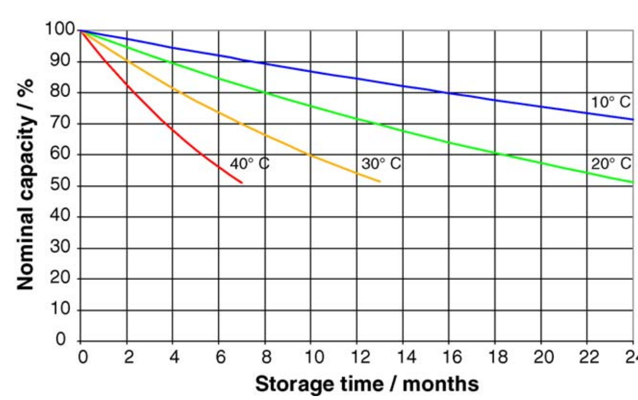

Fig. 5. Typical capacity evolution during shelf life (EXIDE document).

Table 1
Energy and power in relation of the temperature (Saft)

	HE cell		HP cell	
Energy				
+40 °C	110%	D/3 rate		10 D rate
+20 °C	100%		100%	
0 °C	90%			
−20 °C	80%		90%	
Power				
+40 °C	100%	30 s peak 80% DOD	120%	18 s peak power 50% DOD
+20 °C	100%		100%	
0 °C	80%			
−20 °C	50%			

discharge, it means of the capacity remaining in the battery depending on time it is left at rest depending on the temperature.

2.2. Lithium batteries [1]

Lithium-ion batteries are designed to operate within ambient temperature window of −25 °C/+45 °C (Table 1).

Today the limiting factors are:

- at low temperature (less than −5 °C), the charge rate must be limited;
- below −10 °C, the performance is drastically decreasing (at least for some products);
- at high temperature, the thermal behaviour of the system and the irreversible self-discharge decrease the life very much;

70 °C at cell level could be considered as an upper limit (of course, 80–90 °C could be reached for short period of time).

For these reasons, it is recommended to implement a thermal management system to optimise performances and to maximise lifetime (not for consumer applications).

Regarding influence of temperature on lifetime, it is difficult to give global rules because others parameters like operating profile and SOC have an impact. Nevertheless, we can assume that between 20 °C and 40 °C, lifetime is divided by 3.

Lithium metal cells (as developed by Tadiran) are designed to operate in a temperature range from 0 °C to −40 °C. Operation between −20 °C and 70 °C is possible (Fig. 6).

At lower temperatures, the internal resistance increases and at higher temperatures the lifetime is reduced. Fig. 6 shows the discharge capacity for different temperatures and different charge currents.

2.3. Supercapacitors [1]

The operating range is given from −40 °C to 60 °C or even 70 °C.

In comparison to a lead-acid battery, the temperature dependence of the useable energy of the double-layer capacitors is very small and its dependency with respect to the discharge of electric current is not significant (see Fig. 7).

According to information provided by Saft (Fig. 8), the temperature influence is very dependent from the choice of the cell components and their characteristics. With the right choice of parameters, the temperature effect is only seen for temperature below −20 °C. Compared to accumulators and due to the nature of the electrolyte, the use at temperatures as low as −40 °C is unproblematic.

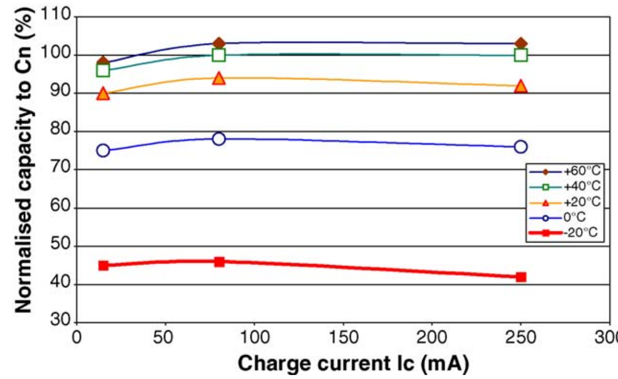

Fig. 6. Discharge capacity for different charge currents (Tadiran Incharge cell, discharge at 250 mA = C/3.2).

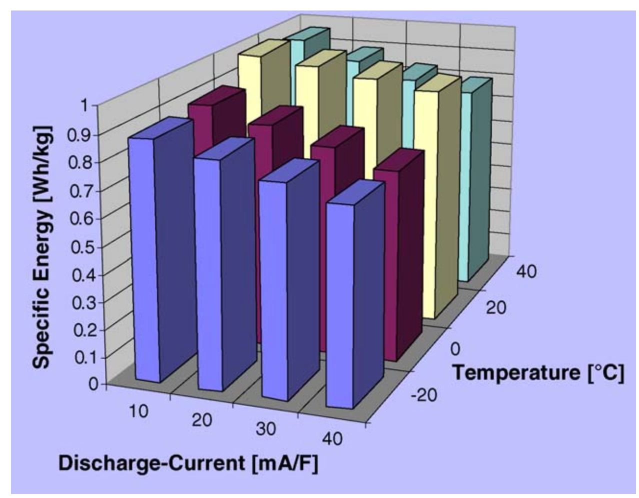

Fig. 7. Dependence of the usable energy of a double-layer capacitor 1500 F with respect to discharge-current and temperature (ISET).

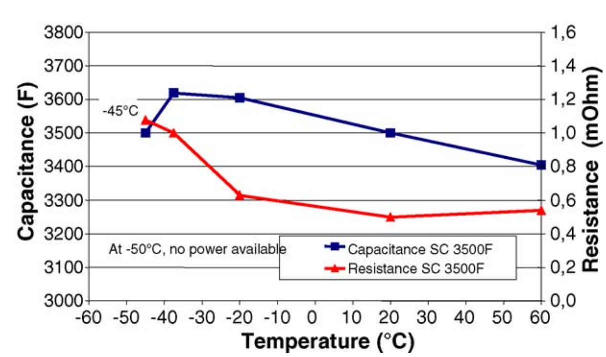

Fig. 8. Temperature dependence of cell parameters (Saft).

Table 2
Operating temperature ranges

	Temperature range (°C)
Ni–Cd	
Pocket plate vented	−20 to +45
Sinter/PBE vented	−20 to +45
Fibre vented	−20 to +60
Sinter/sinter vented	−40 to +50
Sealed cylindrical	−40 to +45
Ni–MH	
Sealed cylindrical	0 to +40
HEV, EV (industrial) sealed	−20 to +60
Ni–Zn	
Evercel sealed	0 to +60

2.4. Nickel-based batteries [1]

Typical values for normal operating temperatures for Ni–Cd, Ni–MH and Ni–Zn batteries are shown in Table 2. Vented Ni–Cd cells can be operated down to −40 °C if filled with special electrolyte with high concentration.

2.5. Hydrogen-based storage [1]

As fuel cell performances are related to the Nernst equation, temperature directly influences the reversible potential of FC electrochemical reactions as depicted in Fig. 9.

It can be pointed out from this figure that the voltage increases when the temperature is decreasing. This is very different from all typical generation technologies based upon heat engine designs, which exhibit decreased performance with reductions in temperature. But such a behaviour is quite similar with PV.

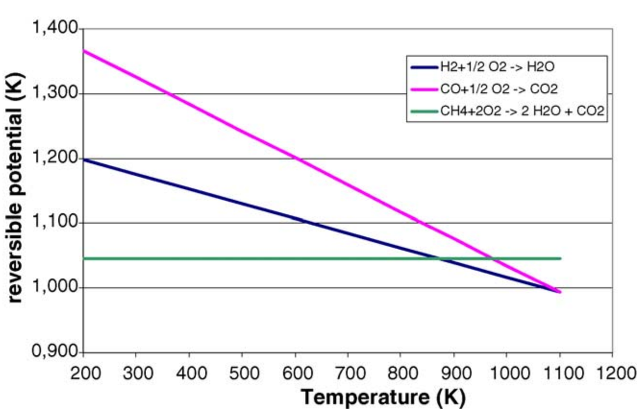

Fig. 9. Reversible ideal potential for FC electrochemical reactions vs. temperature (source CEA).

Table 3
Effect of temperature

FC type	Temperature range (°C)	Under temperature effect	Over temperature effect
AFC	60–90	Conductivity loss of the electrolyte	Electrolyte dissociation
PEMFC + DMFC	80–130	Conductivity loss of the electrolyte	Drying out of the membrane and membrane degradation
PAFC	200	Conductivity loss of the electrolyte	
MCFC	650	Conductivity loss of the electrolyte	
SOFC	750–1050	Conductivity loss of the electrolyte	

Table 4
Operating temperature range for different metal/air systems

System	Operating temperature range (°C)	Electrolyte
Zn/air	−20 up to +60	6 M KOH
Mg/air	−20 up to +60	4 M NaCl
Al/air	−20 up to +60	4 M NaCl

Each fuel cell technology has its own operating temperature range, out of which typical degradation affect both the efficiency and moreover, the integrity of the components.

Table 3 summarises the effects.

2.6. Flywheel [1]

A wide operating range from −20 °C to 40 °C is quoted by many manufacturers, however, any of the system components (including the power electronics interface) can restrict the operating range. The operating temperature range may depend on system configuration and installation, for example, operation at low temperatures can be extended when a small flywheel and associated power electronics interface are contained within a single enclosure or where the flywheel is installed underground. There is no information published by the manufacturers regarding the influence of temperature on lifetime or losses and the dependence is likely to be minor.

2.7. Redox flow batteries [1]

The available temperature range for VRB system extends from 5 °C to 45 °C.

At low temperature, the electrolyte viscosity increases, so the transportation of electrolyte becomes difficult.

At high temperature, the electrolyte stability decreases and the vanadium oxide (charged positive active mass) tends to precipitate (***SEI Data***).

2.8. Pneumatic storage [1]

If no fast temperature change occurs, temperature influence is limited to slight efficiency changes in the hydraulic pump/motor. Standard oil range is from −10 °C up to +50 °C, with special oil −40 °C should be possible.

2.9. Metal/air systems [1]

Table 4 sums up the different operating temperature ranges for different metal/air systems (Zn, Mg and Al).

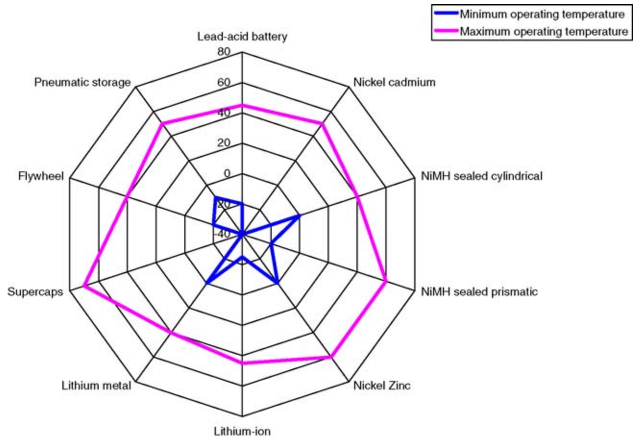

Fig. 10. Minimum and maximum operating temperatures in °C of the storage technologies investigated within INVESTIRE.

3. Synthesis of the INVESTIRE contributions

Fig. 10 makes a recapitulation of the adaptation of the technologies to operating temperatures.

Clearly, for working in low temperature environments, the nickel-cadmium battery is best adapted. Supercaps seem to be promising too, as well as potentially pneumatic storage when optimised for these conditions.

For working in hot environments, all technologies have improved performance with an increase of the temperature at the cost of the life duration of the technology. High operating temperatures also increase the kinetic of side and parasite reactions, such as corrosion or irreversible self-discharge, they favour thermal runaway associated to drying out in sealed electrochemical systems with gas recombination.

Acknowledgement

The authors are thankful to the European Commission for the financial support of the present work.

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