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Petroleum waste as raw materials for production of electricity by Photogalvanic solar cell



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ABSTRACT

Petroleum industry produces a bulky rate of harmful environmental wastes. Recycling of these wastes to produce added value products is of prim importance. In this work, Synthesis of sodium 4-dodecyl benzene sulfonate (SDBS) anionic surfactant from petroleum waste was done through two steps method. The composition of the produced anionic surfactant was investigated by using FTIR, ¹HNMR, and 13CNMR spectra techniques. Anionic surfactant was applied in photogalvanic cell (PGC) for production of electricity. PGC can be described as an electrochemical cell where the change in both voltage and current arises from the generated photochemical changes in the reactants during the oxidation-reduction reaction in the cell. the recorded electrical cell performance are; maximum power (P_{PP}) 39.8 μ W, short circuit current (i_{SC})145.2 μ A, open circuit potential (V_{OC}) 490 mV, fill factor (FF) 0.65, conversion efficiency (η) 0.77%, and storage capacity t_{0.5}65 min for system containing Tris (2,2'-bipyrdyl) Ruthenium (II) chloride hexahydrate (TBRC) as photosensitize, Oxalic acid (OX) as reductant, and (SDBS) as anionic surfactant under artificial illumination. The cell performance is optimized and the preliminary mechanism for the solar energy conversion in PGC is also proposed.

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1. Introduction

The linear efficiency of linear Alkyl benzene (LAB) has been clearly identified, and it is one of the most widely applied products. LAB is an organic compound with the structural formula $C_6H_5CnH_2$ (n + 1); n is often 11–12. LAB is almost used entirely as a feedstock in the production of Linear Alkyl benzene Sulfonate (LABS), LAB is primarily produced as an intermediate component in the production of surfactants for detergent use. LABS have emerged as the main predominant precursor of biodegradable detergents since the 1960s. LAB preparation is complex and has a high-cost production. There are various methods for producing linear alkylbenzene as shown in Fig. 1 [1]. n-paraffins are dehydrogenated into olefins within the HF / n-paraffins process, and hydrogen fluoride is used as a catalyst during the subsequent reaction with benzene. This method accounts for the majority of the world's installed LAB production. PACOL stage involves the conversion of n-paraffins to mono-olefins (typically internal mono-olefins) using DEFINE Unit. The primary purpose of the DEFINE Unit is to transform residual diolefins into mono-olefins. The productivity and quality of the LAB is improved by a PEP unit, which is basically an aromatic removal unit introduced before the alkylation step. An alkylation

* Corresponding author. E-mail address: samar.epri90@gmail.com (S.H. Bendary). step in which the LAB is produced by the reaction of mono-olefins, whether both internal and alpha olefins with benzene in the presence of HF as a catalyst.

The DETAL process, in which n-paraffins are converted to olefins by dehydrogenation and subsequent reaction with benzene using a fixed bed catalyst this is newer technology and has several of the stages depicted in the HF / n-paraffins process but it is principally different in the benzene alkylation step, during which a solid-state catalyst is employed. There is a developing Tran's alkylation (TA) stage to the DETAL process in which any higher alkylated benzene (HAB) is contacted with additional benzene over a Tran's alkylation catalyst.

Chlorination of n-paraffins into mono-chloro-paraffins followed by alkylation of benzene using aluminum chloride (AlCl₃) catalyst is part of the Friedel-Crafts alkylation process, which one of the oldest commercial routes to LAB [2].

This paper discusses the linear alkyl benzene extracted from petroleum waste to obtain surfactants with high surface activity and applied in solar energy conversion.

Surfactants have great importance in many environmental fields such as detergents (54%); as associates for textiles, leather and paper (13%); in chemical processes (10%) such as water treatment and electrical energy production; in cosmetics and medicines (10%); in the food industry (3%); and agriculture (2%) and as antibacterial [3].



Fig. 2. SDBS structure.

Critical micelle concentration (CMC) is an important factor affecting the performance of the PGC, which maximizes the output value [4]. PGC considered one of the types of the solar cells responsible for the conversion of the solar energy as they are a prominent example of photochemical systems, which consists of electrodes that are dipped in a mixture of different l solutions of photosensitive dye, Surfactants, and reductant. The purpose of adding Surfactant is to increase the solubility and stability of the dye and consequently improving and stabilizing PGC performance. PGC through light on the Photoelectric effect, where light has a strong impact on the electrode potential, due to the occurrence of a photomechanical process in the greater part of the electrolyte which occur on the surface of the electrode. Mixing occurs clearly between the types of solar cells where many believe that the difference between the photovoltaic cell and the PGC is unnoticeable but there is a clear difference where the mechanism process in producing electricity is completely different. The photovoltaic cells depend on the direct excitation of the electron by the photon to produce electricity while the PGC rely on photonic molecule excitation that stimulates chemical reactions to deliver products. The PGC can also split into two groups by using semiconductors as an electrode.

We hereby focus on the synthesis of SDBS from petroleum waste and characterize through different spectral techniques. The product is mixed with OX as a reducing agent and TBRC as photosensitizer to improve the conversion efficiency of the PGC.

2. Experimental

2.1. Materials

LAB is a local raw material provided from Al- Amria Petroleum Refining Company. Sulfuric acid, Hydrochloric acid, Di ethyl ether Adwic, Egypt. TBRC, OX and Sodium hydroxide were provided from Sigma-Aldrich. Isopropanol was purchase from Bio. Chem. Egypt.

There are also glassware and simple equipment used in the measurements of the PGC as; platinum electrode (Pt), saturated calomel electrode (SCE), a digital pH meter (HANNA Model-212), a microammeter (Extech EX420 Autoranging), a carbon pot as the resistance variation device were used, H-glass tube and tungsten lamp200W (Philips) as artificial light source.

2.2. Synthesis of SDBS

SDBS was synthesized through two steps:

1 Sulfonation of LAB was carried out as follow:

1.5 mole of fuming sulfuric acid containing (7–8% sulfur trioxide) was added drop wise to 1 mole of LAB with vigorous stirring to avoid foaming. After complete addition, the reaction temperature is kept at 35–50 °C for 3 hrs. Then the reaction mixture was cooled to ambient temperature and poured slowly into a separating funnel containing concentrated HCl mixed with crushed ice. Then the mixture was shaken for 15 min and linear alkyl benzene sulphonic acid (LABSA) was extracted from aqueous layer dissolved with diethyl ether. Ether extracts was then evaporated in a rotary evaporator. (LABSA) was obtained as a dark brown liquid.

1 2 Sodium salt formation

Sodium salt of sulfonic acid was prepared by neutralization of the obtained sulfonic acid of LAB using10% aqueous sodium hydroxide with constant stirring. The obtained sodium salt was then dissolved in isopropyl alcohol, shake, left for 10 min to settle and get two separate layers. The upper organic layer consists mainly of surfactant-isopropanol solution while the aqueous inorganic layer consists of inorganic sulfate and the excess sodium hydroxide. The



Fig. 3. (A) PGC parts. (B) Technique of PGC operating mechanism.

upper layer was taken and the solvent was removed using a rotary evaporator to obtain the anionic surfactant SDBS Fig. 2.

2.3. Chemical structure

The chemical structure of the SDBS was confirmed by FTIR, 1 HNMR, and 13C NMR. FTIR was carried out using ATI Mattson Infinity series TM (Pine Instrument Company, Grove City, PA), Bench top 961 controlled by Win First TM V2.01 software. The measurement of 1 HNMR was done in DMSO using BRUKER. 13 CNMR analysis was carried out using Brucker instrument in DMSO.

2.4. Method for preparation PGC

Firstly, H-shaped glass tube was manufactured and darkened while keeping one side illuminating. Secondly, the tube was filled with a known concentration mixture of TBRC, OX, and SDBS with maintaining the total volume of the cell at 25 ml. A fixed distance between the two electrodes (2 cm) was used in this study. The Pt (area 0.5cm²) and SCE electrodes are placed in the illuminated side and dark one of H- tube, respectively. The tungsten lamp is used as a light source with water filter to avoid IR radiation. Finally, each of the terminals of the electrodes is connected to a digital pH meter and micro-ammeter through a key and resistance to measure both the voltage and the current produced by the photoelectric cell. Fig. 3 shows the PGC structure and mechanism of operation.

3. Results and discussion

3.1. FTIR and ¹HNMR spectra of SDBS

Fig. 4A-C shows the FTIR, ¹HNMR, and 13C NMR spectra of SDBS. Fig. 4A shows characteristic bands observed at 2859.56cm⁻¹ and 2925.63cm⁻¹ assigned to the presence of -C-H stretching of two alkyl groups. 3382 and 3032 cm⁻¹ assigned to the =C-H stretches of aromatic ring. The vibrational bands at1409, 1459.78 and 1593 cm⁻¹ confirmed the presence of C-C bonds of aromatic.

The appearance of two vibrational bands at $1171.91-1120 \text{ cm}^{-1}$ confirmed the R-SO2-R^{*j*} (Sulfones). A shoulder at 1080–1010 indicate the presence of R-SO₃H, where *R* = the aromatic ring. The vibrational band at 678.94cm⁻¹ is due to C-H out of plane bending while the band at 1035 is due to C-H in plane bending of benzene ring. The C-H wag of the para-substituted benzene ring falls at 843 and 884 cm⁻¹. The bands at 580 and 678 cm⁻¹ confirm the stretches of S-O bond.

Fig. 4B shows the ¹H NMR (DMSO-d₆) spectrum of SDBS. Different peaks observed at δ=0.72 ppm (t, 3H, C₆H₄CH₂ (CH₂)₉CH₂C **H**₃); δ=0.739 ppm (m, 2H, C₆H₄CH₂ (CH₂)₉C **H**₂CH₃); δ=1.116 ppm (m, 18H, C₆H₄CH₂ (C **H**₂)₉ CH₂CH₃); δ=1.5 ppm (t, 2H, C₆H₄CH₂C **H**₂ (CH₂)₉CH₃); δ=2.59 ppm (t, 2H, C₆H₄C **H**₂CH₂ (CH₂)₉CH₃); δ=6.36 ppm (s, 1H, SO₃ **H**); δ=7.07 (d, 2 **H**, Ar-H); 7.5 (d, Ar-H).

The spectral characteristic indicates that the compound could be aromatic with aliphatic side chains with sulfonate group depicted in Fig. 4C. The presence of signals in the region between 7.65 ppm and 7.12 ppm in the ¹H NMR and resonance at 126 and 127 ppm in the 13C NMR confirmed the presence of the aromatic ring. Moreover, the peak pattern in the 1H NMR spectrum corresponds to the protons on the aromatic ring having parasubstitutions. Signals in the region between 2.0 and 0.75 ppm in 1H NMR spectrum and in the range 120–130 in the in the 13C NMR spectrum. The magnetic resonance at 125.95, 126.61, 127.21, and 127.32 ppm confirm the presence of 1, 4 di-substituted benzene ring. The presence of 14.5–47.27 ppm confirmed the presence of the long-chain aliphatic group.

3.2. Determination of the voltage-current curve in the PGC

The results of the voltage and current are recorded by putting the PGC in the dark while keeping the circuit open until stable potential is achieved. The water filter is placed between the cell and the lamp to cut off the infrared which could negatively affects the cell and leads to decrease the performance. Upon illumination, the photovoltaic voltage (V) and the photocurrent (i) are generated by the system. After cell charging, the cell parameters such as maximum voltage (V_{max}), open circuit potential (V_{oc}), maximum cur-



Fig. 4. A-C: FTIR, 1H-NMR and 13CNMR spectra of SDBS.

rent (i_{max}), and equilibrium balance (i_{eq}) or short circuit current (i_{sc}) are measured. I-V curve was obtained by registering different data of the voltage by changing the resistance value so that the potential current data are obtained until the value of the zero-current reached. The curve study shows the highest amount by which the cell can be used. The cell is operated at highest power (i.e., power at power point P_{pp}) at corresponding external load to study its performance by monitoring the change in current and potential with time. After establishing the I-V curve and recording the result product the fill factor and conversion efficiency were calculated.

Fill factor is defined as the ratio of the maximum (actual) energy that can be obtained from solar cells to the theoretical value Eq (1).

While conversion efficiency known as the ability to convert the amount of forthcoming solar radiation to electricity Eq (2). Both can be expressed as follow:

$$FF = \frac{\text{Vpp} \times \text{Ipp}}{\text{Voc} \times \text{Jsc}}$$
(1)

$$\eta\% = \frac{\text{Vpp} \times \text{Ipp}}{10.4\text{mW cm} - 2 \times \text{A}} \times 100\%$$
(2)

where (V_{PP} i.e., potential at power point), (I_{PP} i.e., current at power point) and (A) is the area of Pt electrode.

The PGC charges were studied in a PGC system and the effects of different variables were discussed in order to achieve the highest conversion efficiency [5-20] as; the variation in the pH values of the solution, and variation in the concentration of TBRC, SDBS and OX.

3.3. Influence of the variation of pH

The effect of the variation of the pH concentration of complex solution, TBRC-OX and SDBS in PGC has been discussed by fabricating the six PGC. So that the concentrations of TBRC, OX and SDBS are the same for all cells but the NaOH (i.e. pH) concentration is different. The pH values were adjusted at 1.1, 1.2, 1.4, 7.0,



Fig. 5. a and b: I-V curve (a) and the variation of the potential and current with pH (b).

Та

Table 1 Influence of the variation of pH on the performance of PGC.

	рН					
Parameters	1.1	1.2	1.4	7	8	12
Photo potential (mV)	470	490	430	347	250	180
Photocurrent (μ A)	126.1	145.2	118.7	65.0	45.5	33.1
P_{pp} (μW)	32.5	39.8	27.1	10.4	5.1	2.4
FF	0.55	0.56	0.53	0.46	0.44	0.40
ŋ%	0.62	0.77	0.52	0.21	0.10	0.05

 $[SDBS] = 2.5 \times 10^{-3} \text{ M}; [OX] = 1.9 \times 10^{-3} \text{ M}; [TBRC] = 4.1 \times 10^{-4} \text{ M}; \text{ Pt}$ electrode area 0.5 cm², light intensity = 10.4 mW cm⁻².

8.0, and 12.0. The results are depicted in Table 1 and Fig. 5a &b which show the I-V curve and the variation of the potential and current with pH. The PGC showed a maximum potential of 470, 490, and 430 mV in the acidic pH values of 1.1, 1.2, and 1.4, respectively. . In acidic medium at pH =1.2 the highest values of Voc = 490 mV, isc=145.2 μ A, (FF=0.56), and η =0.77%. On the other hand, at pH1.4 the PGC produce the lowest Voc and isc as it recorded 430 mV and 118.7 µA. This is due to the degradation of the dye molecules in very strong acidic environment and inefficient light harvesting [21]. On the other hand, in alkaline media the lowest Voc of 180 mV was recorded due to the combination of OH- (from the NaOH used in this system) with the cationic reductant (formed upon electron donation from the reductant to the dye), and inhibits the regeneration of the reactive species in its original form and leading to poor performance of the cell.

3.4. Influence of the variation of SDBS concentration

Previous studies were conducted on PGCs in presence/absence of the surfactant in solution. The results show that the cell containing SDBS recorded the highest results compared to others, due to the improvement the solubility of the dye, increase the stability in the solution, and increases life time of the excited state of dye molecule. These could lead to increase in the output energy and consequently increased the η ., SDBS also enhances η by suppressing the thermal back electron transfer and promoting the processes of electron transfer to photosensitizer, and in turn to Pt electrode.

As mentioned previously, CMC point is a major factor in determining the cell performance, as the maximum conversion efficiency is recorded around CMC also the photo-ejection of electron from surfactant depends on charge of micelle [4]. The negative potential in an anionic micelle's aggregation promotes the ejection of electron and thus increases the performance of the PGC. Alkalitis et al., [22] has observed the photo-ejection of electron from

Table 2	
Influence of the variation of SDBS surfactant concentration on the electrical ou	t-
put.	

	SDBS \times [10 ^{- 3} M]					
Parameters	1	1.5	2	2.5	3	5
Photo potential (mV)	380	400	450	490	460	340
Photocurrent (μ A)	93.1	105.2	120.7	145.2	134.5	82.1
P_{pp} (μW)	18.1	21.8	29.3	39.8	34.1	13.8
FF	0.51	0.52	0.54	0.56	0.55	0.47
ŋ%	0.35	0.42	0.56	0.77	0.65	0.27

 $[\text{TBRC}] = 4.1 \times 10^{-4} \text{ M}; [\text{OX}] = 1.9 \times 10^{-3} \text{ M}; \text{ pH } 1.2; \text{ Pt electrode area } 0.5 \text{ cm}^2,$ light intensity = 10.4 mW cm^{-2} .

dye-surfactant system indicating the tunneling of photoelectron from micellar to aqueous phase. Whereas Bhowmik et al., [23] and Mukhopadhyay and Bhowmik [24] observed a photoinduced transfer of electron between micelles and dye during a charge transfer interaction. The electron photo-ejection from dye-surfactant depends on the micelle charge. The results of these methods for dyesurfactant interaction supposed that the opposite charged dye and surfactants are the strongest interaction while the same charged have zero interaction. In this system, the opposite charged SDBS and TBRC have stronger electrostatic force of attraction which dominant over the electrostatic repulsive force of same charged of individual TBRC / SDBS molecules. Table 2 and Fig. 6a &b show I-V curve and Variation of the SDBS concentration. It shows that the maximum cell output as V_{OC}, i_{SC} , FF and η using 2.5 \times 10⁻³ M of surfactant and any increase or decrease after that leads to significant decrease in cell performance.

By applying a low concentration there are a limited number of surfactant molecules available to transfer the electron and decrease solubility of the TBRC. On the other hand, High concentration of the surfactant molecules impedes the movement of the dye molecules to the electrode thus results in a decrease in the output energy. Moreover, the formation of rod-like micelles, which leads to an increase in viscosity and also decrease in the cell's output [25].

3.5. Influence of the variation of TBRC concentration

In recent years, there has been a remarkable growth and evaluation in the field of harmonization and organometallic chemistry of Ruthenium complex. Photocells based on [Ru(bipy)₃²⁺, have several advantages over some of the better known PGC systems such as; (i) favorable photoelectrochemical properties, (ii) The oxidation and reduction properties appropriate to the state of metal to ligand



Fig. 6. a and b: I-V curve (a) and Variation of Potential and Current with SDBS concentration (b).

 Table 3

 Influence of the variation of TBRC photosensitizer concentration on the electrical output.

	TBRC[M]					
Parameter	$4.1~\times~10^{-3}$	3×10^{-4}	$3.5~\times~10^{-4}$	$4.1~\times~10^{-4}$	4.6 \times 10 $^{-4}$	
photo potential (mV)	380	410	475	490	460	
Photocurrent (μ A)	80.3	101.7	137.8	145.2	119.5	
P_{pp} (μW)	30.5	21.7	36.00	39.8	29.67	
FF	0.48	0.52	0.55	0.56	0.54	
ŋ%	0.29	0.42	0.70	0.77	0.56	

[SDBS] = 2.5 \times 10⁻³ M; [OX] = 1.9 \times 10⁻³ M; pH 1.2; Pt electrode area 0.5cm²; light intensity = 10.4 mW cm⁻².

charge transfer (MLCT), (iii) their relatively long-life time. Ru" tris-2,2'-bipyridyl complex, Ru(bipy)₃²⁺, absorbs light in the visible region at about 350 nm to yield a set of metal-ligand charge-transfer excited states denoted * Ru(bipy)₃²⁺, equation (3). These species are strong reducing agents, deliver an electron to the oxidizing substrates and generating Ru^{III} tris-2,2'-bipyridyl, Ru(bipy)₃³⁺, equation (4). The latter, being a relatively strong oxidizing agent and may be reduced to ground state Ru- (bipy)₃²⁺, equation (5).

The three equations constitute a photodriven cycle, which may be possible to exploit within schemes for the photochemical cleavage of water and conversion of solar energy into electrical energy within a PGC [26,27].

The observed V_{OC} depends upon the incident light intensity and on the surfactant used in the cell and under typical conditions potentials of 380 to 490 mV have been observed. The long-term stability of the system is relatively good since only approximately 20 percent of the ruthenium complex is degraded after 6 days on a cycle of exposure of the cell to a 500 W tungsten lamp for 10 s/min [28].

Table 3 and Fig. 7a and b show I-V curve and Variation of photopotential and photocurrent with TBRC concentration. the maximum cell outputs from of photovoltaic power, photoelectric current, power at the power point, FF and η were obtained at concentration of 4.1 × 10⁻⁴ M TBRC and the change in concentration by increasing/decreasing. The decrease in the concentration after that leads to a significant reduce in the cell performance. Fig. 8 shows the UV spectra for different concentrations of TBRC and it confirmed that the concentration at 4.1 \times 10⁻⁴ M recorded the highest visible light absorption. At low concentration of the TBRC, there is a restricted number of Photosensitizer atoms expected to absorb photons and give provide an electron to the Pt electrode in the cell so, there is a decrease in the cell's output while high concentration of TBRC (i) doesn't allow the ideal light intensity to arrive at the particles close to the electrodes and thus, there was a fall in the power of the cell; (ii) due to the high concentration there are short lived excited dye states therefore, an excited dye molecule must reach Pt within its short life for electron donation. Only those dye molecules that exist and absorb photons near Pt have greater chance for electron donation to Pt electrode; (iii) on the other hand, an increased concentration of the dye under operating conditions may also lead to an acceleration of recombination between the injected electrons and dye molecules causes a fall down in the output current and voltage and thus a decrease in the η occurs.

3.6. Influence of the variation of the OX reductant concentration

The reducing agent plays an active role in the basic principle of PGC. TBRC in the presence of the OX reductant shows high V_{OC} and i_{SC} , indicating its electro-active nature and the electron exchange between dye and OX molecules. This confirms the formation of the reduced and oxidized states of OX. This fact is supported by



Fig. 7. a and b: I-V curve (a) and Variation of photopotential and photocurrent with TBRC concentration (b).



Fig. 8. Fig. 8: UV-vis absorption spectra of different concentrations of TBRC.

published literature. In an illuminated region of the cell a photon excites an electron from the ground state orbital (HOMO) to a higher energy orbital (LUMO) (i.e., the excited singlet state, which collapses to the excited triplet state through inter-system crossing (ISC)) of TBRC photosensitizer. The formation of the excited state forms a vacancy in the ground state that can be filled by an electron donor such as OX reductant because the redox potential of the excited TBRC state is higher than that of the OX reductant. The net result is that an excess electron is produced in the higher energy state of the TBRC molecule. The excited state of dye molecule cannot hold this excess electron for long therefore; this electron can be donated to an electron exchanger (Pt electrode). The electrons from the Pt electrode (high potential) flow through the external circuit to SCE (low potential) produce electric current [29]. At SCE, the TBRC molecules in solution accept electrons because the redox potential of the ground state of dye is higher than that of SCE. In this way, the PGC enables solar energy conversion into solar power (dc current) with inherent storage capacity. The current carrier in the electrolyte is the diffusion-controlled ions. Ideally, the PGC system acts as a (cyclic) light-driven electricity generator [30, 31]. The photoinduced electron transfer from SDBS to TBRC photosensitizer through a charge transfer (CT) interaction enhances the processes of electron transfer to photosensitize.

Different concentration of the OX was discussed in Table 4 and Fig. 9a and b show J-V curve and Variation of the OX concentration, the result show that the electrical output of the PGC was increase to the maximum and optimum value; thereafter, it was found to decrease. The optimum cell performance was observed at 1.9×10^{-3} M concentration of the OX reductant. The electrical output is low at a lower concentration range of the OX reductant because there are fewer molecules to donate electrons to the excited molecules of the TBRC photo-sensitizer while a higher concentration of the OX reductant may hinder the movement of the TBRC molecules to wards the electrodes in the desired time limit and may also promote back electron transfer from the TBRC molecules to the OX reductant molecules [32]. The hydrolysis of OX occurs in two steps as follows:

$$H_2C_2O_4 \rightarrow H^-C_2O_4 + H^+$$
; pKa = 1.27

$$H^{-}C_{2}O_{4} \rightarrow O_{4}^{-2}C_{2} + H^{+}$$
; pKa = 4.27

The two acid dissociation constants, pKa1 = 1.2 and pKa2 = 4.2,38 suggest that all three forms of oxalate are present in solution. The formed fragments H_2C_2O4 , $HC_2O_4^{-1}$, and $C_2O_4^{-2}$ are known to be e^{-1} and OH, scavengers [33-36]

The formed $HC_2O_4^-$ could be mineralized and form CO_2 and H_2O which cause a fall in electrical output. $HC_2O_4^- + \frac{1}{2}O_2 + H^+ \rightarrow 2CO_2 + H_2O$

Also, upon irradiation there are series of reaction which could be occurred and affect the electrical output as follows $H_2O \rightarrow H^+$ +⁻·OH

$$HC_2O_4{}^- + \cdot {}^-OH \rightarrow HC_2O_4{}^{\cdot -} + \, {}^-OH$$

In the presence of oxygen, this radical intermediate undergoes bond cleavage and electron migration leading to the formation of $\rm CO_2$ and a more stable carboxyl radical, $\rm CO_2^-$

$$HC_2O_4^{-} \rightarrow CO_2 + CO_2^{-}$$

Another reaction could be occurred in the solution,

$$HC_2O_4^- + \frac{1}{2}O_2 + H^+ \rightarrow 2CO_2 + H_2O_2$$

Table 4

Influence of the variation in OX concentration on the electrical output of the cell.

	OX concentration[M]					
Parameter	1×10^{-3}	1.3×10^{-3}	$1.9~\times~10^{-3}$	$2.4~\times~10^{-3}$	$4~\times~10^{-3}$	
photo potential (mV)	360	440	490	410	306	
Photocurrent (μ A)	78.9	133.7	145.2	119.2	53.2	
$P_{pp} (\mu W)$	13.5	31.8	39.8	25.4	7.16	
FF	0.47	0.54	0.56	0.52	0.44	
ŋ%	0.26	0.61	0.77	0.49	0.17	





Fig. 9. a and b: I-V curve (a) and Variation of Potential and Current with OX Concentration (b).



Fig. 10. Variation of the potential and power with the I-V characteristics of the cell. (1) Potential vs. current (2) Power vs. current.

4. (I-V) characteristics of the cell

The Voc and isc of all these systems were measured with the help of a digital pH meter (keeping the other circuit open) and a microammeter (keeping the other circuit closed), respectively. The electrical parameters in between these two extreme values (Voc and isc) were determined with the help of a carbon pot (log 470 K) connected in the circuit, through which an external load

in the circuit was applied. After studying a series of variables on the PGC, the highest outputs were reached for PGC containing $(4.1 \times 10^{-4} \text{ M of TBRC}, 2.5 \times 10^{-3} \text{ M of SDBS}, 1.9 \times 10^{-3} \text{ M of OX}$ at pH 1.2, Pt electrode area 0.5 cm^2 and light intensity=10.4 mW cm⁻². Fig. 10 shows I-V curve and the power point (a point on the curve where the output voltage and current are at a maximum) was determined and FF, η were calculated by Eq (1) & Eq (2) as indicated earlier. These data are summarized in Table 5.

Table 5



Fig. 11. Storage capacity of the cell (retrieval of the stored power in dark from the cell).



Fig. 12. Stability test of PGC at different time.

5. Storage capacity of PGC

In order to find out the energy storage capacity of the PGC, a study was made to recover the energy stored in the dark where the energy drops to half its initial value and this time is called t0.5. Fig. 11 shows a decrease in both voltage and current and this decrease in each of them is slow and may record a steady reading of several minute. This is an additional advantage of the PGCs as they do not require an external energy storage device due to the stability of their storage capacity. The storage capacity of the PGC which has the highest parameters output could be active for 65 min.

6. Stability tests of PGC

To analyze the durability of the PGC composed of 4.1×10^{-4} M of TBRC, 2.5×10^{-3} M of SDBS, 1.9×10^{-3} M of OX at pH 1.2, Pt electrode area 0.5cm² and light intensity=10.4 mW cm⁻², the performance of cell was studied for 15 days under natural conditions.

Fig. 12 showed the variation of PGC parameters such as Voltage (V), Current (μ A), FF) and (η). it was observed that the allparameters were slightly changed and most of the time records constant value at 490 mV,145.2 μ A, 0.65, and 0.77% respectively after 15 days of stability studies. Based on these results, it can be considered that the system used has proven successful as a possible alternative to generate electrical energy from petroleum waste.

7. Conclusion

LAB is considered a primary material in synthesis of SDBS anionic surfactant which has wide applications. In this paper, SDBS was successfully prepared and characterized by different techniques as FTIR, HNMR, and 13 CNMR. SDBS was successfully applied with OX as reductant and TBRC as photosensitizer in PGC. The study of some variants effectively improved the electrical performance of the PGC as Ppp 39.8 μ W, isc 145.2 μ A, Voc 490 mV, FF 0.56, η 0.77% and t0.5 65 min. From these facts, it can be concluded that the use of the chemical combination of the TBRC as photosensitizer dye -SDBS as surfactant and OX as reductant is a promising application for the high-efficiency PGC for solar energy harvesting with energy storage.

Credit author statment

The authors accept the submission and the publication of our manuscript in the Molecular Structure Joournal.

Declaration of Competing Interest

Authors declare that they have no conflict of interest.

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