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Textile Battery Based on Carbon and Silver Yarn

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Abstract

Gone are the days of textiles being used as fashion code rather it is generating a huge momentum as 'Electronic-textile'. Integrated textile energy storage devices may power new functions, while preserving good wear ability. The aim of this research was to develop a yarn-based battery that ensures high flexibility, light weight and ease of use, which can be integrated in smart textile systems. Electro-conductive yarns will serve as anode and cathode. As yarn materials Carbon and silver yarns were used as electrodes. An active gelatin layer was prepared by mixing it with potassium Iodide (KI) in the sample box with those electrode yarns. By characterization of samples; for instance- current and voltage values were measured with different resistances to find out whether the varying distances between electrodes really have any effect on storage efficiency or not. Finally possibilities for efficient production and application as newly developed yarn- based battery were discussed.

Keywords: battery, electrodes, gel-like electrolyte, power storage, nanotechnology, yarn coating, yarn electrodes

Introduction

"Textile-based electronic components are gaining attraction in the fields of science and technology. Now day's developments in nanotechnology have enabled the integration of electronic components into textiles while retaining desirable characteristics such as flexibility, strength, and conductivity. Various materials were investigated in detail to obtain current conductive textile technology, and the integration of electronic components into these textiles shows great promise for common everyday applications. The harvest and storage of energy in textile electronics is a challenge that requires further attention in order to enable complete adoption of this technology in practical implementations." (Kaushik et al. 2015) Up to now, these systems use external power sources, such as lithium batteries with a limited flexibility, which may decrease the wearing comfort and complicates the full integration into the textile. Against this background, this research aims at developing a fiber-based battery which is flexible.

Maintaining the comfort ability alongside fulfilling the requirements of textile batteries is a hard task to do. Recently, a rechargeable textile battery was created by Bhattacharya et al. It was fabricated on a textile substrate by applying a conductive polymeric coating directly over interwoven conductive yarns (Liu et al. 2012) A team of scientists from Korea Advanced Institute of Science and Technology (KAIST) has reported advancements in textile battery structures, which exhibit comparable electrochemical properties with metal foil cells and also have some of the features of textiles. (Bhattacharya et al. 2009) Approaches to produce stretchable and foldable integrated circuits have also been reported (Kim et al. 2008). Yarns could be spun using porous fibers, which usually have a large pore volume. Thus, it is achievable to load significant amount of energy storage materials into existing textiles to function as electrodes. (Hansora et al 2013). In 2013, Jost et al. knitted carbon fiber yarns into carbon stripes in existing textiles. The carbon strips served as both substrates and current collectors (Jost et al. 2013). In a more recent work, Jost et al. first deposited activated carbon in to cellulose fibers as energy storage electrode. Stainless steel yarns were twisted with cotton yarns as current collectors. Next, two rows of electrodes were knitted in parallel within a textile with a non-conductive strip between them as separator (Jost et al. 2015). These are some of the approaches for the yarn-based battery development.

The textile based energy storage depends on several factors. This research work is mainly done to initially develop a yarn-based battery which can store charge. The temperature and ability to withstand washing are big challenges for this type. The gel used as electrolyte, can be destroyed easily during washing and against high temperatures. That's why all procedures to develop this battery were done under controlled conditions. So the target is to develop new fiber-based batteries which can be integrated in smart textile systems an emerging and growing market field that attracts likewise the electronic and textile world. In our research we focused on a three layer set up consisting of conductive yarns as electrodes. In between them a gel like layer was positioned. As the electrode yarns were placed in a parallel manner next to each other, the influence of varying distances between the electrode yarns was investigated. For this reason; voltage and current values were measured for different resistance values. The characterization was done with the help of these measurements.

Materials and methods

Materials

As electrodes:

- Silver coated yarns; Twist per inch = 4.5; Syscom Advanced Materials inc. [USA]
- Carbon yarn; SIGRAFIL C SBY 70; SGL Group [Germany]; this is a Stretch-broken carbon yarn.

These yarns were used. As electrolyte, KI (Potassium Iodide) and gelatin (Dr. Oetker GmbH) were mixed together during the preparation of gelatin. The temperature needs for gelatin preparation in around 80^0c and stirring was done on a magnetic stirrer.

Methods

Anode and cathode preparation: As electrode materials, two conductive yarns were used. Silver coated yarns used as cathode while a carbon containing yarn served as anode.

As depicted in Figure 1, both electrode yarns were sewn in a parallel manner to each other. The distance between the parallel electrode yarns was varied between 2 to 10 mm. The length of each sewing line was 10 cm.

Electrolyte

To prepare the electrolyte, 9g of gelatin was prepared in a beaker with 180 ml of water. 0.9 M of potassium iodide (KI) is needed. The mixture was kept on a magnetic stirrer with high temperature (around 80^0C) for about 25 minutes. At first, the color of that solution was orange. As the time passed by it became white in color. After preparation of electrolyte, the solution was poured onto a plastic sample box in which the sample yarns were already fixed parallel by varying distances.

Current and voltage measurements

Figure 2 and 3 are the schematic circuit design and complete set up with sample to determine voltage and other values necessary. According to this schematic design, sample's positive pole is connected directly with ammeter [MASTECH]. Resistance and voltmeter [VOLTCRAFT] should be connected in a parallel connection which will connect the sample and ammeter to complete the circuit.

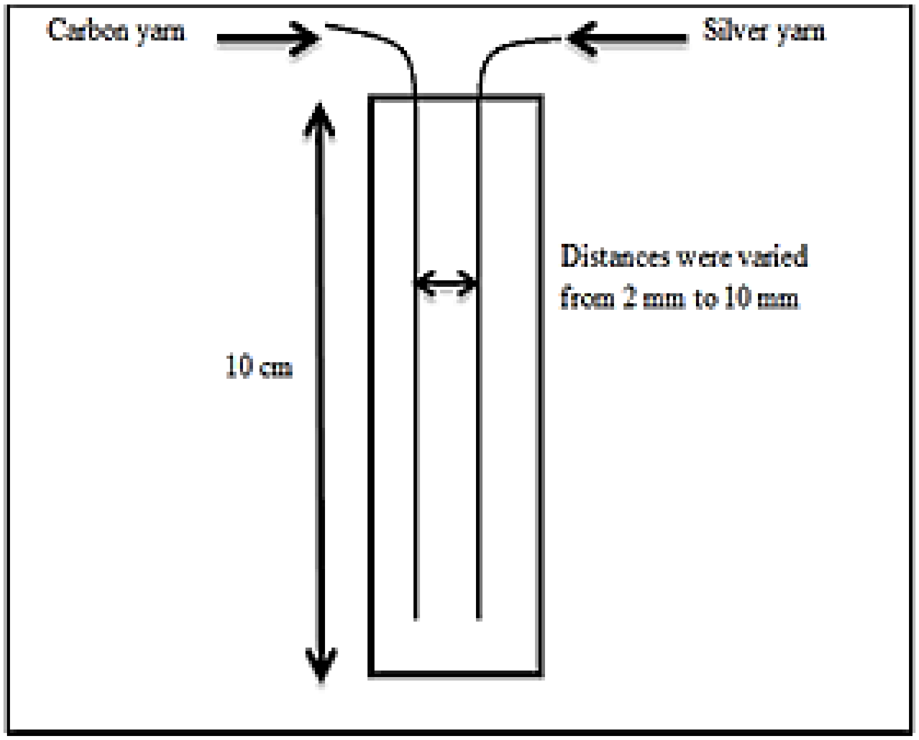


Figure 1: Scheme of sample set-up: carbon and silver-coated yarn in a plastic sample box

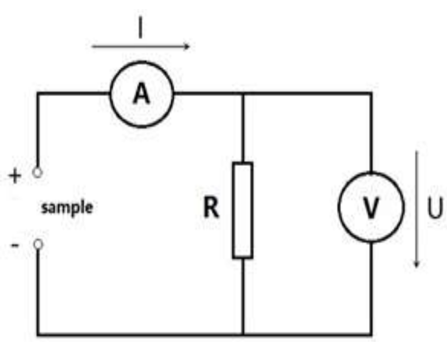


Figure 2. Schematic design of circuit

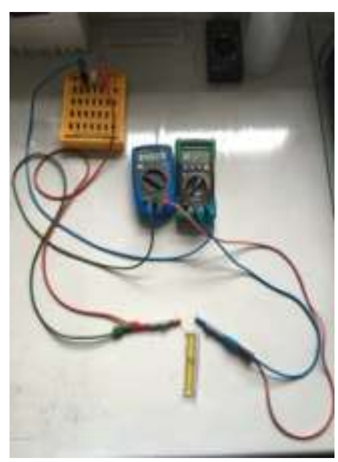


Figure 3. Connected circuit with sample for measure-

From the resistance box one higher resistance of 100 kohm (100000 ohms) and a lower resistance of 100 ohms were selected. Also the samples have the different distances between electrodes to check the characteristics. Only voltage values were measured for each sample. Each and every sample was used only one time. When the voltage values started dropping, the stopwatch was started. Every sample was measured for 300 seconds (5 minutes). The resistances were changed for each and every sample. Subsequently, current, charge and internal resistances were calculated.

Formulas for calculations

1. V = IR…….. (1)
2. I = V/R ……… (2)
3. Q = I.t……… (3)
4. Ri = (E-IR)/I … (4)

E = electromotive force in volts (V); I = current in amperes (A); R = resistance of the load in the circuit in ohms; Ri = internal resistance of the cell in ohms,

Results and discussion

The distance between electrodes was varied from 2 mm to 10 mm to monitor the effect on those battery characteristics. Only a higher resistance of 100 kohm and a lower resistance of 100 ohm were used to see the effect of resistances on battery performance. From the values of measured voltages, currents, charges, internal resistances were calculated. In Figure 4, the samples with all 5 distances showed similar characteristics. Samples connected with lower resistances showed far better charge than the samples with higher resistances. With the increasing time voltage values were dropped. Means the current flow was also dropping with time according to Ohm's law. Here voltage is proportional to current. According to current, charge and time relationship [Q = I.t], charge is proportional to time. So it can be said while the voltage and current flow were dropping with the time, charge values should be increased. The charge values were increased with the time. So it went in line with battery mechanism.

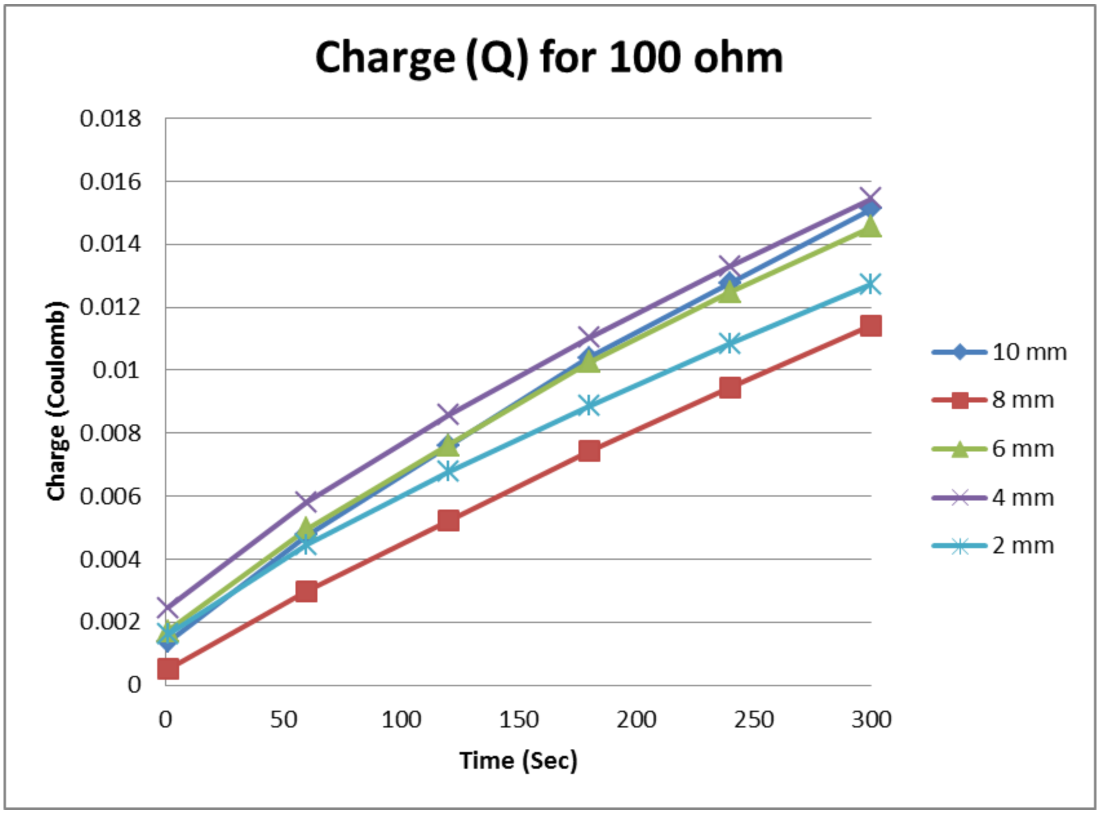
According to figure 5, internal resistances were higher for lower resistance and vice versa. According to battery basic mechanism, the internal resistance should be lower with lower current. The basic equation is

Ri = (E-IR)/I … … (1)

E = electromotive force in volts, V; I = current in amperes, A; R = resistance of the load in the circuit in ohms; Ri = internal resistance of the cell in ohms

From the above equation, internal resistance is inversely proportional to resistance and current. The values showed that with the increasing time, internal resistances were increased. That means for higher resistance, current flow was lower and internal resistance was also lower comparing with lower resistance Ri value. The reason is higher resistance restrict the current flow than lower resistance and as the time passed by naturally internal resistance supposed to increase. The battery heats up with current flow which makes the internal impedance to increase. A battery with low internal resistance delivers high current on demand. High resistance causes the battery voltage to drop.

Generally the internal resistance will rise during discharge due to the active materials within the battery being used. However, the rate of change is not consistent. We assume that battery chemistry, depth of discharge, drain rate and the age of the battery can all impact internal resistance during discharge.



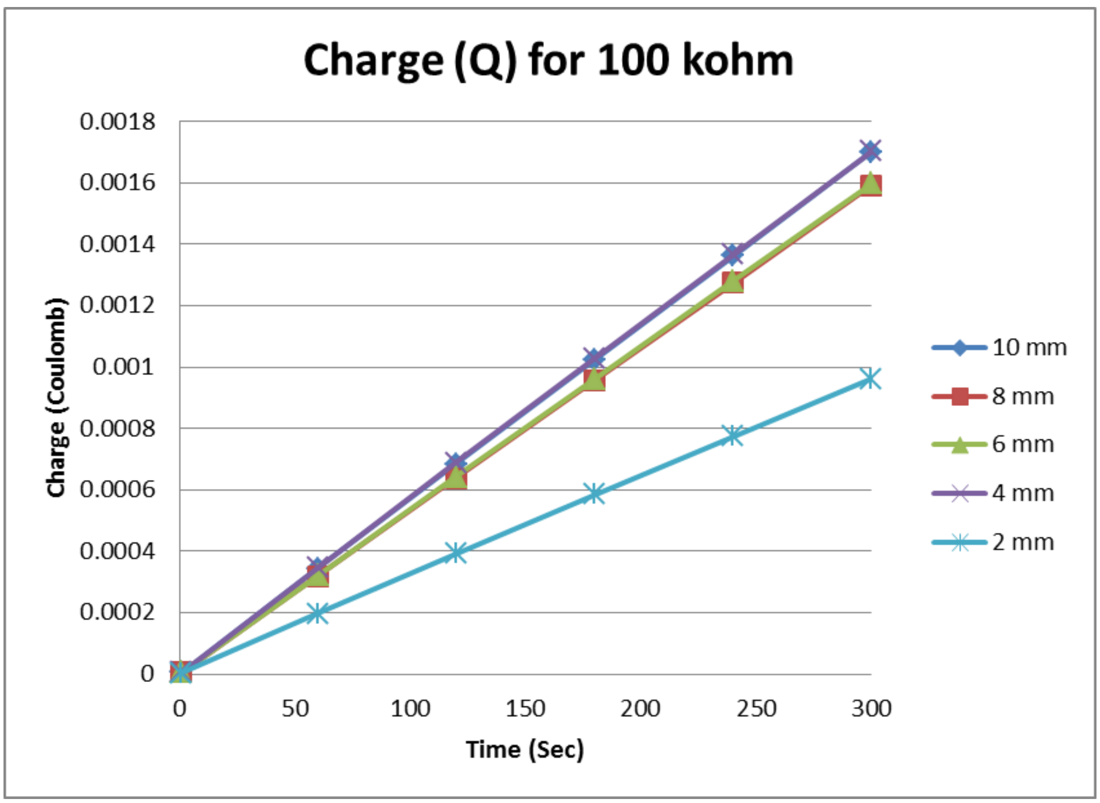


Figure 4. Charge (Q) vs. Time for 2 mm to 10 mm distance between electrodes

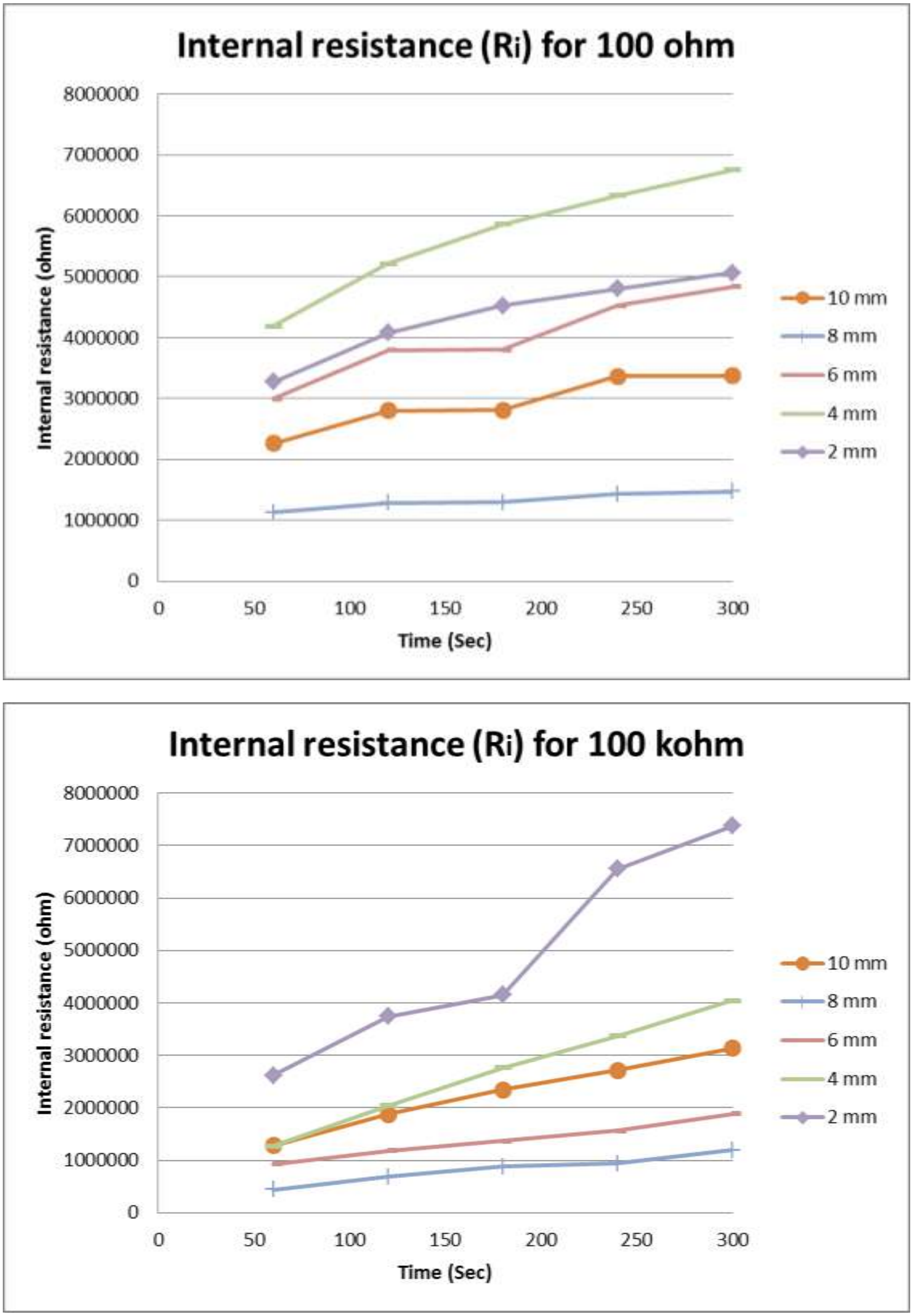


Figure 5. Internal resistance vs. Time for 2 mm to 10 mm distance between electrodes

Considering basic battery mechanism, shorter distance should be better in case of electron transfer. Bigger distance might not show good battery performance in this type of battery. In case of maximum charge (Qmax) showed by the samples [Figure 4], distances did not create any influence that much. For internal resistance (Ri) [Figure 6] there is something can be drawn out. With the increasing distance the Ri dropped. That means if the distance is bigger Ri will drop, because the flow of current drops.

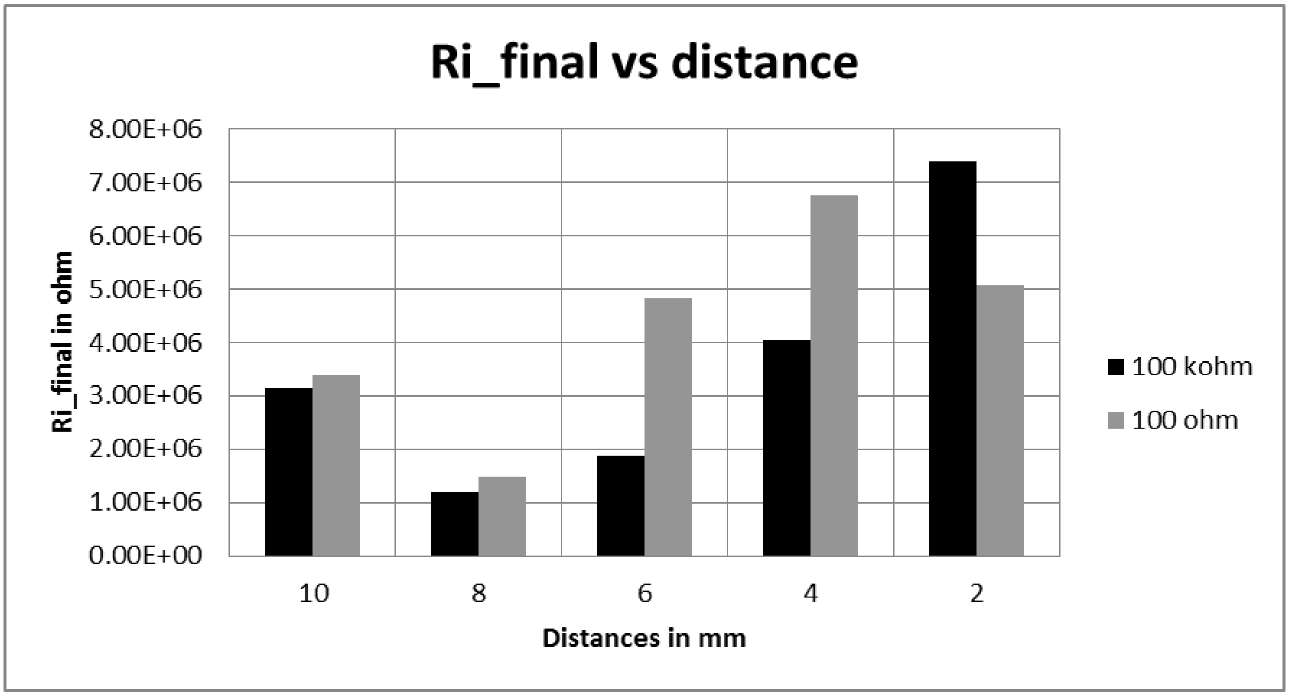


Figure 6. Final internal resistances vs. distances between electrodes

According to battery mechanism, if the resistance is higher, then the current flow will be lower and Ri will also be lower as the voltage would be lower as well. Ri is always lower with lower current for connection with higher resistances. But with the increasing time it can increase. So it is clear that current is proportional to internal resistance if connected with higher or lower resistances. For lower resistance, internal resistance (Ri) is higher comparing with connection with higher resistances.

As there must be some chemical reactions were taking place between KI and silver and carbon, the characteristics of battery samples varied a lot. Because in this case carbon is negative and silver is positive. Which means silver is cathode and carbon is anode. Most probably the carbon and potassium (K) are not taking part in any kind of reaction and silver and iodine is doing the reactions needed. The battery reactions are like oxidation and reduction. First oxidation starts to supply the electrons which will be reduced and take part in reaction with solution of KI. In this research work from carbon most probably loosing electrons which means oxidizing and electrons are going to positive side of silver where those are gained by the ions in water or solution in a process called reduction. Thus voltage is building up. Any battery has finite supply of material. Once most of its electrons are oxidized the battery dies. In this research work, the samples just oxidized and loosing electrons from one side and after some time it became totally discharged because the electrons were not available for more oxidation. Oxidation and reduction happened very quickly here due to very small amount of surface on yarns acting as electrodes. If the conductive chemicals were more, then it might take more time to discharge. However, the results were promising to get better battery efficiency. If electrons can be flown back in opposite direction, (like first reduction and then oxidation) it can be recharged by application of electricity which would make more electrons available for oxidation.

Conclusions

In this paper, the development process of a new yarn-based textile battery is described. Gelatin can be used with Potassium Iodide (KI) as an electrolyte because of its capability of holding the semi-solid form of gel. As soon as the battery started discharging, charge (Q) and internal resistance (Ri) continued to increase with lower resistance (R) and the current flow was higher accordingly, which follows the basic mechanism of a battery.

Each and every sample of those yarn-based batteries could be used one time only with one type of resistance. The characteristics were different with different resistances. Due to chemical reactions, shorter distances between electrodes showed better performances than bigger distances while considering the internal resistance values. For maximum charge, distances showed mixed up characteristics. All the characteristics of this type of batteries depend on several factors like: battery chemistry, depth of discharge, drain rate and the age of the battery. These can all impact internal resistance and charge during discharge. Instead of carbon and silver yarns other different conductive coated yarns could be used as electrodes. The temperature needs to be lower in order to get better battery efficiency; otherwise, it would be difficult to hold the gel-like form of gelatin and the transfer of electrons would be hampered. In conclusion it can be said that, this type of yarn-based battery could be used as a power source for wearable electronics and other purposes.

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