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DESIGN AND CONSTRUCTION OF A CAR AUTOMATED BY CHEMICAL PROCESSES

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ABSTRACT

The need for affordable and efficient alternative energy sources is a defining issue of the twenty-first century that is receiving growing attention from both the scientific community and the public. While hydrocarbons have driven a majority of the world's energy consumption for over a century, such sources are both unsustainable and environmentally detrimental. Hence, this research has been carried out to focus on the use of chemical processes to control a vehicle known as MODEL C, which was developed and modelled using a 3D computer graphics software called BLENDER, without the use of any form of internal combustion engine fuel in order to eradicate any form of hazardous emission. MODEL C is a chemical engineering car that is powered by chemical reactions. The car design is composed of separate processes for starting and stopping. The energy to move the car was taken from the sealed lead acid battery which consisted of two plates, viz. lead peroxide for the positive and sponge lead for the negative of which both plates were immersed in an electrolyte (sulphuric acid) for the conversion of chemical energy into electrical power. An iodine clock reaction was used in conjunction with a light dependent resistor (LDR) and a circuit board to stop the car after the reaction was going to completion. In this case, the iodine and the potassium iodide formed a complex with the starch solution that turned it black after a certain amount of time. This was based on the concentration of sodium thiosulphate that allowed the manipulation of how far the vehicle could travel at constant velocity.

Keywords: Chem-E-Car, model C, chemical, power source, lead-acid, iodine-clock, battery, circuit.

1. INTRODUCTION

Transportation systems are structured and designed to withstand all types of weather and climate change. This is the reason why transportation engineers refer to historical records of climate and extreme weather conditions when designing transportation structures such as ports, airports, railway tracks, bridges and roads to withstand severe weather conditions [1].

Nigeria's total greenhouse gas emissions (GHG) in 2014 were 492.44 million metric tons of carbon dioxide equivalent ($MtCO_2e$), totaling 1.01 percent of global GHG emissions. In Nigeria, 38.2 percent of GHG emissions came from the land-use change and forestry sector, followed by the energy, waste, agriculture and the industrial processes sector which contributed 32.6, 14.0, 13.0 and 2.1 percent respectively to GHG emissions [2]. According to CAIT data (a suite of online data and visualizations tools that support the many dimensions of climate policy making and provides free, open and user-friendly access to world-class climate data), Nigeria's GHG emissions increased by 25 percent from 1990 to 2014. The average annual change in total emissions was 1 percent. In its Intended Nationally Determined Contribution (INDC), Nigeria pledged to unconditionally reduce GHG emissions by 20 percent by 2030, compared to business as usual (BAU) emission levels. It aims to achieve this goal by improving energy efficiency by 20 percent, providing 13 GW of renewable electricity to rural communities that are currently not connected to the electric power grid, and by ending the flaring of gas [3].

In light of the recent movement towards reducing fossil fuel consumption, the need for a suitable alternative energy source is greater than ever. To explore the utility of household products as unconventional yet efficient energy sources, a car powered entirely by chemical reactions was built. A shoebox-sized car was then built with both the battery and the stopping mechanism implemented and tested. The iodine clock reaction was also found to follow a first-order law, with a reaction time linearly proportional to the concentration of iodine. Although the battery (lead-acid battery) and iodine clock were implemented to power only a shoebox-sized car, the scale-up of similar and widely available materials could mean a future of globally accessible transportation [1].

Thus, it is clear that the world needs to find a feasible alternative. While substantial advances in alternative energy have recently been made in the automobile industry, current alternative energy sources for powering vehicles are either expensive or not widely accessible to all. Ethanol fuels, for example, are not practical because they provide low mileage per gallon and require a large number of organic materials and land to produce. Currently, hydrogen fuel cars are very expensive and often require high running temperatures, which are reducing their longevity and efficacy. Besides, hydrogen fuel is difficult to safely transport for mass distribution because it needs to be compressed and purified. Because of the public inaccessibility to many "green" technologies, the future depends on developing a less demanding way to encourage the use of alternative energy in vehicles [4]. This has led to proposing the design and construction of a vehicle type known as Chem-E-Car in this work.

Chem-E-Car is a designed and constructed prototype car powered by chemical reactions. The car needs to travel a particular distance and has to carry a certain amount of weight. The three main aspects of the design are the mechanism of power source, stopping mechanism, and aerodynamic behaviour. These aspects involve chemical engineering optimization, which can be obtained from data research [5].

The most common design mechanisms for a chemical engineering car involve galvanic/voltaic cells, built-up pressure, and fuel cell technology. The galvanic/voltaic cell utilizes electrochemical reaction to produce electricity. This electric current is transferred to an electric motor to run the car. The fuel cell technology meanwhile utilizes the reaction between hydrogen and oxygen to produce electricity to run the car. The built-up pressure concept uses gas products obtained from a chemical reaction. The produced gas increases the pressure that can be converted using a pneumatic actuator to move the car's wheels. Each power source mechanism mentioned has advantages and disadvantages. For example, the power source obtained from the built-up pressure concept is the most powerful, but because it requires high pressure, the reaction tank must have a thick shell. This would affect the production cost as well as the safety and total weight of the car. It might not be efficient to run a car with a heavy load. Whereas for the stopping mechanism, an iodine clock is a reaction commonly used in Chem-E-Car development. The car will stop moving when the solution turns dark due to the iodine reaction that subsequently cuts off the electrical circuit through a photosensor. Other stopping mechanisms include sodium thiosulphate clock reaction, elephant toothpaste reaction, galvanic cell timing reaction, hydrogen peroxide clock reaction amongst others [6].

Even though past researches on the subject matter are scarce, the literature has revealed that Barnhill *et al.* [7] carried out the design and construction of a small-scale vehicle that was powered by a set of thermoelectric generators utilizing a heat gradient between boiling water and an ethanol-dry ice mixture [8]. In the work, an iodine clock reaction was used in conjunction with photoresistors and an Arduino microcontroller to stop the car after the reaction goes to completion.

As it is known, our society is faced with challenges such as energy, water, health care, transportation and others that are very crucial for the sustainability of our planet. Chemical Engineers learn principles that help us provide innovative solutions to solve some of these challenges so that we can look forward to having a better future. Going forward, this research has been carried out to demonstrate the application of chemical engineering principles to real-world problems and, in this case, the development of a vehicle automated by chemical processes.

2. METHODOLOGY

This methodology used for the development of the Chem-E-Car in this work involved three sections, viz. Mechanical Section, Electrical Section and Chemical Section.

2.1 Mechanical Section

In this section, the car design and materials involved in its mechanical production were described.

2.1.1 Car design

For this vehicle, since it is 'shoe-box sized' it would not be as big as a normal conventional car. The car was designed using two applications, namely blender and AutoCAD [9].

Blender

This is an open-source 3D computer graphics software toolset used for creating animated films, visual effects, art, 3D printed models, motion graphics, interactive 3D applications, and computer games. For this research, Blender was used to design a 3D model of the DC motor, chassis and the overall car.

Design process using Blender

It all started with a plane, which was then extruded (that is, to create objects of a fixed cross-sectional profile) upwards, after that, a rough measurement of the inner dimensions of the chassis was done. Then it was cut out using a loop tool, so that space could be made in between the plane after it had already been scaled to the exact size of the outer part of the chassis, and the inner measurement of the chassis was carried out. Those sides that have edges going upwards were extruded upwards. Then, from there, the middle point which just involved adding a new plane and joining the mesh together that was then mirrored to get the other half was made. Furthermore, the chassis was hidden to concentrate on the wheels. The wheel involved getting a picture of the wheel (the narrow side of the tyre) so that the exact way and thread of the wheel could be obtained. Thereafter, polylines were used to do them first in the z-axis. After that, screw modifier was used (i.e., it was used to create a helix-like shape) around the x-axis thereby forming the wheel. The same thing was done for the hub. The next thing was to make a hole in the tyre, which involved cutting, and then the bool tool was used to subtract a cylinder from the wheel hub to get those spaces in between. Then, the shaft of the wheel was just a cylinder that was smoothened out and subdivided. The 12V DC motor was also a cylinder that was subdivided to make it look cleaner and all those points where the wire came from using another bool tool were attached. This was added to a cylinder with space in between so that it would look like the wires were coming through from the inside. The other parts where the gear mechanisms of the motor were located in a flattened cylinder and a square were joined together. All the spaces in between it were also booled out using the bool modifier of triangles in a circular pattern. The wires involved using the bezier curve tool and adding a parent (the way the bezier curve should work), so it had to be parented to a circle which made it look like a tube and could be bent anyhow. The top of the chassis, which was a cube that was extruded and subdivided, cut through. The cylinders were attached using the bool tool to the cube. To get the lights, the top part of the cylinders had to be extruded in a circular pattern, and textures such as glass, emission, etc. were added. Everything else including the glass container, syringe, switch where all cylinders were extruded, subtracted, and scaled to my desired shape.

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DC motor

This is a 12V direct current motor which is used to propel the car when active (when in contact with electricity). This is attached to the back-right wheel of the chassis. See Figures 1 and 2.

Figure-1. 12V DC motor.

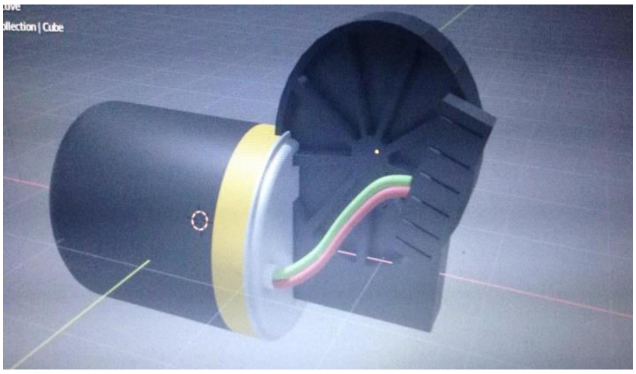

Figure-2. Blender model of 12V DC motor.

Chassis

This is the skeleton of a motor vehicle consisting of a steel frame that holds the body, motor, and wheels. For this research, the chassis had a dimension of approximately 35cm x 25cm. Each of the wheels has a radius of 10cm with a total diameter of 20cm. See Figures 3-4.

Figure-3. Car chassis after construction.

Figure-4. Blender model of chassis.

Overall car

After the chassis, the body of the car was made using a paper-board material. Cylindrical cans were used to elongate the light-emitting diode (LEDs), a glass vessel with an attached syringe was used for the chemical reaction, and an analog circuit board was used for the sensor reading. Figure-6 shows the blender models of the car.

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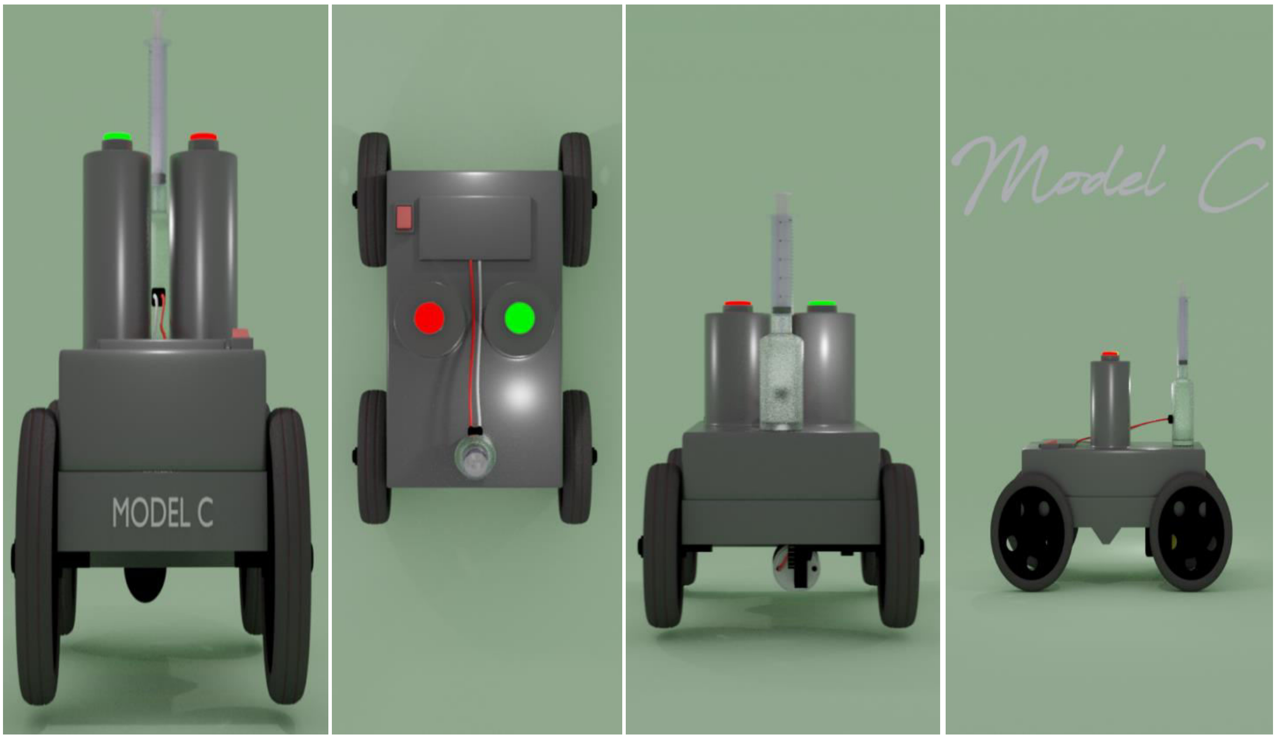

(a) (b) (c) (d)

Figure-5. Views of the car: (a) Front view, (b) Top view, (c) Back view, (d) Side view.

AutoCAD

This is a computer-aided design and drafting software application. For this research, it was used to design the chassis and the wheels. To design this, the blender model of the chassis was exported from the blender application to the AutoCAD application. See Figure-7.

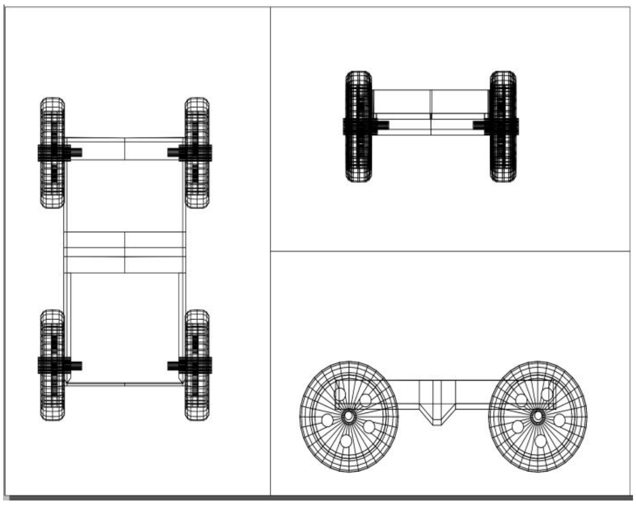

Figure-6. AutoCAD model of the chassis.

2.1.2 Materials

The materials used in the car production were as outlined thus:

1. Iron steel for car frame(chassis)
2. Rubber for the car wheels

Figure-7. Rubber wheels.

3. Black paint spray for body beautification
4. Paper-board for the car body

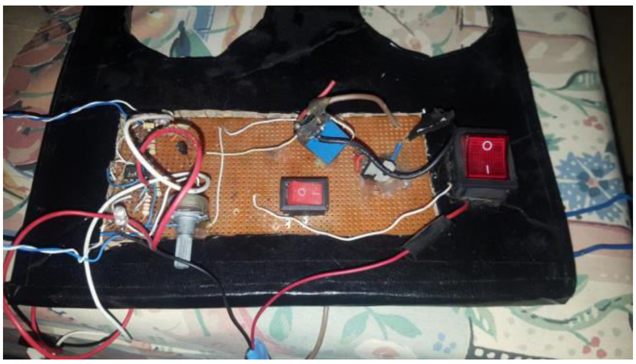

Figure-8. Circuit placement.

5. Paper Cylinders for LEDs

Figure-9. Cylinder showing the LED.

Figure-10. Model C.

2.2 Electrical Section

In this section, the circuit configuration will be looked at, and all the components needed to design the circuit for the overall circuit diagram will be seen. Here, the circuit acts as the 'brain' of the car and plays a vital role in the car's movement and helps in sensor reading.

2.2.1 What is a circuit?

This is an electrical device that provides a path for electrical current to flow. It is essential for maximizing voltage and current output. Three definitions that require an understanding of basic circuitry are as follows:

a) Voltage (V) is the measure of potential difference between two points, in volts (V)
b) Current (I) accounts for the amount of electrons that flow in the wire, in amperes (A)
c) Resistance (R) measures any hindrance of movement for the electrons, in ohms (Ω)

2.2.2 Circuit components

Vero Board

Vero board is a brand of stripboard, a pre-formed circuit board material of copper strips on an insulating board. For this research, it was used as a base to hold and assemble all the circuit components.

Soldering lead

This is a fusible metal alloy used to create a permanent bond between metal workpieces. For this research, it was used to join all the circuit components to the Vero board.

LDR

A photoresistor (or light-dependent resistor, LDR, or photo-conductive cell) is a light-controlled variable resistor. The resistance of a photoresistor decreases with increasing incident light intensity; in other words, it exhibits photo-conductivity. For this research, the LDR acted as a sensor to detect the colour change in iodine clock reaction box. When the reaction started as a clear liquid, the LDR sensed light that switched on the green LED, and when the reaction was complete and turned to a blue-black liquid, the LDR sensed darkness and switched on the red LED.

LED

A light-emitting diode (LED) is a two-lead semiconductor light source. It is a p–n junction diode, which emits light when activated. When a suitable voltage is applied to the leads, electrons can recombine with electron holes within the device, releasing energy in the form of photons.

For this research, two colours of LEDs were used, viz green and red. The green meant the LDR read light from the reaction vessel which made the car move while the red meant the LDR detected darkness from our reaction vessel which made the car stop.

1K Ohms Resistor

This was connected to the LED. For this research, it helped protect the LED from being burnt or fried up. It was also used to protect the circuit from a surge.

Variable resistor

A resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, divide voltages and bias active elements, and terminate transmission lines, among others.

For this research, it was used to control the amount of resistance that would be initiated on the LDR (Light-dependent resistor).

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10K Ohm Resistor

These are pull down and pull up resistors. The pull up is sent to the positive, while the pull-down is sent to the negative. For this research, it helped to protect the amount of voltage entering the system so that the integrated circuit would not get destroyed.

LM358

LM358 is a Dual Low Noise Operational Amplifier which has two Op-Amp in a single chip. This is a general-purpose Op Amp that can be configured in many modes like comparator, integrator, amplifier, differentiator, inverting mode, non-inverting mode, and many more. It is designed to operate from a single power supply over a wide range of voltage.

For this research, two LM358 Dual Comparator ICs were used for comparing voltages coming from variable resistor and LDR. Comparator IC1a was configured as non-inverting mode and 100 K potentiometer was connected at its inverting terminal and Comparator IC1b was configured as inverting mode from the output of 1C1a and 10k was connected at its non-inverting terminal to positive and negative lines. An LDR was used for detecting light or darkness concerning ground through the variable resistor.

One terminal of LDR and 10k resistor was directly connected to non-inverting terminal of IC1a and 100k potentiometer to inverting terminal of IC1a comparator. A red led was connected at the output pin of comparator IC1a through a 1k resistor for indicating dark coloured solution, and a green LED was connected at the output pin of IC1a comparator through a 1k resistor for indicating a crystal-clear solution.

The IC1b comparator was connected to the as IC1a from the output to the invert input, and IC1b was connected with two 10k ohms resistor from the non-inverting terminal to positive and negative lines. The IC1b comparator output signal was fed to the base of transistor c945 to amplify the signal to control the switching of an output device, in this case, a RELAY.

C945 Transistor

This is a type NPN bipolar junction transistor. For this research, this transistor was used to amplify the voltage from the LM358 and drive the relay. Without the C945, the output voltage from the LM358 would not be able to drive the relay, and it would need to switch the relay for it to work providing it with negative since it is an NPN transistor.

Relay

A relay is an electrically operated switch. It is an electromagnetic switch that is used to turn on and turn off a circuit by a low power signal, or where several circuits must be controlled by one signal.

For this research, the input to the inverting input would be the voltage across the LDR. At darkness, the resistance of the LDR would be high and so was the voltage across it. At this condition, the voltage at the inverting input would be higher than the reference at the non-inverting pin and the output of the comparator would be low (~0 V). When the LDR was illuminated, its resistance dropped and so was the voltage across it. Then, the voltage at inverting input would be lower than that at non-inverting input and the output of the comparator went high (~12 V). That made transistor Q1(c945) ON and it drove the relay. As a result, a relay switching according to the intensity of the light falling on the LDR was obtained.
In this circuit, the low power from transistor c945 was used to switch on high a power device, in this case, the 12-volt DC Motor.

It should be noted that most of the high-end industrial application devices have relays for their effective working.

9-Volt battery

For this research, this was the battery was used to power the circuit and all the components on it.

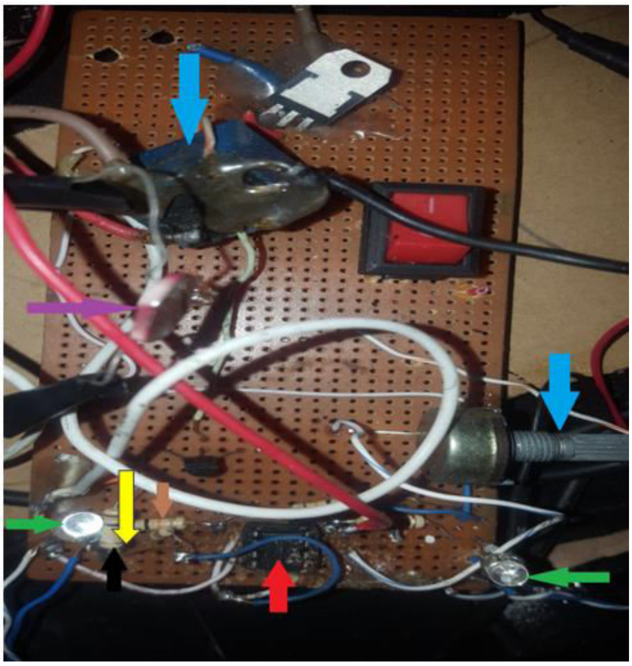

Figure-11. Circuit board with description.

2.2.3 Circuit design

The circuit was designed and simulated using Circuit Wizard software. The steps involved in the design are outlined below:

2.3 Chemical Section

2.3.1 Preparation of iodine clock reaction

Materials used

1. Potassium iodide (KI)
2. Sodium thiosulphate ($Na_2S_2O_3$)
3. Starch ($C_6H_{10}O_5$)
4. Sulfuric acid (H_2SO_4)

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5. Hydrogen peroxide solution (H_2O_2)

Procedure

Two solutions were made.

Solution A

1. 7.5 g of Potassium iodide (KI) was weighed in a 250ml beaker.
2. 150 ml of 0.001 M Sodium thiosulphate $(Na_2S_2O_3)$ was added to the 250 ml beaker.
3. 1 g of starch was then added.
4. Distilled water was added to make up to 150 ml.

Solution B

1. 20 ml of 1.0 M (H_2SO_4) was added in a 250 ml beaker.
2. 55 ml of distilled water was then added to dilute the acid.
3. 25 ml of 3% (H_2O_2) solution was then added.

2.3.2 Power source

In this case, a sealed lead acid battery was used. The battery uses a sponge lead (Pb) for the negative plate and lead dioxide (PbO_2) for the positive plate of which both plates were immersed in an electrolyte (sulphuric acid) for the conversion of chemical energy into electrical power. The sulphuric acid (H_2SO_4) has a composition of 62% as distilled water and 38% as H_2SO_4. The battery was acting as the 'power house' for the car, that is, it was giving energy to the car.

2.3.3 Sealed lead acid battery

The sealed lead-acid battery is made up of six cells mounted side by side in a single case. The cells were coupled together, and each 2V cell added up to the overall 12V capacity of the battery. Despite being relatively heavy, lead-acid batteries were still preferred over other lightweight options owing to their ability to deliver large surges of electricity (which is required to start the 12 V DC motor in the car).

All these parts are placed in a concentrated solution of sulphuric acid. Inter-cell connectors connected the positive end of one cell to the negative end of the next cell; hence, the six cells were in series.

2.3.4 Working principle of the lead acid battery

The electrolyte (sulphuric acid and water) contains charged ions of sulphate and hydrogen. The sulphate ions were negatively charged, and the hydrogen ions had a positive charge. This is what happened when the switch was turned on. The sulphate ions moved to the negative plates and gave up their negative charges. The remaining sulphate combined with the active material on the plates to form lead sulphate. This reduced the strength of the electrolyte, and the sulphate on the plates acted as an electrical insulator. The excess electrons flowed out the negative side of the battery, through the electrical device, and got back to the positive side. At the positive battery terminal, the electrons rushed back in and were accepted by the positive plates. The oxygen in the active material (lead dioxide) reacted with the hydrogen ions to form water, and the lead reacted with the sulfuric acid to form lead sulphate.

The ions moving around in the electrolyte were what created the current flow through the load(the wire), but as the cell became discharged, the number of ions in the electrolyte decreased and the area of active material available to accept them also decreased because it was becoming coated with sulphate. The chemical reaction took place in the pores on the active material that was bonded to the plates.

Chemical reactions during discharge were:
At the anode:

$$PbO_2 + SO_4^{2-} + 4H^- + 2e^- \rightarrow PbSO_4 + 2H_2O \quad (1)$$

At the cathode:

$$Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^- \quad (2)$$

Overall chemical reaction:

$$PbO_2 + Pb + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O \quad (3)$$

Chemical reactions during charging were:
At the anode:

$$PbSO_4 + 2H_2O \rightarrow PbO_2 + SO_4^{2-} + 4H^- + 2e^- \quad (4)$$

At the cathode:

$$PbSO_4 + 2e^- \rightarrow Pb + SO_4^{2-} \quad (5)$$

Overall chemical reaction:

$$2PbSO_4 + 2H_2O \rightarrow PbO_2 + Pb + 2H_2SO_4 \quad (6)$$

2.3.3 Stopping mechanism

An iodine clock reaction was used to stop the car. To achieve this, the iodine and the potassium iodide (KI) formed a complex with the starch solution that turned it black after a certain amount of time, which could be controlled based on the concentration of sodium thiosulphate (Na_2SO_3). The mixture existed as a clear liquid at first, then turned blue-black after the reaction was complete. This reaction acted as the 'brakes' for the car.

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2.2.4 Chemical reaction equation

For the first reaction, iodide ions were oxidized to triiodide ions via the action of hydrogen peroxide:

$$3I^{-}(aq) + H_2O_2(aq) + 2H^{+}(aq) \rightarrow I_3^{-}(aq) + 2H_2O(l) \quad (7)$$

For the second reaction, triiodide ions were reduced back to iodide ions via the action of the thiosulphate anion:

$$I_3^{-}(aq) + 2S_2O_3^{2-}(aq) \rightarrow 3I^{-}(aq) + S_4O_6^{2-}(aq) \quad (8)$$

Once the thiosulphate anions were depleted, an excess of triiodide ions was produced, which bound to the starch in the solution to form black triiodide-starch complex. At this point, the solution then turned blue black.

2.3.5 Role of iodine clock reaction

The car circuit contained a switch, 12V DC motor, LDR, and batteries (9V and 12V) as well as other components. When the car first started, a light shined through a glass vessel containing the iodine clock onto the LDR, switching it "ON" and keeping the circuit open. At this point, the vessel was clear as the iodine clock reaction had not reached completion. As the iodine clock reaction was progressing, the car was moving until the glass beaker suddenly turned dark, preventing light from reaching the LDR and breaking the circuit. This was because reaction time was a function of iodine concentration and could be easily measured. The iodine clock could be effectively used to control the time and distance that the car was travelling. Different concentrations of sodium thiosulphate were analysed to see the time for the reaction rate. The iodine clock was useful in analytical determination of the rate of reaction via colourimetry.

3. RESULTS AND DISCUSSIONS

results will be based on the aftermath of the circuit simulation, the experimental preparation and procedure involved in the iodine clock reaction.

3.1 Circuit Simulation

From the circuit configuration, the steps of how the circuit was designed were seen. The simulation of the circuit is given in Figure-12.

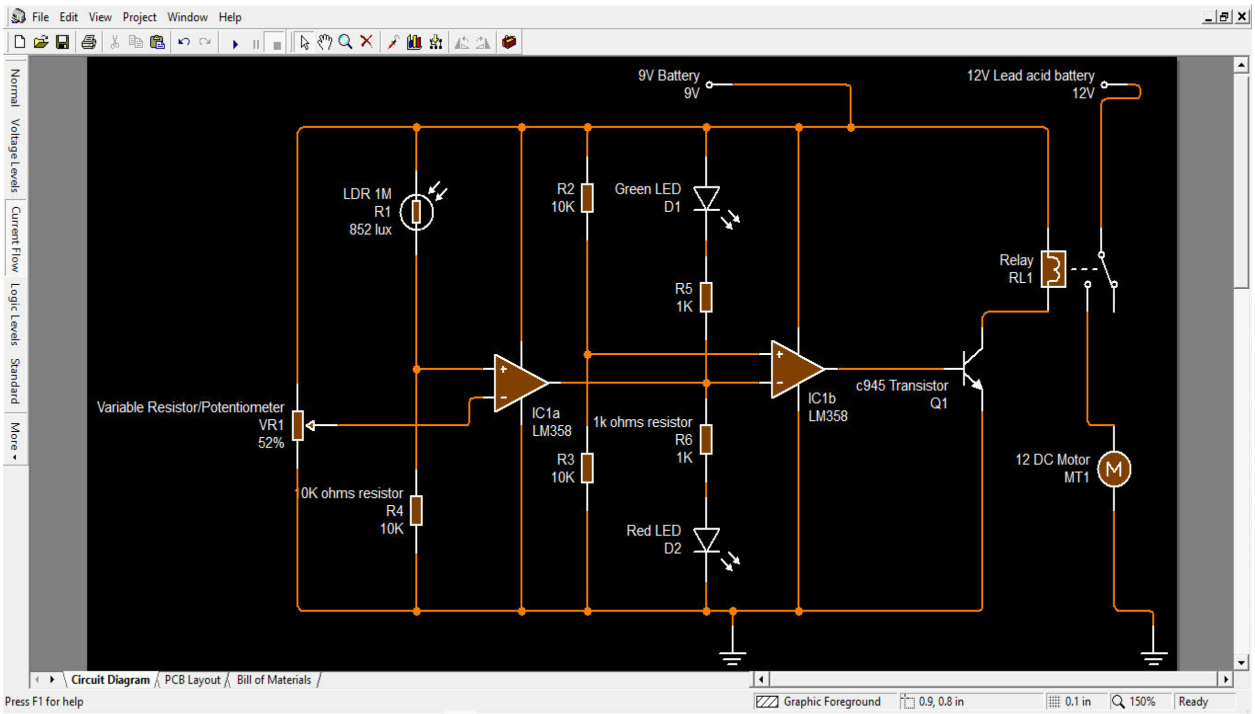

Figure-12. First stage of simulation.

From Figure-12, it can be seen that the view changed, and this was done to see a clearer and more detailed view of the full simulation process.

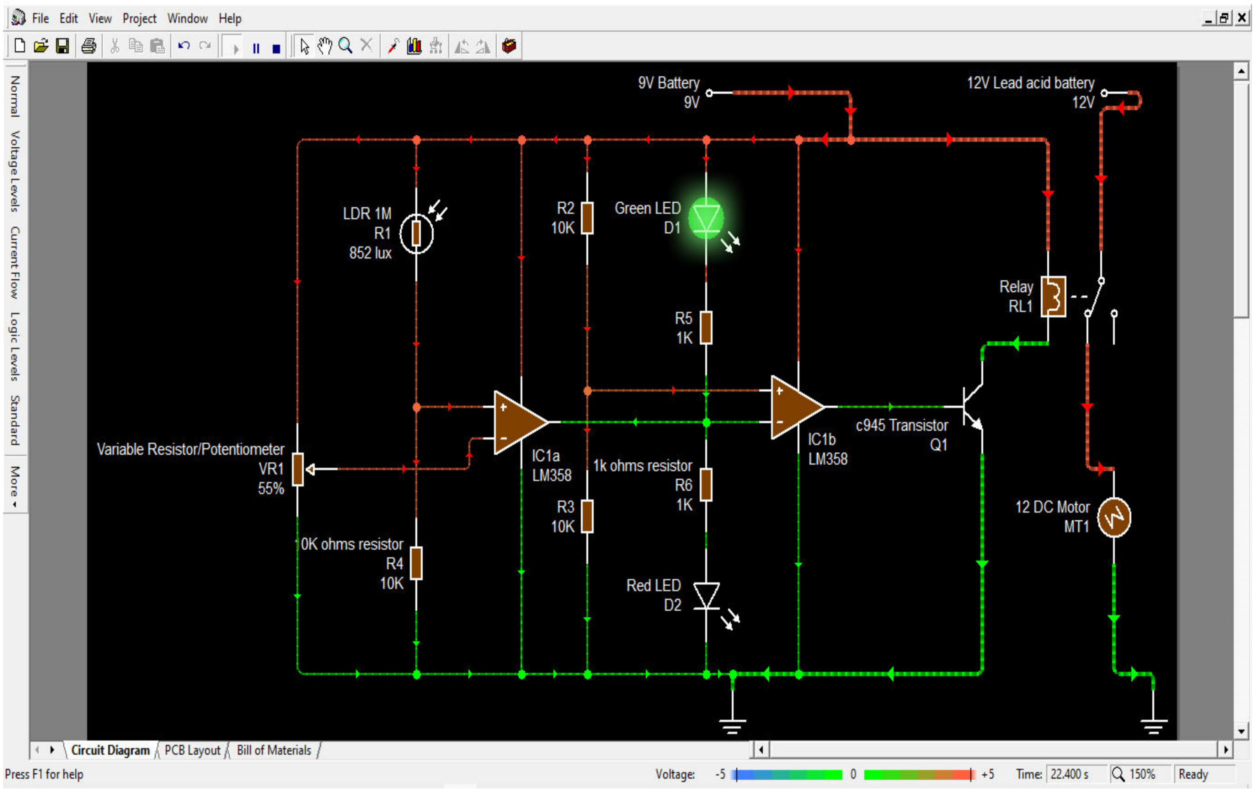

Figure-13. Stage 2 of simulation.

It can be seen from Figure-13 that the switch for the circuit was turned ON, and a green LED shone. This indicated that the LDR read a clear solution from the glass vessel that contained the iodide clock reaction. This activated the 12 V Lead acid battery and made current to flow to the electric motor thus making the car to move.

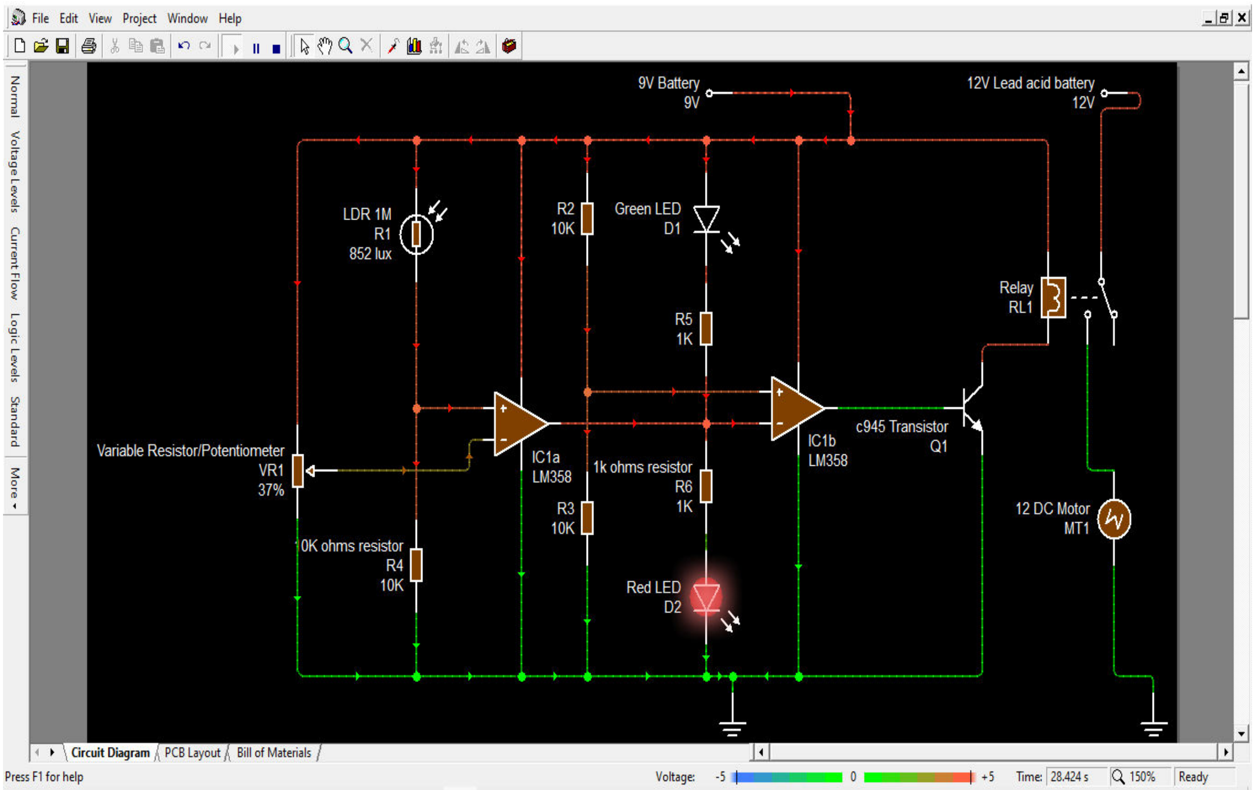

Figure-14. Stage 3 of simulation.

From Figure-14, the red LED was seen to shine, indicating that the LDR read darkness from the glass vessel, which was found to be an indication that the iodide clock reaction was complete. Hence, the 12 V lead acid battery was deactivated and current stopped to flow to the electric motor, thus the car stopped.

3.2 Analysis

The time taken for the solution to change from clear to black was recorded, and five trials were conducted for each quantity of sodium thiosulphate added. A graph was plotted to show this relationship as shown in Figure-15.

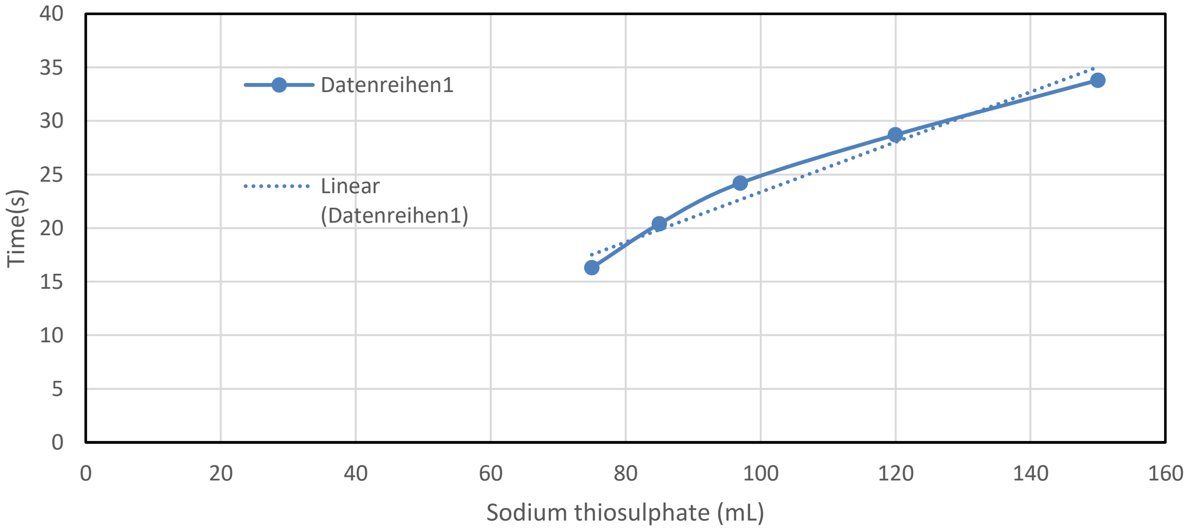

Figure-15. Time versus sodium thiosulphate concentration for iodine clock reaction**.**

Figure-15 showed that increasing the concentration of sodium thiosulphate decreased the rate of reaction thus increasing the time for colour change. As seen in the figure, the time of sodium thiosulfate clock reaction decreased exponentially when the amount of sodium thiosulfate decreased.

4. CONCLUSIONS

MODEL C car prototype has been designed and constructed using eco-friendly materials. All materials used for this project were locally sourced. The car was also designed for maximum safety consideration. The energy to run the car was obtained from a sealed lead acid battery and an iodine clock reaction was used to stop the car. Based on the results, the stopping mechanism analysis showed that the higher the concentration of sodium thiosulfate, the slower the car was coming to a stop. It is possible that in the future, all vehicles would be powered entirely by chemical reactions as can be seen now with electric vehicles.

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