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Solar Photogalvanic Energy - Optimisation and Challenges

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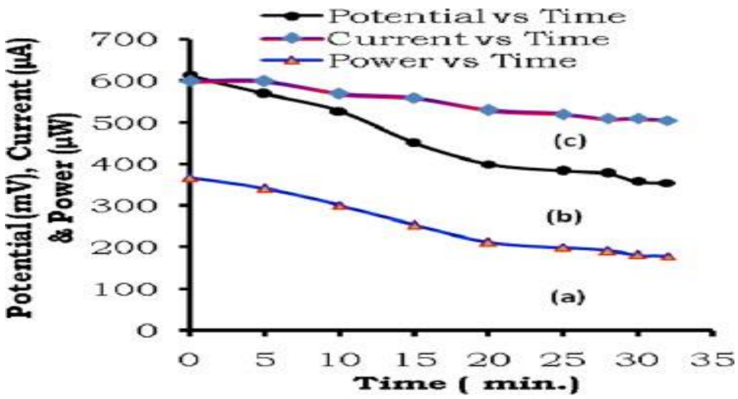
ABSTRACT: Solar cell converts solar energy into electricity directly. Among such solar cells, the photogalvanic cells are unique as these are only solar cells that are capable of doing solar power generation and storage simultaneously. Therefore, such an inherent solar power storage capacity that too with good efficiency of these cells needs to be exploited for making solar cell technology a reliable source of power in the future. The fabrication and experimentation of photogalvanic cells is very simple to demonstrate its unique property. The power, short-circuit current, open-circuit potential, conversion efficiency, and power storage (in terms of half change time) for photogalvanic cells are reported of the order of 1159 μW, 4500 μA, 1.07 V, 14, and 260 min, respectively.However, to make photogalvanic cells realty in life for simultaneous solar power and storage, some challenges have to be tackled. Some of the challenges are photodecay of dye, corrosion of platinum (Pt), evaporation of liquid, breaking vulnerability of SCE/combination electrode, further need to increase the power and efficiency and storage, assembly operation of cells for augmentation of power, cell study in natural sunlight, and so on.

KEYWORDS: solar photogalvanic energy, optimization, challenges, current, power, circuit, sunlight

I. INTRODUCTION

Photogalvanic cell is a dye sensitized photo-electrochemical cell chargeable in light for solar power generation and storage.[1,2]



Sudan-I dye and Fructose chemicals based photogalvanic cells for electrochemical solar energy conversion and storage at low and artificial sun intensity

A photogalvanic cell consists of H-shaped glass tube containing two electrodes dipped in solution of dye, reductant, NaOH and surfactant (if used). Rabinowitch suggested that the photogalvanic effect might be used to convert sunlight into electricity. To explore this suggestion, some photogalvanic cells using the iron-thionine system as the photosensitive fluid were tested. The observed electrical parameters (like power, etc.) were very low. Despite it, these cells have been considered energy source for the future if their electrical performance is increased. Because of this, lot of work has been done by using various dyes, reductants, and surfactants. I have also done lot of work by using various dye photosensitizers (like Brilliant Cresyl Blue, Rhodamine B, Fast Green FCF, etc.) with Fructose reductant and NaOH alkaline medium. Radically high cell performancepotential 1.07 V,[3,4] short-circuit current density 12.15 mAcm-2, power 3.05 mWcm-2, efficiency 7.58% and storage capacity 3.6 hour was observed. It is viewed that the photogalvanic cells, with additional advantage of low cost, chargeable/rechargeable in diffused light and storage capacity, can give electrical output comparable to that for commercially used power storage property lacking photovoltaic cells. But to realize this aim, further enhancement in electrical out put of these cells is needed. The option of use of diversity of chemicals like dye, reductant and surfactant has already been exhausted. Therefore, the design and use of alternative/new electrodes may be tried[5,6]

The performance of photogalvanic cells for the direct conversion of solar energy to electrical energy depends on the cell photochemistry, the homogeneous kinetics, the mass transport, the electrode kinetics and the load on the cell. The variation of the power output with the concentrations of the redox couples, their transport and kinetic parameters and the dimensions of the cell is found. The power conversion efficiency of the optimal cell could be as large as 18% but it is unlikely that all the necessary conditions can be met. A more realistic estimate of the maximum power conversion efficiency that could be achieved from a photogalvanic cell is between 5 and 9%.[7,8]

In a study, Photogalvanic effect was studied in photogalvanic cells containing EDTA as reductant, new methylene blue, and safranine O as photosensitizer. The photopotential and photocurrent generated were 740 mV and 110 µA, respectively. The observed conversion efficiency was 0.4442% and the maximum output (power) of cell was 81.4 µW. The photogalvanic cell can be used for 95 min in the dark due to the storage capacity of the cell. The effects of various parameters on the electrical output of the cell were observed. The mechanism of generation of the photocurrent in these photogalvanic cells has also been proposed. Photogalvanic cells are photoelectrochemical cells chargeable in light for solar energy conversion and storage. They may be energy source for the future, if their electrical performance is increased. In this study, a photosensitizer Lissamine green B, a reductant Ascorbic acid and a surfactant NaLS have been used in the photogalvanic cell.[9,10] The generated photopotential and photocurrent are 850.0 mV and 375.0 µA respectively. The conversion efficiency of the cell, fill factor and the cell performance were observed 1.0257%, 0.2598% and 170.0 minutes in dark respectively. The effects of different parameters on the electrical output of the photogalvanic cell were observed. A mechanism was proposed for the photogeneration of electrical energy.

The photogalvanic effect was first observed by Rideal and Williams , systematically investigated by and later by various other workers.We discussed various problems encountered in the development of this field. A detailed literature survey reveals that different photosensitizers have been used in photogalvanic cells along with reductants and surfactants. Recently, observed the photogalvanic effect in cells containing dyes, reductants and surfactants, but negligible attention has been paid to the use of heterocyclic dye (azur A, azur B, azur C) in photogalvanic cells with ascorbic acid and NaLS for solar energy conversion and storage and therefore, the present work was undertaken.[11,12]

It is seen that all the three systems with heterocyclic dye work effectively in the strong alkaline range. The working range for the present work was pH = 11×6–13×2. The potential of the system is found to increase as the pH increases, reaching a maximum value for a particular pH, and then decreases on further increases in pH. It is quite interesting to observe that pH at the optimum condition for reductant has a relation with its pKa value, i.e. the desired pH should be slightly higher than their pKa values (pH = pKa + 1 to 3). Three different types of heterocyclic dyes (azur A, B and C) were used in photogalvanic cells containing the NaLS–ascorbic acid system. The effects of variation of concentration of the three heterocyclic dyes have been studied. It is observed that there is an increase in photopotential and photocurrent values on increasing the concentration of the dyes. It is necessary to keep the concentration at 10–5 , 10–5 , 10–4 M for azur A, azur B and azur C respectively, for effective results in electrical output. The heterocyclic dye azur B is the most efficient dye, followed by azur A and azur C, for generation of electrical output, conversion efficiency and storage point of view due to presence of the trimethyl group. On the lower side of the concentration range of dyes, there are a limited number of dyes molecules to absorb the major portion of the light in the path and, therefore, there is low electrical output, whereas a higher concentration of dyes does not permit the desired light intensity to reach the molecules near the electrodes and hence, there is corresponding fall in the power of the cell. Effect of variation of diffusion length on the electrical output (imax, ieq) and initial rate of generation of current of the photogalvanic cell were observed by using H-cells of different dimensions. [13,14]The diffusion length (distance between the electrodes) greatly affects all the three systems. It is observed that in the first few minutes of illumination there is sharp increase in the photocurrent and then there is gradual decrease to a stable value of photocurrent. This behaviour of photocurrent indicates an initial rapid reaction followed by a slow rate-determining step. The results are also discussed to know about electroactive species by considering various probable processes and combinations of electroactive species for the electrical output of photogalvanic cells. The oxidized form of the reductant is formed only in the illuminated chamber and if it is taken to be the electractive species in dark chamber, then it must diffuse from the illuminated chamber to the dark chamber to accept an electron from the electrode. As a consequence, the maximum photocurrent (imax) and rate of generation of photocurrent should increase with increase in diffusion length, but this is not observed experimentally. The value of (ieq) is also observed to be independent with respect to change in diffusion length (rather it decreases slightly). Therefore, it may be concluded that the main electroactive species are the leuco or semi leuco form of dyes (photosensitizers) and the dye in the illuminated and the dark chamber respectively. The reductant and its oxidation product act only as electron carriers in the path.[15,16]

II. DISCUSSION

Photopotentials and photocurrents of photogalvanic cells have been measured at different temperatures and the effect of temperature on electrical output in all three systems has been studied. On the basis of the obtained results it is clear that there is a linear relation between electrical output of the cell and temperature. It is also observed that on increasing temperature, the photo current increases but the photopotential decreases. This is due to the fact that internal resistant of the cell decreases at higher temperature resulting in a rise in photocurrent and corresponding there is a fall in photo potential in all the systems. Lights source of different intensities (different wattages) were used to observe the effect of light intensity on the output of the cell. It is observed that the photocurrent shows linearly increasing behaviour with increase in intensity of light, whereas photo potential increases with increasing light intensity in a logarithmic manner (i.e. the plot of log V vs i is linear). Increasing light intensities increase the number of photons per unit area (incident power) striking the dye molecules around the platinum electrode and, therefore, increase in the electrical output occurs. Increase in light intensity also increases the temperature of the cell and, hence in our experiment a water filter was used to cut off the thermal radiations.[17,18]

A digital pH meter was used to measure the open circuit voltage (Voc) (keeping the other circuit open) whereas short circuit current (isc) was measured with a microammeter (keeping the other circuit closed). The electrical parameters between these two extreme values (Voc and isc) were determined with the help of a carbon pot (log 500 K) in the circuit of the microammeter, through which an external load was applied. The corresponding value of the potential, with respect to different current values for all the three systems, has already been studied. It was observed that in the entire three systems i–V curve deviated from their expected regular rectangular shapes. The power point (a point on the curve. where the product of potential and current is maximum) on these i–V curves was determined and their fill factors was also calculated. The most efficient system is NaLS–ascorbic acid–azur B followed by NaLS–ascorbic acid–azur A and NaLS– ascorbic acid–azur C system. Performance of photogalvanic cells was studied by applying the desired external load to obtain the potential and current corresponding to the power point after removing the source of illumination. Time t 1/2 was determined after removing the source of light. It is the time taken to reach half the value of power. NaLS–ascorbic acid–azur B is the most efficient system from the power generation point of view (solar energy conversion) and also the most efficient from the performance point of view (solar energy storage), followed by the NaLS–ascorbic acid–azur A and NaLS–ascorbic acid–azur C systems. Properties of a photogalvanic cell with azur B are superior to those of cells with azur A and azur C, due to the presence of a trimethyl group in azur B (structure I) while azur A and C have dimethyl and mono methyl groups respectively (structures II and III). [19,20]We know that methyl (–CH3) groups show a positive inductive effect. This effect is greater in azur B dye than in azur A and azur C. Hence, azur B gives better performance than the others. Conversion efficiencies of all these systems were calculated using the outputs at the power point and the intensity of the incident radiation. The systems (at their optimum conditions) were also exposed to sunlight. On the basis of three observations, the highest conversion efficiency was found in the NaLS–ascorbic acid–azur B system followed by the NaLS–ascorbic acid–azur A and NaLS–ascorbic acid–azur C systems.

III. RESULTS

In the dark, no reaction between heterocyclic dyes and reductants takes place. It may be concluded that the redox potential of reductant (ascorbic acid) is much higher than the dyes used in the present work, as a rapid fall in potential is observed when the platinum electrode is illuminated and after some time, a constant value was obtained. On removing the source of light, the change in potential is reversed but it never reaches the initial value. It suggests that main reversible photochemical reaction is also accompanied by some irreversible side reactions. We have discussed the electractive species in a well-established system the like the thionine iron (II) system, where ferric ions were considered as the reactive species at the dark electrode. In all the three systems, the electroactive species are the leuco dyes and dyes itself at the illuminated and dark electrodes respectively. According to observed results, the most probable rate-determining process for (ieq) should be the recycling reaction of oxidation product of the reducing agent and the semi- or leuco-dyes (photosensitizers). Some experimental evidence has been obtained by scientists supporting the participation of the leuco form of the dyes as electroactive species. [21]

IV. CONCLUSIONS

Scientists have been studying the harvesting of solar energy in various forms of solar cells like photoelectrochemical, photovoltaic and photogalvanic cells. Photovoltaic cells are widely used in most countries for conversion and storage of solar energy but owing to their low storage capacity, photogalvanic cells are preferred because they have the added advantage of inherent storage capacity. On the basis of results obtained in present work by using three types of heterocyclic dyes (azur A, azur B, azur C), we have demonstrated the higher storage capacity of these photogalvanic cells as well as their greater electrical output in comparison to those previously prepared with dye azur B, surfactant tween 80 and NaLS, used by Genwa and Gangotri.19 In these systems, the value of conversion efficiency is 0×2177% and storage capacity is 74×0 min. Other dyes like methylene blue with oxalic acid and NaLS were used by Gangotri and Meena20 and their values of electrical output (conversion efficiency = 0×1211% and cell performance = 35×0 min) and other parameters are lower whereas the present values of electrical output are reasonably higher. Therefore these systems are more efficient than existing ones. Efforts will be made in future to enhance both these factors along with exploring their commercial viability.[21]

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