UC Irvine AIChE Chem-E-Car: The Ron Knight

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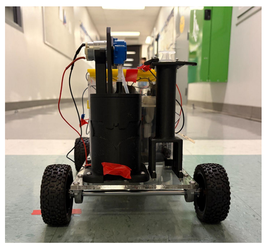
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Objective

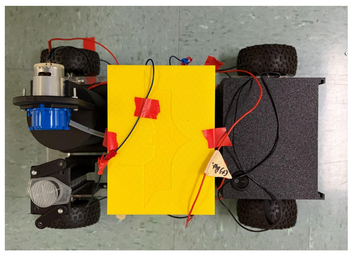
Chem-E-Car is an annual nationwide competition with the American Institute of Chemical Engineers (AIChE) that requires students to utilize critical thinking and problem solving skills to design and manufacture a car that adheres to strict safety rules. The car must be powered by a chemical reaction, stopping autonomously, over a specified distance (15-30 m), and be within the dimensions of a standard shoebox.

Introduction

The Ron Knight is a vehicle powered by a lead-acid battery with an acrylic chassis to support the chamber and mechanism components. The materials used, acrylic, polypropylene, and PLA were selected for their resistance to chemicals utilized on the car. Its drivetrain features stainless steel D-shafts paired with a two-gear system: one gear mounted on the rear shaft and the other connected to a motor positioned beneath the chassis, protected by a cover. The top portion of the chassis houses the main functional components, including the stopping mechanism, lead-acid battery, a syringe containing the diluted bleach solution that runs through tubing into the beaker holding the luminol solution, and an electronics enclosure. These components are all placed in a way that ensures the car drives safely in a straight line with minimal drift.



Front View



Top View

Methods

Starting Mechanism: Lead-Acid Battery

The propulsion system is driven by a lead-acid battery consisting of a series connection of 7 cells to produce a potential of 14 V.

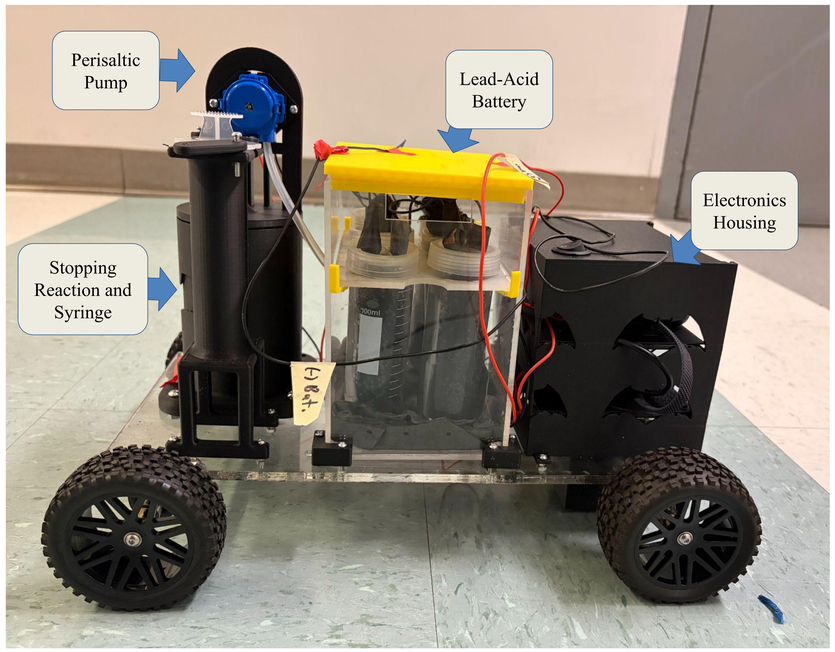
1. The lead dioxide electrode is manufactured by applying positive potential (2-3V) to an inert titanium mesh in a 0.2 M nitric acid, 0.4 M lead nitrate, and 0.3 M cupric nitrate solution, which electroplates lead dioxide onto to the titanium mesh.
2. Each cell is assembled with a lead and lead dioxide electrode, separated by fiberglass to prevent a short circuit.
3. The electrolyte is made by gently heating to 80ºC 400 mL of 5M sulfuric acid and 27.4g ~ aluminum sulfate so that the solute dissolves, and let to cool.
4. The electrolyte solution (about 40 mL for each cell) is transferred into the cells to submerge the electrodes.
5. To charge the battery, a DC power supply is connected to the positive and negative terminals, applying 16 V.
   Lead Electrode Half-Reaction (Cathode while charging): $PbSO_4 + 2e^- \rightarrow Pb + SO_4^{2-}$
   Lead Dioxide Half reaction (Anode while charging): $PbSO_4 + 2H_2O \rightarrow PbO_2 + SO_4^{2-} + 4H^+ + 2e^-$
6. The battery is discharged by connecting the terminals to the motor and completing the circuit. As the lead electrode oxidizes and the lead dioxide electrode reduces, electrons flow from the negative terminal, through the circuit that powers the motor, and to the positive electrode.

Stopping Mechanism: Luminol Oxidation Reaction

The reaction will produce light at around 425 nM that is collected by a sensor with a photodiode that converts the light into an electrical signal. The signal is converted into analog to a digital converter before the sensor produces a unitless digital value to Arduino code. The script is designed to respond to inputs from the sensor and only power the motor of the car when sensor readings are detected. Following the completion of the reaction and the stop of light being generated, the lack of signal will indicate to the car to stop by cutting power to the car's motor.

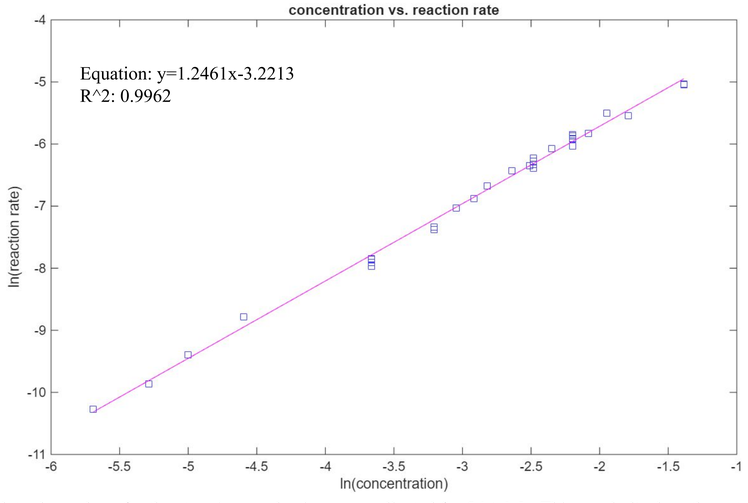
1. Create a stock solution of basic luminol solution
   a. Dissolve 2 mg of KOH and 0.3 mg of luminol in 100 mL of DI water
2. Make oxidizer solution
   a. Calculate the amount of bleach needed using the formula for desired reaction length.
3. Place 40 mL of the luminol solution into the reaction beaker
4. Load 30 mL of bleach solution into syringe and attach to pipe tubing
5. Flip on switch and RGB sensor waits to detect a light signal
6. Once RGB sensor readings return to original state, the car will stop

Vehicle Design Diagram



Results

Stopping Mechanism Data



The data shown here for the stopping mechanism was collected for **34 trials**. This graph displays the natural log of the concentration of bleach versus the natural log of the reaction rate. For our mechanism, luminol remains inside the reaction chamber while the bleach solution is fed in over time. This system is modeled as a semibatch reactor. The linear regression of this plot provides the reaction order (1.2461) and the rate constant (0.0399). By utilizing this data along with a velocity profile, which will be determined from the starting mechanism, we can relate distance to time. This will allow us to calculate the concentration of bleach required to reach the stopping point at a specific distance.

Chemistry Involved

Starting Mechanism: Lead-Acid Battery

Electrochemical cells consisting of lead oxide, lead, sulfuric acid, and an AGM battery separator to comprise our secondary battery mechanism. By charging the system, power can be stored and discharged later for electrical work, powering the car. The discharge of the combination of two half-cell reactions happening at a negative and positive electrode supply energy for propulsion:

Lead Electrode(Anode) Oxidation During Discharge: $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$

Lead Dioxide(Cathode) Reduction During Discharge: $PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$

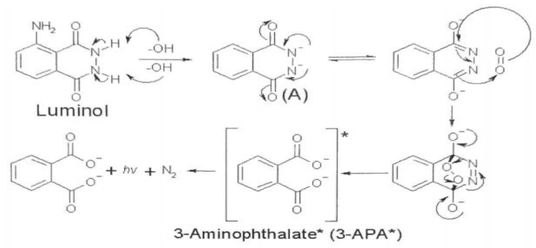
Overall Reaction: $PbO_2 + Pb + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$

The oxidation half-reaction has a standard reduction potential of -0.356V, and the reduction half-reaction has a standard reduction potential of 1.685V, resulting in a theoretical standard potential of 2.041V for an entire cell. When connected in series with 6 cells in total, the whole system has a total potential difference of 14.28 V, capable of supplying power to a motor rated at 12V. Charging the battery with an external power supply will reverse the direction of the reaction, reconverting lead sulfate to lead and lead oxide and storing energy for later discharge.

Stopping Mechanism: Luminol Oxidation Reaction

The stopping mechanism consists of a redox reaction from two aqueous solutions. One is a basic solution dissolved with our luminol which acts as the reducing agent. The other solution contains our oxidizer ^-OCL. The basic conditions in the luminol solution deprotonates the luminol as well as increasing solubility. The reaction creates nitrogen gas as well as our major 4-nitrophthalide in an excited state. The molecule releases energy in the form of photons that a RGB sensor detects the intensity and sends signals to the an Arduino board to stop the car.

Luminol Oxidation Reaction: $C_8H_7N_3O^{2-}$ (aq) + NaOCl (aq) $\rightarrow C_8H_5NO_4$ (aq)+N_2(g)+hv



Environmental and Safety Features

To make sure all team members are safe in lab, the wearing of PPE when entering the lab is strictly enforced by all teammates. Members must have pants, closed toed shoes, gloves, goggles or safety glasses, and a lab coat at all times in the lab.

Both starting and stopping reactions have chemical clean up procedures to eliminate any hazards to people or the environment. The product from the chemical reactions must be disposed of in a proper waste containers as well as rinsings of the glasswear will also be placed into the waste container.
Emergency Shutdown of the car can be achieved by simply turning the power switch to the ‘off” position.

Acknowledgements

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