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Optimization of power of alkali metal thermo electric convertor

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HIGHLIGHTS

- We have optimized the efficiency and power output of AMTEC by varying the thickness of electrodes and electrolyte.
- We have found the optimum value of the thickness of the electrodes.
- The variation of the thickness of electrodes is not as effective as that of the electrolyte.

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ABSTRACT

Alkali Metal Thermo Electric Convertor (AMTEC) uses infrared radiation to knock out electrons from some alkali metal acting as the working material. In the present paper sodium is chosen as the alkali metal. The freed electrons after going through a circuit and having done the prescribed work meet the sodium ions. A solid electrolyte, called beta" alumina solid electrolyte (BASE) is used for diffusing the working material ions. The system is closed and continues working as long as the heat source is kept turned on. The longevity, power and efficiency of the device depend inversely to some extent on the thickness of the electrolyte and electrodes. In this work we have optimized the thickness of electrodes. This optimization improved the efficiency and power output by 28 and 14.8% points respectively.
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1. Introduction

Alkali Metal Thermal Electric Converter (AMTEC) is an infrared regenerative electrochemical device for the direct conversion of heat into electricity. It has the ability to use infrared energy as an input from high temperature combustion, nuclear, radioisotope, solar or heat rejected from other devices [1–5]. In the working of AMTEC infrared and near infrared region of electromagnetic radiation or in simple language the radiation of thermal range are used. Therefore, the design, manufacture and working of AMTEC as a whole pertains to the domain of optoelectronics. An earlier paper “Effect on geometrical variations on AMTEC” showed improvements both in efficiency and power generated by changing the geometry of the cell [1]. In that paper the lengths of electrodes and electrolyte were varied along with the variation of other parameters of the cell. Though the variation of other parameters was discussed thoroughly but the sensitivity of the instrument based on the thickness of electrodes and electrolyte, which is rather important, was ignored earlier [1]. In the present work we have focused on the variation of thickness of electrodes and electrolyte. These parameters are very sensitive and difficult to handle as they are of nano scale in size. AMTEC has no moving part, except the working fluid, thus creating no noise with the potential for low maintenance, high durability and reliability. It is also not subjected to any material wear and tear. There is no vibration or uncompensated momentum present in AMTEC, which reduces the chances of corrosion. Its simulated design has shown its longevity as much as fifteen years [6]. Some of its laboratory devices have achieved efficiencies as high as 19%. Small system designs using AMTEC have shown 27% cell and 23% system efficiencies. An Optimized AMTEC can, however, potentially provide a theoretical efficiency close to

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Carnot efficiency, almost up to 40% [7]. Because of its longevity and high efficiency under static conversion, historically AMTEC technology development had primarily been focused on deep space missions. It is, however, expected also to have many terrestrial applications as well. A number of research programs on AMTEC have been directed for improving its performance characteristics and technology improvement. Of course, these efforts have successfully resolved many of the important technological issues pertaining to its design and fabrication. The performance level, however, achieved until today is still below the expected potential of AMTEC. During an extended testing of an AMTEC model the maximum power of its output was observed (Fig. 1) to be decreasing from 2.49 W to 1.27 W over a period of 18,000 h of operation [8]. The bêta" alumina solid electrolyte (BASE) is primarily responsible for the power degradation. The role of electrodes is insignificantly small compared to that of the BASE [9].

Before we discuss their respective contributions to the power out and efficiency it may be in order to give a brief description and working principle of AMTEC. This is mostly borrowed from an encyclopedic article of one of the authors [10].

2. Physical description of AMTEC

Initially AMTEC was developed as liquid–anode cycle but soon the vapor–anode cycle system took over. The use of the vapor-fed AMTEC cycle system has presently been in the vogue and being investigated. A typical AMTEC unit is housed in a sealed container. It looks in dimension like a D-size dry cell. The working fluid is so selected that it should have a high negative potential, lightweight and abundantly available for cost effectiveness. An alkali metal with relatively low melting point would satisfy these qualities. Out of number of possible samples sodium (Na) is chosen for this task. A solid electrolyte, made of a dense micro-crystalline sintered ceramic material beta" aluminum solid electrolyte (BASE) ($Na_{5/3}Li_{1/3}Al_{32/3}O_{17}$), lies at the heart of AMTEC. The BASE is in the form of individual tubes connected in series as shown in Fig. 2.

The BASE separates two regions of alkali (sodium in this case) vapor introduced; at high-temperature (900K–1300 K), high-pressure (20–100 kPa) region and a low-temperature (400–700 K), low-pressure (<100 Pa) region, see Fig. 2. Two thin, porous electrodes are spray plated on inside and outside walls of the BASE, shown schematically in Fig. 3.

The electrode mounted on the inner side of the BASE acts as anode and the one on the outer side of the BASE is treated as cathode. The inner and outer electrodes are each connected with current collectors. One of the collectors collects electrons at the anode (high pressure side of BASE) and conducts them through an external load. Electrons from the external load are brought back to the cell at the cathode (low pressure side of the BASE) for the recombination with sodium ions. The requisite leads connecting the two electrodes carry the electric current through the load. The working fluid, initially in the liquid state is stored in the condenser at one of the ends of the cell. It is carried by the a capillary tube, called sodium return artery into the evaporator placed at the other end of the cell, where it is heated and turned into vapor, see Fig. 2. The evaporator thus maintains liquid–vapor interface during the operation of the cell. The evaporator side carries a hot plate, which is heated from the external infrared source. The far end of the cell, where the condenser is housed releases the heat of sodium condensation. The cell contains a radiation shield, laid against the cell walls above the BASE tubes to reduce the parasitic energy losses through the cell walls. In addition to radiation shield a chevron radiation shield system consisting of a requisite number of chevrons at desired angles is placed above the BASE tubes when needed for maximizing the power output and efficiency. The cell is operated in the vacuum.

3. Working principle of AMTEC

On applying the infrared radiation from any source of heat at one end of the cell the electric current at the other end of the cell is produced. The sodium vapor pressure at the anode/BASE interface (the high-pressure side) is equal to the saturation pressure at the evaporator temperature. The pressure differential between the two sides of the BASE is associated with potential energy, which can be converted to useful work through sodium. As the liquid sodium at condenser temperature enters the evaporator in the hot region of the cell, it starts absorbing the externally supplied heat until it vaporizes and reaches the desired temperature of the inside BASE tube. The inside BASE tube temperature is kept slightly higher than that of the evaporator to prevent condensation of sodium in the anode cavity and the potential electric shorting of the cell. As a result of the high pressure, sodium vapor tries to expand. The β″-alumina is impermeable to neutral atoms and negative charges. Thus the only way for the pressure to be released is for neutral sodium atoms to ionize. The sodium atoms, hence, are ionized producing sodium ions and free electrons allowing the sodium ions to pass through the BASE wall. Due to the thermodynamic pressure

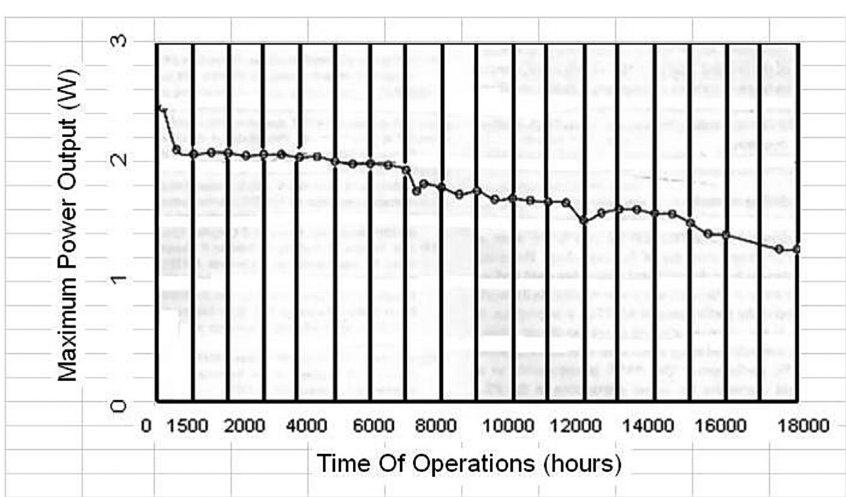

Fig. 1. Power output of AMTEC as a function of time of operation.

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