

**"A PRESENTLY AVAILABLE ENERGY SUPPLY  
FOR HIGH TEMPERATURE ENVIRONMENT (550-1000° F)"**

by J. JACQUELIN  
and R. L. VIC

Electrochemistry Department  
Laboratoires de Marcoussis  
Route de Nozay  
F. 91460 MARCOUSSIS

**ABSTRACT**

Sodium-sulfur cells are an attractive electric energy storage for long service, in strong environment.

State of art is given. More than 200 Wh/kg cells have been tested. The known range of working temperature is 550 - 750° F. Self-discharge is quite nonexistent for months in operation.

Technical basis for expecting an operating range up to 1 000° F under high pressure atmosphere are given. Possibilities to adapt size and characteristics to particular interplanetary mission are discussed.

**1) - OPERATION AND TECHNOLOGY OF THE SODIUM-SULFUR CELL**

Figure 1 is a schematical view of a sodium-sulfur cell. The sodium, which is the negative pole, is inside a  $\beta$ -alumina glove finger.  $\beta$ -alumina is a ceramic having the property of transiting  $\text{Na}^+$  ions ; it is therefore a solid electrolyte. Outside the  $\beta$ -alumina glove finger is located the positive electrode which is formed from sulfur held in a graphite-fibre conducting network. The whole is enclosed in two steel containers, separated electrically from each other by a ceramic insulating ring  $\alpha$ -alumina.

The cell is manufactured in the charged condition. During discharge, the sodium passes through the solid electrolyte in the form of  $\text{Na}^+$  ions and reacts with the sulfur while giving off polysulfides.

For the operation to be correct, it is necessary for the reagents, sodium, sulfur, polysulfides, to remain liquid. For that, the temperature must be greater than 500° F and preferably close to 650° C.

The cell may be recharged and so operate as an accumulator, able to effect a large number of successive charging cycles. But for that, the sulfur-graphite electrode must have special properties which are obtained through complex and elaborate manufacture. However, even the primary sodium-sulfur cells are capable of being partially recharged and of operating for a long time as an accumulator, but with a capacity of only one-third of the normal capacity.

The open-circuit voltage is 2.08 volts. The practical operating voltage may be chosen between 1 volt and 2 volts depending on the power and on the discharge conditions.

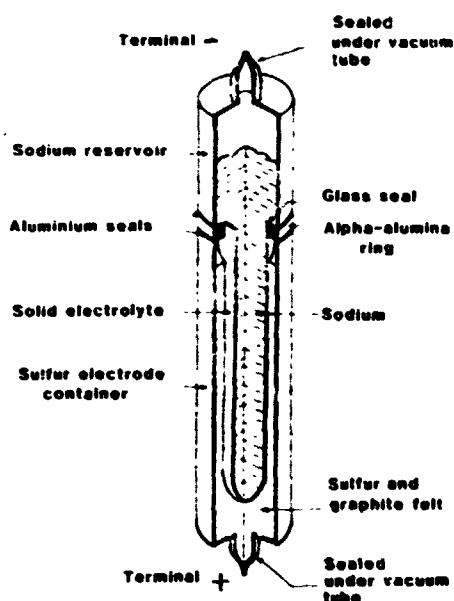


Fig. 1 : Schematic section of a sodium-sulfur cell

**2) - STATE OF THE ART**

The principal technological problems have been resolved during recent years.

It was a question of :

- the manufacture of the solid electrolyte
- soldering of the solid electrolyte to the insulating  $\alpha$ -alumina ring
- perfectly tight sealing of the steel containers on the  $\alpha$ -alumina ring
- the manufacture of the sulfur electrode
- and different other practical filling problems and sealing in an atmosphere perfectly free of any trace of water or of other polluting molecules.

At the L.d.H. sodium-sulfur cells are at present manufactured in two sizes.



Fig. 2. Size of standard sodium-sulfur cells

A small-size cell model (4.5 Ah) is manufactured and used solely for laboratory research and experimentation purposes. A large-size model (260 Ah) is also at present manufactured in the laboratory. Its dimensions are optimized for load leveling.

The principal characteristics of these cells are given in the following table :

Performances for discharges within 10 hours	Small-size cell	Large-size cell
Effective capacity	4.5 Ah	260 Ah
Average voltage	1.6 V	1.5 V
Effective energy	7.2 Wh	390 Wh
Weight	100 g	1730 g
Energy per mass unit	72 Wh/kg	230 Wh/kg

The above characteristics relate to cells fitted with sulfur electrodes able to operate as accumulators (secondary generator). Similar cells, but provided with primary electrodes (primary batteries) would have capacities and energies about 20 % greater.

Figure 3 gives the electrical characteristics of a cell depending on the charging condition.

It should be noted that manufacture is easier and more reproducible in the large size than in the small size, which favours then high-energy applications on board and not miniaturized applications.

One very interesting characteristic of the sodium-sulfur generators is the absence of self-discharge. There is no self-discharge at ambient temperature and even after a long period of storage (greater than 1 year) at 650° F no self-discharge was measured.

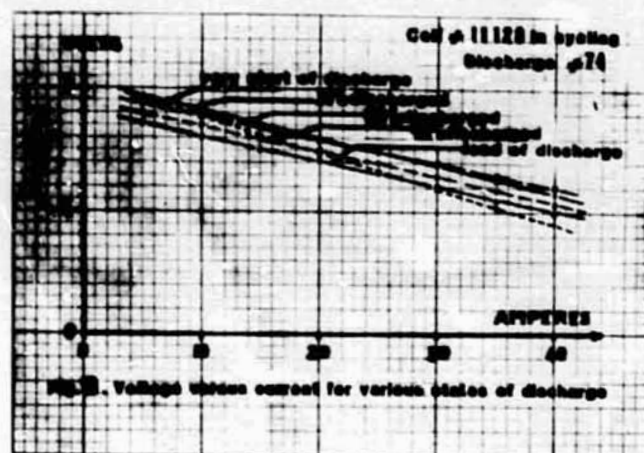


Fig. 3. Voltage versus current for various states of discharge

### 3) - SPATIAL APPLICATION

The operating temperature (650° F) which is a difficulty and a handicap for ground applications may become an extremely favourable factor for some spatial applications.

We think immediately of the cases of interplanetary probes which must travel through high-temperature atmospheres. Such is the case of probes whose mission is the exploration of VENUS. For example, at an altitude of 17 km, the temperature is 630° F and under these conditions the sodium-sulfur cells operate freely, without needing any heating or heat insulation. The high pressure (28 bars) which reigns at this altitude can be withstood by the containers because of their cylindrical shape and small diameter. Nothing stands in the way of very long duration missions, which may be considered in months or even in years.

However, it must be recognized that the present cells have not been optimized for such spatial applications and that certain modifications would have to be made. For example, for operating in any position and with any orientation, it would be necessary to provide the inside of the solid electrolyte with a porous layer wettable by the sodium which is designated sodium wick.

A great number of experimental checks remain to be made, during which certain imperfections might appear and involving studies and modifications with respect to the present state of the technique. These tests relate for example to :

- resistance to high accelerations (several hundred g)
- resistance to shocks and vibrations
- possible problems of thermal shocks on rapid entry into hot atmospheres
- the problems of checking and guaranteeing reliability.

### 4) - FUTURE POSSIBILITIES

From the mechanical and sealing point of view, present cells are able to withstand substantially 1 000° F. But the problems of corrosion of the containers, which are overcome at about 650° F, limit the serviceable life for higher temperatures.

However certain simple solutions may be considered. For high-pressure atmospheres, the use of deformable containers would be a neat solution, both for reducing the weight and for resolving the operating problems. In fact, it would be possible to balance the internal pressure with the external pressure, which would allow operation at practically unlimited pressures. Under high pressures, boiling of the sulfur only occurs at much higher temperatures and consequently operation close to 1 000° F would become possible (at 1 000° F, it is sufficient for the pressure to be greater than 3.3 bars).

Figure 4 shows the possible operating range.

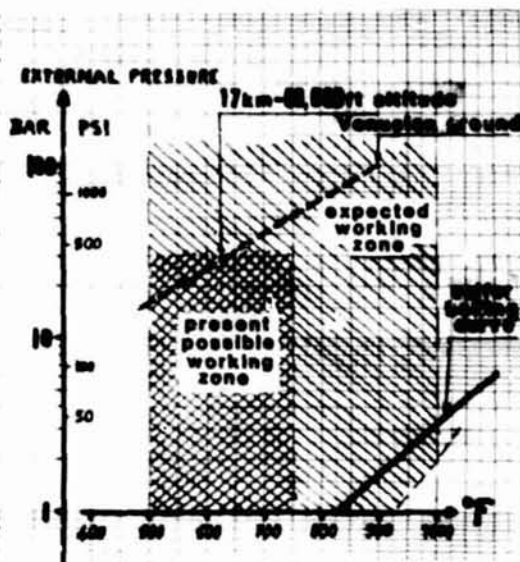


Fig. 4. Sodium-sulfur working zones.

The principal problem would become that of high-temperature corrosion of the container by the polysulfides. The anticorrosion protection used at the present time and limited by its cost, could be substantially increased and solutions using more studied materials and techniques may be considered.

In any case, the corrosion problems are less serious when the missions are limited to a few days or a few tens of days and not to years.

It is then not utopian to put forward the sodium-sulfur generators as extremely valid candidates for future ground explorations on VENUS (900° F, 100 bars), for missions of fairly long duration.