جمهورية مصر العربية
وزارة التربية والتعليم

Grade 10
2nd Semester

Industrialized!

Group 109

Keywords: Industry, Wasted Energy, Heat Energy, Wearable Generators, Triboelectric Effect, Seebeck Effect.

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STEM School for Boys 6 of Oct. Egypt

Abstract

Given the current situation that Egypt is currently confronted by, where it hopes to use the less pollutant, more economical alternative energy, a solution has been put into quest. This solution hopes to suffice Egypt's use of energy as well as help eliminate the consequences of energy deficiency, including the grand challenges: increased pollution, decreased recycling, and public health problems. The purpose of the study is to construct a solution that recycles wasted aluminum and harnesses unexploited heat and mechanical energy, impeding the problem. Moreover, the prototypes meet the design requirement, the highest efficiency with the lowest possible cost, where the testing results are satisfactory. They have also broadened the project's vision even more, ensuring some major findings. For instance, it has been found that heat energy is very advantageous to exploit, and so are a number of wasted materials. In brief, this project is granting Egypt the opportunity to reduce the impacts of many grand challenges, most importantly, energy deficiency. In the following sections, all of the above will be more elaborate.

Introduction

It is known that Egypt, as a developing country, is struggling to solve a variety of grand challenges, including overpopulation, pollution, recycling, and public health problems. All of the previous challenges are related to the specific grand challenge aimed to be solved this semester, which is the lack of energy resources, as seen in Figure 1. The later challenge is divided into two specific problems to be solved, which are wasted energy forms, and wasted materials. Wasted energy is the result of a process that outcomes two or more forms of energy, a primary form (used form), and a secondary one (unused form). On the other hand, wasted materials have the potential to be used, producing valuable energy. Figure 2 shows the amount of MSW produced by each governorate daily.

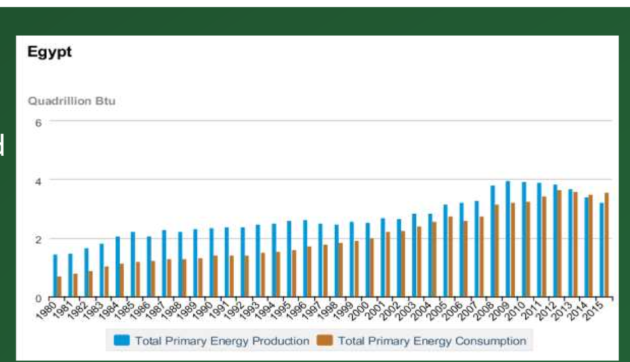

Figure 1 Energy production and consumption values

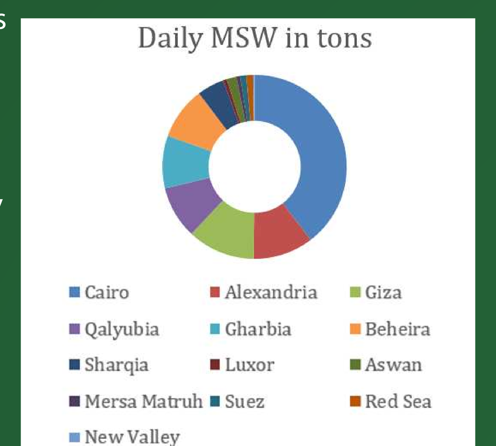

Figure 2 Daily municipal solid waste for each governorate

Accordingly, several attempts have been made in order to solve these problems, e.g., Hong Kong built a facility that treats sludge. It did not only provide the country with energy from a harmful material, but it also helped decrease the pollution rate in the country by the disposal of sludge, which led to improvements in public health as well. Another prior solution was featured by KSA, where it constructed a wasted material recovery facility generating energy. The facility helped decrease the amount of waste in KSA by 24.2% and saved energy equal to 10000 TJ. The negative side of the facility that it emits harmful gases from materials such as plastic.

The chosen solution tries to solve the problem further, with its design requirement being to achieve the highest efficiency with the lowest possible cost. Testing the prototypes involves testing the output power using a Multimeter and dividing it by the input power. For the design requirement to be met, numerous trials have taken place and the most efficient of them were chosen. First, heat energy from industrial machines is harvested using a Thermoelectric Cooler (TEC), which uses the difference in temperature to generate electric current. Second, wasted mechanical energy of workers in factories is harvested using a triboelectric nanogenerator (TENG). Last, wasted aluminum is used to generate electricity in an aluminum-air fuel cell. The result of the aforementioned solutions is a more well-developed ecosystem in industrial cities that does not waste energy. Together, these solutions frame the end of the mentioned problems. In the next section, the materials and methods used to construct this project are discussed.

Materials and Methods

Materials

Materials	Description	Illustration
Thermoelectric cooler (3 pieces)	A device that produces energy from tempertature difference.	
Ammonium chloride (500g)	Added to water causing an endothermic reaction.	
Water faucet (1 piece)	½ inch water faucet.	
T-connector (1 piece)	1 to ½ inch t-connector.	
pipe (3 ½ meter pieces)	2 1-inch pipes with one with a whole and a ½ inch pipe.	
Stainless steel container (1 piece)	A container with a whole made in one upper side.	
Hose (1 piece)	Connects the pipe and the container.	
Pipe elbow (1 piece)	½ to ½ water elbow.	
Silicone rubber / PDMS (1 pack)	A heat conducting adhesive.	

Table 1 Thermoelectric generator materials.

Materials	Description	Illustration
Silicone rubber / PDMS (5 g)	An adhesive, biocompatible electron acceptor.	
Sand paper (3.5 x 5 cm)	A rough surface used to make pores in the PDMS film.	
Copper foil (3.5 x 5 cm)	Used as an electrode.	
Elbow pad (1 piece)	Used to attach the TENG on the elbow.	

Table 2 Triboelectric generator materials.

Materials	Description	Illustration
Wasted aluminum foil (10 × 12 cm)	Collected from junkyards and cleaned.	
Activated carbon (30 g)	Used for filtration.	
Metal mesh (10 × 12 cm)	A net-like metallic wires.	
Epoxy (7 g)	Super adhesive.	
Filtering paper (10 × 12 cm)	Used for filtration.	
Pottasium hyrdoxide (KOH) (20 g)	Used as an electrolyte.	

Table 3 Aluminum air battery materials.

Methods

Triboelectric Generator:

1. Silicone rubber/PDMS is uniformly casted on sandpaper.
2. The PDMS is pressed hard to flatten it .
3. The film is left to cure for 4 hours.
4. The film is peeled off the sandpaper.
5. A cut of dimensions 5 * 3.5 is taken from the thin layer.
6. An identical cut of copper is made.
7. The two are glued together with silicone rubber.
8. A wire is attached at the copper electrode.
9. The nanogenerator is attached to the elbow pad at above the elbow.Steps are shown in Figure 3.

Figure 3 Steps of the TENG construction

Thermoelectric Generator:

Preparing the container:

1. A hole is made in the container.
2. The 3 TECs are glued to the lower part of the container using the thermally conductive glue. The container is shown in Figure 4.


Figure 4 The container used with 3 TECs attached

Preparing the pipe system:

3. A divergence from a water disposal system is made
4. A water faucet is fixed at the end of the divergent pipe in order to regulate the flow
5. A hole is made in the lower main pipe

Connecting

6. Below the faucet, the metallic container is put
7. The container and the lower main pipe are connected using a hose

Aluminum-Air fuel cell:

Formation of the solution:

1. About 200 ml of water is poured into a beaker.
2. Ten percent of water mass (20 g) is poured as KOH.
3. The solution is stirred with glass rod, then it is left until its temperature declines to about 30°C .

Air-Cathode construction:

4. Epoxy is distributed well above stainless steel, then activated carbon is scattered on the stainless steel.

Assembling:

5. The aluminum foil is sandwiched between two filtering papers and two carbon cathodes on both sides, with the dimensions of each being 10 cm × 12 cm.

Submersion:

6. The assemblage is then submerged in the electrolyte. Steps are shown in Figure 5.


Figure 5 Steps of the Aluminum-Air fuel cell

Test plan

Triboelectric Generator:

1. The device is worn on the elbow, as shown in Figure 6.
2. Continuous motion of the elbow is made at a constant rate.
3. Output voltage and ampere is measured, calculating power using the relation $W = VI$, where W is the power in watt, V is the voltage and I is the current intensity.
4. A relation between the rate at which the elbow moves and the output power is made.


Figure 6 Testing the TENG

Thermoelectric Generator:

1. With the container containing water, it is put on a heater at a known temperature.
2. Add ammonium chloride to the water.
3. Measure the temperature of the water, calculating the difference.
4. Measure and calculate the output power.
5. A relation between the difference in temperature and the output power is made.

Aluminum-Air fuel cell:

1. Immerse the fuel cell in the electrolyte.
2. Measure and calculate the output power (as shown in Figure 7).


Figure 7 Testing the Aluminum-Air fuel cell

For all prototypes the following is done:

Relate the cost of the prototype to the output power.

Results

Negative:

At first the aluminum-air fuel cell behaved unexpectedly when put in the electrolyte. We tried to investigate the reason behind this and we couldn't know the answer. At the end, we found out that the high concentration of KOH solution caused a reaction between the aluminum foil and the solution, which is illustrated in Equation 1.

$$2Al + 2KOH + 6H_2O = 2K[Al(OH)_4] + 3H_2$$

Equation 1 Reaction of Aluminum with Potassium hydroxide

Triboelectric generator:

Having performed the test plan on the prototype, the device produced an alternating electrical potential that reached 183 V (shown in Figure 8) when slapped hard on by hand. With the same method, the current intensity reached 100 µA, producing a power of 18.3 milliwatts. If installed in a factory of 750 workers, the output Furthermore, the cost of the generator is significantly low. The cost of the nanogenerator without the elbow pad is 0.75 L.E. only, making the power per cost unit 24 milliwatt/L.E.


Figure 8 The triboelectric generator producing 180 V

Testing using the prototype attached to the elbow pad produced less power (a voltage of 1.5 V). This is because of the less pressure caused by the human hand than caused by slapping. Storing such power in a power storage system such as a super capacitor could be highly beneficial because of the high alternating of the output. By doing so, one nanogenerator could power small devices or sensors making it advantageous in emergencies.

Thermoelectric cooler:

After the test plan, the test was performed on one TEC, producing a voltage of 3.93 V (shown in Figure 9) and 0.075 A, with a power output of 294 milliwatts. The conditions of these tests were a cold side of 15°C and a hot side of 105 ° C, with a temperature difference of 90°C. The cost of thermoelectric cooler is 240 L.E. Knowing that connected in series the voltage adds, the output of the three TECs is 891 milliwatts, making the power per cost unit 3.7 milliwatt/L.E.


Figure 9 Each thermoelectric cooler producing 3.93 V

Aluminum-Air fuel cell:

Having recorded the results of the test plan, 0.9 V and 0.029 A was generated, making the power output 26 milliwatts. The cost of a single fuel-cell is 2.88 L.E., making the power per cost unit 9 milliwatts/L.E.

The different results for the three prototypes are shown in Table 4.

Prototype	Voltage (V)	Current intesity	Power (W)
Triboelectric	180 V ±10	100 µA ± 2	18.3 mW
Thermoelectric cooler	11.79 V ±2	75 mA ± 2	884 mW
Aluminum-Air fuel cell	0.9 V ±2	0.029 A ± 2	26 mW

Table 4 The results for the three prototypes

Analysis

As affirmed in the results section, the project has achieved its design requirement, producing power that is usable and highly helpful in its adoption-site.

Triboelectric Nanogenerator:

The nanogenerator consists of the electron acceptor (polydimethylsiloxane [PDMS]) and an electrode (copper [Cu]). When the human skin comes into contact with the PDMS, the human skin loses electrons, and the PDMS accepts them, creating a potential difference. This is due to the materials (human skin and PDMS) being far apart in the triboelectric series. The mechanism behind electric generation is as follows: When a pressure force is applied on the device by hand, the PDMS film fully contacts with the surface of skin. The produced triboelectric charges with opposite polarities are fully balanced, so that no electron flows in the external circuit. Once the pressure force is removed, the porous thin film starts to separate from the skin and the interacting surfaces have opposite triboelectric charges. The negative charges on the surface of PDMS film induce positive charges on Cu electrode; thus, free electrons flow from Cu electrode to the ground, which leads to producing an output current signal. When the PDMS film continues to completely separate from the skin, the device will reach a charge equilibrium state. As the PDMS film moves toward human skin again, the electrons start to move back toward Cu electrode, resulting in a reversed output current signal. When the PDMS film and human skin overlap again, the electric potential will return to the original status. The above cycle is illustrated in Figure 10.

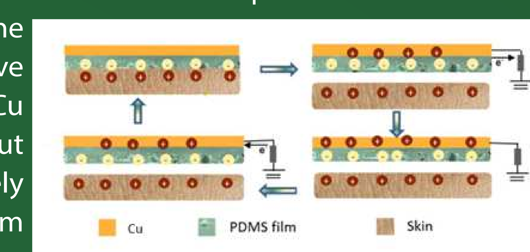

Figure 10 Charge cycle

The reason behind pressing the mixture against the sandpaper is the increasing in roughness, resulting in more friction between the film and the skin. A SEM image is shown in Figure 11, revealing its uniform microstructured rough surface.

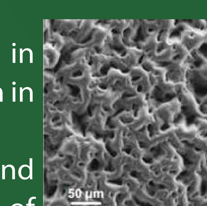
Figure 11 A SEM of PDMS film

This nanogenerator is intended to harness the mechanical energy of workers in factories and other working sites. With a number that reaches 750 worker per factory, the amount of generated electricity could be significantly high reaching 13 watts per factory per movement.

Aluminum-Air fuel cell:

The cell consists of an aluminum anode, an air cathode, and a KOH(aq.) electrolyte. The aluminum anode has an oxidation potential of 1.66. Therefore, it reacts with hydroxide ions, producing aluminum hydroxide and releasing electrons, which flow through an external circuit to the cathode. In the cathode, oxygen and water react receiving the electrons flew, synthesizing hydroxide ions, which return back to the anode through the electrolyte and restart the reaction. Equation 2, Equation 3, and Equation 4 (3 & 4 being the half-reactions) illustrate all the redox chemical reactions occurring in the Al-Air cell, where chemistry especially Electro-Chemistry helps in understanding.

$$4Al + 3O_2 + 6H_2O \rightarrow 4Al(OH)_3$$

Equation 2 The overall reaction occurring in the cell

$$Al + 3OH^- \rightarrow Al(OH)_3 + 3e^-$$

Equation 3 The chemical reaction happening in the anode

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

Equation 4 The chemical reaction happening in the cathode

Regarding the components of the fuel cell (shown in Figure 12), the first layer, which consists of metal mesh with activated carbon glued on using epoxy. It acts as a current collector and the site of the oxygen-water reaction. The second layer consists of a filtering paper that permits hydroxide ions to move from the cathode to the anode. The third layer consists of aluminum foil that acts as the anode, reacting with hydroxide ions forming aluminum hydroxide and electrons move through an external circuit, with the cycle repeating. The theoretical cell voltage, which was estimated to be 1.2 volts, could not be achieved due to the absence of the standard conditions (which are 1 atm, 25°C, and one molar solution, as we learned in Chemistry). Instead, the cell voltage mentioned in the results section was achieved.

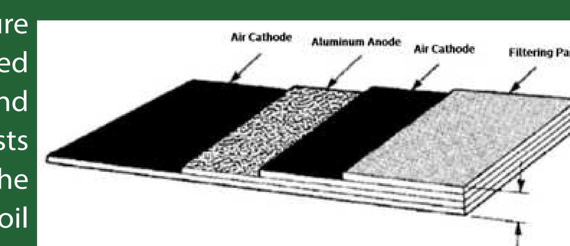

Figure 12 Layers of the Aluminum-Air fuel cell

Thermoelectric cooler:

Thermoelectric cooler (shown in Figure 13) is based on converting the difference in temperature between its two sides into electricity through a phenomenon called Seebeck effect. Seebeck effect states that when heat is applied to one of the two sides, excited electrons (because of heat) flow toward the cooler side. If the pair is connected through an electrical circuit, direct current (DC) flows through that circuit. The device consists of a cool side, a hot side, and a semi-conductor couple (P-N type). An example of a semiconductor couple can be Antimony (N type) and boron (P type) added to silicon (shown in Figure 14). Since boron has 3 valence electrons in its outermost level, it will form three covalent bonds with silicon leaving a hole (an unmade bond) with a fourth boron atom. Antimony has 5 valence electrons, that are formed four covalent bonds with silicon, leaving one electron. When N and P type are combined it creates what is called PN junction. When heat is applied electrons migrate from N to P type through an external load.

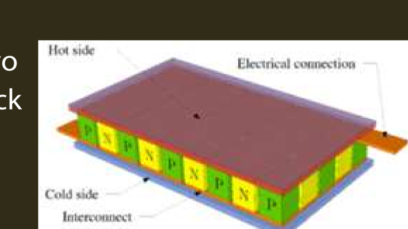

Figure 13 The arrangement of the TEC

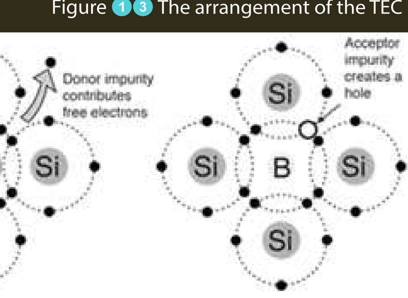

Figure 14 Thermo-Couple lewis structure

The more difference in temperature gradient, the more voltage is created. So, inspired by Chemistry, an endothermic reaction that would make a side of TEC cooler was used, which is $NH_4Cl + H_2O \rightarrow NH_4^+ + Cl^- + H_2O$. The reaction of ammonium chloride with water will occur in a container which is connected to a pipe that fitch water from an external source. TEC is stacked on the outer side of the container with heat applied to the hot side. The water is disposed to the outside the container through a pipe to the disposal system. Furthermore, according to the equation studied in Physics through fluids, Bernoulli's equation, when water flows from low level to high level with constant area of pipe its velocity will decrease, so we made the container on a higher level than the pipe make the water take much time to react completely with ammonium chloride.

Meeting design requirement:

The prototypes clearly show how the design requirement was met, being highly efficient, highly usable, and highly advantageous. With each having a high efficiency as stated in the design requirement, the prototypes help solve the problems to be solved, and thus contribute to the diminishing of the related grand challenges. They also evidently help industrial cities recover several forms of wasted energy (mechanical and heat), in addition to a major wasted material (aluminum).

Conclusion

According to all the required scientific analyses, reasoning, and tests that have taken place, the results show that the project have successfully fulfilled its design requirement and that it is implementable in real life. They also show that the project is capable of solving the problem to be solved, and thus, help eliminate the related grand challenges.

Recommendations

Liquid-Metal electrode:

Using a liquid-metal electrode may significantly enhance the stretchability and, consequently, usability of the triboelectric generator (illustrated in Figure 15). This type of electrode exhibits stretchability that reaches 300%, owing to the flexibility of the liquid metal and silicon rubber. Galinstan, which is an alloy of indium, tin, and gallium, can serve as the electrode (the liquid metal). The obstacle hindering its usage is the scarcity of the component elements in Egypt, resulting in a high price.

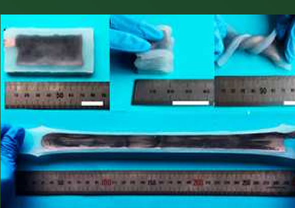
Figure 15 Liquid-Metal electrode stertchability

Triboelectric generators in car wheels:

Another deployable place for a triboelectric generator is a car wheel, as demonstrated in Figure 16. This usage offers a unique capability for scavenging the otherwise-wasted friction energy between a rolling wheel and the ground. By increasing the number of TENGs on the wheel surface, the number of induced charges can be effectively increased, and thus improve the electric output power.


Figure 16 TENGs put on car wheels

Thermoelectric generators:

Instead of using TECs, which are directed towards the usage as a peltier (cooler), TEGs (exemplified in Figure 17) produce the same effect when a difference in temperature exists on both of its sides (the Seebeck Effect), but TEGs can withstand higher temperature on the hot side. Therefore, using them can in hot places can result in a higher power produced.


Figure 17 A TEG

Porous Na_2CO_3:

Mixing PDMS with sodium carbonate and then using an ultrasonic cleaner to break down the sodium carbonate could significantly increase the efficiency of the TENG. The reason behind this is that it would make the PDMS film porous so it would hog more electrons, making it transfer more electrons on one push (shown in Figure 18). They also make the material more hydrophobic, increasing its usage sites. The downside of implementing such film was the unavailability of the ultrasonic cleaner and other conditions required for its application.

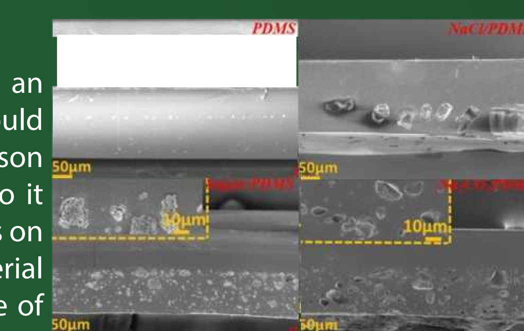

Figure 18 A SEM of PDMS, NaCl/PDMS, Sugar/PDMS, and Na2CO3/PDMS.

Hydrophobic Insulating materials:

In order to increase the usability of TENG attached to the skin, a hydrophobic insulating material is in urgent need. Sweat secreted by the skin could hinder the function of the TENG or possibly decrease its efficiency. Figure 19 shows an example of a hydrophobic material. This material should also be biocompatible for it will be in constant contact with the human skin. It should not interfere with the function of the PDMS layer (becomes an electrical insulator).


Figure 19 A drop of water over a hydrophobic material

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Acknowledgements

After we finished our project, we would like to thank all people who helped us, including Eng. Ahmad Towfeq (Capstone supervisor), Mrs. Doaa Ragab (English teacher), and Mrs. Hanan Mahmoud (chemistry teacher). Special thanks to Professor Zhen Wen whom we have contacted regularly and who has helped us a lot understanding his work.

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