

Short Communication

Exploratory studies on some electrochemical cell systems

Srikumar Chaudhuri* and **D. Guha**

Department of Applied Chemistry, Indian School of Mines, Dhanbad, PIN 826004 (India)

(Received March 23, 1990, in revised form August 2, 1990)

Abstract

Exploratory studies were conducted on cell systems with different metal anodes, and iodine and sulphur mixed with graphite powder in a polymer matrix as cathodes, using different electrolytes in non-aqueous and aqueous media as ionic charge carriers. The electrical conductance of the electrolyte solutions in aqueous and non-aqueous solvents, the open circuit voltage (OCV) and short circuit current (SCC) for the different cell systems were measured. To date, the non-aqueous solvents used in our studies were dimethylformamide, formamide, dioxan, and nitrobenzene, and the electrolytes used were potassium iodide, caustic potash, cetyltrimethylammonium bromide (CTAB), sodium lauryl sulphate (SLS) and calcium chloride. These electrolytes were used in both non-aqueous and aqueous media. In general, aqueous electrolyte solutions gave a better performance than non-aqueous electrolyte solutions. Of the aqueous electrolytes, the highest conductance was shown by potassium chloride solution in water (conductance = 0.0334 mho). However, the best OCV and SCC were shown by aluminum as anode and iodine as cathode with a saturated solution of caustic potash in water. The OCV was 1.85 V and the SCC was 290 mA cm⁻². The highest conductance among the non-aqueous systems was shown by caustic potash in formamide (Conductance = 0.013 mho). The best OCV and SCC, however, were shown by a zinc anode and iodine cathode with saturated potassium chloride in formamide, having an OCV of 1.55 V and an SCC of 150 mA cm⁻². Further studies are in progress to obtain detailed performance data and recharging characteristics of some of the more promising systems reported here.

Introduction

Portable electricity in the form of primary and secondary batteries finds a number of domestic and industrial uses where other forms of energy are inconvenient or unsuitable. Electrochemical power generation is also free from noxious gas emissions which almost invariably occur in conventional power generation.

The scientific and technological attention paid to conventional energy generation systems has resulted in the systematic development and elucidation

*Author to whom correspondence should be addressed

of scientific principles for power generation, and the provision of motive power for traction purposes using the thermal route

The electrochemical aspects of power generation have received comparatively little attention for large scale use, probably because the purity of components is an essential pre-condition for an electrochemical power generation system, and because fossil fuels were available in abundance and at economic rates until the last quarter of the present century

An interesting aspect of an investigation of electrochemical power generation is the ability to explore different electrode and electrolyte combinations and to pick out promising ones for detailed investigation. A large number of such combinations have yet to be studied systematically and data generation in this area can be rewarding

The present work was undertaken with a view to generating data on selected electrode–electrolyte combinations that show the promise of subsequent development into viable electrochemical cells, and which could provide an alternative to existing portable electricity sources

Experimental and results

(i) Cell design

For the purpose of these investigations, the electrodes consisted of metal anodes (using metal sheets (99.9% pure) of dimensions $5.3 \times 2.5 \times 0.1$ cm, and carbon cathodes of dimensions, $5 \times 2.5 \times 0.2$ cm, with a graphite power coating (99.5% purity) mixed with iodine or sulphur in the ratio iodine or sulphur, 1 mole graphite, 50 mole, with sufficient rubber solution to attain a working consistency. The thickness of the coated layer was about 0.5 mm.

The electrodes, spaced at a distance of about 1 cm, were dipped in the required electrolyte solution.

The ionic charge carriers used in these studies were saturated solutions of potassium iodide, potassium hydroxide, calcium chloride, CTAB (cetyltrimethylammonium bromide) and SLS (sodium lauryl sulphate) in water, formamide, or nitrobenzene at ambient temperature (30 °C).

TABLE 1
Specific conductance in aqueous media

Electrolyte	Solvent	Sp conductance (mho cm ⁻¹)
KI	Water	0.02
KOH	Water	0.0357
KCl	Water	0.0384
CaCl ₂	Water	0.0333
CTAB	Water	0.002
SLS	Water	0.01

TABLE 2

Specific conductance in non-aqueous media

Electrolyte	Solvent	Sp conductance (mho cm ⁻¹)
KI	nitrobenzene	6.66×10^{-6}
KOH	nitrobenzene	6.67×10^{-7}
KCl	nitrobenzene	7.143×10^{-6}
CaCl ₂	nitrobenzene	2×10^{-6}
CTAB	nitrobenzene	2×10^{-4}
SLS	nitrobenzene	1.8×10^{-6}
KI	formamide	7.40×10^{-3}
KOH	formamide	1.33×10^{-2}
KCl	formamide	0.01
CaCl ₂	formamide	5.00×10^{-3}
CTAB	formamide	1.33×10^{-3}
SLS	formamide	1.66×10^{-3}

TABLE 3

Voltage-current data on aqueous systems

Cathode	Anode	Electrolyte (solvent water)	OCV (V)	SCC (mA)
Iodine	aluminium	KI	1.00	275
		KOH	1.85	290
		KCl	1.10	280
		CaCl ₂	1.15	220
		CTAB	1.10	75
		SLS	1.05	60
Iodine	zinc	KI	1.20	225
		KOH	1.65	150
		KCl	1.35	285
		CaCl ₂	1.35	275
		CTAB	1.30	100
		SLS	1.35	250
Iodine	iron	KI	0.60	150
		KOH	0.75	50
		KCl	0.75	275
Iodine	nickel	KI	0.45	60
		KOH	0.80	50
Sulphur	aluminium	KOH	1.45	140
		KCl	1.15	8
		CaCl ₂	1.05	15
Sulphur	zinc	KI	0.80	270
		KOH	1.3	260
		KCl	1.0	15

TABLE 4

Voltage-current data on non-aqueous systems

Cathode	Anode	Electrolyte (solvent)	OCV (V)	SCC (mA)
Iodine	aluminium	KOH (Formamide)	1.2	2.5
		KCl (Formamide)	1.2	150
		CaCl ₂ (Formamide)	1.2	90
		CTAB (Formamide)	1.00	5
		SLS (Formamide)	1.00	1.5
		KI (Nitrobenzene)	1.00	0.75
		CTAB (Nitrobenzene)	1.25	6
Iodine	zinc	KI (Formamide)	1.20	2.5
		KOH (Formamide)	1.45	100
		KCl (Formamide)	1.55	150
		CaCl ₂ (Formamide)	1.5	125
		CTAB (Formamide)	1.35	5
		SLS (Formamide)	1.4	3
		CTAB (Nitrobenzene)	1.15	2.5
Iodine	iron	CaCl ₂ (Formamide)	0.9	10
		KCl (Formamide)	0.8	25
Iodine	nickel	KI (Formamide)	0.35	100
Sulphur	zinc	KOH (Formamide)	0.95	14
		CaCl ₂ (Formamide)	1.2	12.5

(The necessary data for these studies were obtained using YX-360 TR Multitester, Sanwa, India.)

Non-aqueous solvents were dehydrated using quicklime and then distilled at the boiling point of the pure liquids to ensure that no moisture was present. This was further tested using crystals of anhydrous copper sulphate. Finally, the b.p. of the liquids were determined and checked against the respective reported boiling points. However, a nitrogen atmosphere was not available, so interference from atmospheric oxygen could not be avoided.

(ii) Measurements

(a) Conductance measurements

These were carried out to determine the electrical conductance of the saturated solutions of electrolytes in the different solvents. The relevant data are shown in Tables 1 and 2.

(b) Voltage and current study

The open circuit voltages (OCV) and short circuit currents (SCC) for different combinations, in both aqueous and non-aqueous media, were also measured. These data are presented in Tables 3 and 4 for the aqueous and non-aqueous systems, respectively.

Discussion

Bagotsky [1] has discussed the genesis and future projection for a number of primary and secondary cells. Many promising primary and storage cells [2–8] have been described in the literature, but most are covered by patents.

Our studies indicate that a number of aqueous systems, e.g., iodine cathode and aluminium anode in aqueous potassium hydroxide solution, or the same electrodes in aqueous potassium chloride or calcium chloride solution, iodine cathode and zinc anode in aqueous potassium hydroxide solution, potassium iodide solution and potassium chloride solution; iodine cathode and iron anode in aqueous potassium chloride solution, sulphur cathode and aluminium anode in aqueous potassium hydroxide and calcium chloride solution, sulphur cathode and zinc anode in aqueous potassium hydroxide solution, etc., all of which show an OCV of about 1 V and SCC from 250 to 90 mA cm⁻², are quite promising. However, the aqueous systems are unlikely to be rechargeable when aluminium is used as the anode. With a zinc anode dendrite formation may be a disadvantage.

Of the non-aqueous systems, the iodine cathode and aluminium anode with potassium chloride or calcium chloride in formamide; potassium iodide in nitrobenzene as the electrolyte, an iodine cathode and zinc anode with calcium chloride or potassium chloride in formamide, an iodine cathode and iron anode with potassium chloride in formamide, a sulphur cathode and zinc anode with calcium chloride in formamide, all appear to show promise. Further studies will be made concerning the reversibility of the electrochemical reactions, the current–voltage behaviour, the shelf life and self-discharge characteristics, the rechargeability of the cell and start-up current, etc. Work is in progress in our laboratory in this direction.

References

- 1 V S Bagotsky, Electrochemical systems in energy, in R Kalvoda and R Parsons (eds), *Electrochemistry in Research and Development*, Plenum Press, New York, 1985, pp 55–68
- 2 Sugawa Hiroshi *et al.*, Secondary iodine–zinc batteries, *Jpn. Kokai Tokkyo Koho*, 63 205 066, *CI H 01 M 12/08* (Aug 24, 1988)
- 3 Sugawa Hiroshi *et al.*, Secondary iodine–zinc batteries, *Jpn. Kokai Tokkyo Koho*, 63 205 067, *CI H 01 M 12/08* (Aug 24, 1988)
- 4 M Terada *et al.*, Lead–acid batteries, *Jpn. Kokai Tokkyo Koho* 63 244 568, *CI H 01 M 10/06* (Oct 12, 1988)
- 5 K Otsuka, Secondary batteries with active carbon cathode and iodide electrolyte, Kuraray Co Ltd, *CI H 01 M 10/40* (July 7, 1988)
- 6 S Atsushi *et al.*, *Bull. Chem. Soc. Jpn.*, 61 (1988) 4401–4406
- 7 K Tange *et al.*, Zinc–Bromine Batteries, Toyota Motor Corp, *Jpn. Kokai Tokkyo Koho* 01 12 473, *CI H 01 M 12/08* (Jan 17, 1989)
- 8 Secondary batteries with organic electrolytes, Matsushita Electric Industrial Co Ltd, *Jpn. Kokai Tokkyo Koho* 63 158 763, *CI H 01 M 10/40* (July 1, 1988)