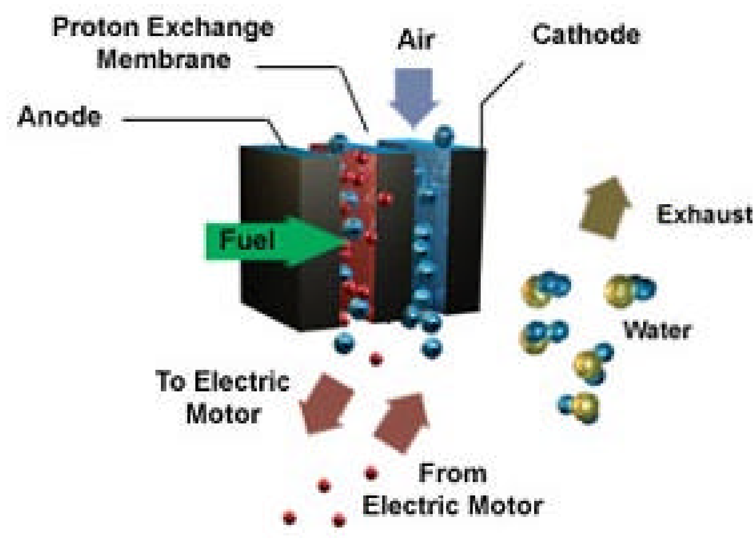

HYDROGEN PRODUCTION FOR FUEL CELLS

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INTRODUCTION

When fossil fuels are abundantly used, the environment is negatively impacted. The four major energy sources that we use are coal, oil, natural gas, and nuclear. Each of these sources of energy has environmental impacts associated with them.

Coal, which is obtained by strip mining and deep mining, is the cause of acid mine drainage when deep mined, and the erosion of land when striped mined. When burned, it emits CO_2, SO_2, and NO_2 gases which cause global warming and acid rain.

Oil is a fuel our country depends upon heavily. It powers our cars, trucks, trains, and airplanes and keeps the machinery in our factories running. Not only are the byproducts of oil hard to dispose of, oil itself has many environmental impacts. When drilling for oil, the land is altered, taking a while for the vegetation to grow back. Also, drilling contaminates soil and water causing acid mine drainage. Oil spills can occur when used in cars, while being transported from the drilling site, and while being drilled, leaving behind oil on the roads and in the forest area affecting wild life and natural resources. The Department of Education and Maryland Energy Administration say that Americans use a billion gallons of motor oil a year, 350 million gallons of which end up polluting the environment (Earthday Network 2001). The disaster of the Exxon Valdez in 1989 is an example of a major oil spill in Alaska causing great damage. Also, fires can occur at refineries.

Another conventional energy, natural gas, also known as methane, emits CO_2, but is the cleanest of the fossil fuels. Natural gas is produced, sometimes along with oil, by drilling into the Earth's crust where pockets of natural gas were trapped hundreds of thousands of years ago. Once the gas is brought to the surface, it is refined to remove impurities. Then it is transmitted through large pipelines that span the continent.

Finally, nuclear energy, which is formed by the release of energy during the splitting of atomic nuclei, is a promising resource but has its disadvantages. One of the byproducts of nuclear energy is highly radioactive and toxic waste. This waste must be stored properly until its radioactivity has reached a safe level. Unfortunately, this process can take anywhere from a few thousand to billions of years.

By reducing the use of these fuels and increasing the use of renewable energy, energy sources that are replaced by natural resources as quickly as they are used, global warming will be slowed down, the duration of fossil fuel existence will be increased, and the number of negative environmental impacts caused by those fuels will be decreased. Some renewable sources of energy are biomass, geothermal, wave or tidal, hydro, solar, wind, and hydrogen fuel cells.

The fuel cell is a device that uses an alternative energy source to produce electricity. The reason the fuel cells are not being used commonly is because there is currently no mass production of Hydrogen. Electricity is generated when there is an electrochemical reaction between Hydrogen and the Proton Exchange Membrane (Ballard Power Systems, 2000). An electrochemical reaction is a chemical reaction that causes electrons to flow. The PEM is one of the two main components of the fuel cell. The other main component is the membrane electrode assembly (MEA). The PEM is located between the MEA, which consists of the anode and the cathode. The anode and the cathode are separated by a polymer membrane electrolyte (Ballard Power Systems, 2000). Each of the electrodes is coated on one side with a thin catalyst layer. Sandwiched between this is the PEM.

The electrodes, catalyst, and membrane together form the Membrane Electrode Assembly (MEA). Each MEA consists of two electrodes (anode and cathode) with a thin layer of platinum, bonded to either side of a PEM. Hydrogen and Oxygen from the outside air are fed through the apparatus. The Hydrogen is on one side of the PEM, and the Oxygen is on the other. They attract each other from opposite sides and go through the membrane. While the Hydrogen protons go through the membrane, the electrons are stripped from the Hydrogen atom. The electrons flow around the PEM through an external circuit. The Hydrogen, Oxygen, and the electrons combine at one side of the PEM apparatus, and the byproducts are heat and water. Since the only byproducts are heat and pure water, the fuel cell is environmentally friendly and can be used in a variety of zero emissions applications.

Ballard is the leading fuel cell provider. According to Ballard (2000), fuel cells are being developed for all types of transportation. Fuel cells are currently being used in cars, buses, and trucks. Ballard's fuel cell technology is enabling automobiles, electrical equipment, and portable power product manufacturers to develop environmentally clean products to sell.

Ballard is becoming partners with strong companies such as Nissan, Honda, Ford, and Volkswagen. Another one of these companies is DaimlerCrysler. In 1997, Ballard and DaimlerCrysler decided to develop clean and efficient engines for the world's vehicles using the Ballard fuel cell. There are other fuel cell production companies such as Fuel Cells 2000 and International Fuel Cell.

Fuel cells are also being designed to use in stationary electric power generators. Ballard has begun to develop portable fuel cell systems that can be used for a wide variety of applications including recreational and emergency uses.

The purpose of this experiment is to test methods of producing Hydrogen. The class has three hypotheses. Those hypotheses are as follows: more Hydrogen will be produced from water (H_2O) at a higher voltage setting by the use of electrolysis. The second hypothesis is H_2SO_4, when mixed with Fe, will produce double the amount of Hydrogen than HCl when mixed with Fe. The third hypothesis is the amount of Hydrogen collected should be less than the theoretical yield.

METHODS

The group's first lab is an electrolysis lab. Electrolysis is the process of using electricity to separate atoms from molecules. When electricity is run through a substance, it energizes the molecules. The more energy a molecule possesses, the faster it vibrates. When the molecules are shaking it causes stress on the chemical bonds; it also causes heat to build up. Once the stress on the chemical bonds reaches a certain point, the molecules break into their base elements. For instance, when electrolysis is used to break away the elements on the molecule H_20, distilled water, the result is one atom of Oxygen and two atoms of Hydrogen for every molecule that is electrolyzed. The group chose to use electrolysis because it is a clean way to produce H_2 for use in a fuel cell. It is clean because when the atoms are separated from the molecule the only elements are H_2 and Oxygen.

The two acid/metal labs use a chemical reaction to separate H_2 from HCl and H_2SO_4. The HCl lab's components are one no-hole stopper, one kilogram of Fe (III) filings, one Erlenmeyer flask with exhaust port, four feet of plastic tubing, one collection tray, six one-liter collection vessels, and one liter of H_2SO_4. The variable for the HCl lab is the amount of reagent used. Uncertainties include the pureness of the reagents, the loss of H_2 due to the collection method, and the completeness of the reactions. The lab being performed uses different amounts of reagents to see how they affect H_2 production. The HCl lab is used to see how to produce H_2 with chemical reactions and to compare it with H_2 production by electrolysis, and with using the acid H_2SO_4.

To construct the lab, the four feet of plastic tubing is connected to the flask's exhaust port and then goes into the hole in the bottom of the collection tray. The tray is filled with an inch of H_2O and with the six one-liter collection vessels, which are filled with water and inverted in the tray. The collection vessels remain filled with H_2O because of the vacuum created between the H_2O in the tray and the H_2O in the vessels. The reagents, HCl and Fe (III), are added to the flask just before the stopper is set in place.

The two HCl labs are each 40 minutes long. The balanced equation for the Hydrochloric lab is $6HCl + 2Fe \rightarrow 2FeCl_3 + 3H_2$. The first trial uses 21 ml of HCl and the second uses 42 ml HCl. Both of the trials use 50 grams of Fe (III). The amount of H_2 in the collection vessel was measured every minute for the first five minutes and every five minutes after that. Stoichiometry was used to predict how much H_2 would be produced in the HCl lab and to compare it with what actually was. Stoichiometry can be done in six steps:

1) Make a list of all the known variables. This includes pressure, temperature, mass, and the ideal gas constant, R.

P=710.2 mm Hg, T= 26 degrees C, M= 21 ml, R= .0821 liters*atmospheres/Kelvin*moles.

2) List the unknown variable, Volume in liters.

3) Convert the mass to moles of HCl.

(21g/1)(1 L/1000mL)(5 moles HCl/1)= .105 moles HCl. The ratio of Cl in the HCl equation is 3/6, so (.105 moles HCl/1)(3mole/6mole)= .0525.

4) Convert the pressure (which is in mm Hg) to atmospheres.

(710.2mmHg/1)(1atm/760mmHg)= .934 atm.

5) Convert the temperature (which is in degrees Celsius) to Kelvin.

26 degrees Celsius + 273 = 297 Kelvin.

6) Use the ideal gas law, which is PV=NRT, where P=pressure, V=volume, N=number of moles, and T=temperature

[(.0525 mole HCl)(.0821 L*atm/Kelvin*moles)(299 K)] / .934 atm

=1.3798 liters.

This amount is estimated for the first HCl trial. The theoretic yield for the second trial is 2.7583

The group's other acid/metal reaction uses Sulfuric Acid (H_2SO_4). H_2SO_4 was chosen so that the amount of H_2 produced can be compared to the amount of H_2 produced with HCl. This happens because of the difference in the amount of H_2 atoms in their molecules. An Erlenmeyer flask is partially filled with 5 molar H_2SO_4. Iron (Fe (III)) filings are added and a stopper is placed on the flask immediately. A reaction begins between the Fe (III) and the H_2SO_4. The experiment is repeated by changing the amount of acid used. The first and second trials use 21 ml of H_2SO_4. The third trial uses 42 ml of

H_2SO_4. After the reactions have finished, in 45 minutes, the H_2 is measured. As in the HCl and electrolysis labs, a 10% standard error is used because of inaccuracies in the measurements of H_2 obtained.

The variable in the H_2SO_4 lab is the amount of acid. The first uncertainty is using pure reagents for the reactions. Impurities, such as sulfur, could change the results of the experiments, making them less accurate. H_2 loss during production is also an uncertainty. Another uncertainty is ensuring the completion of the reactions.

Stoichiometry shows the amount of H_2 that would have been produced in an ideal reaction, which is more than the actual yield. Therefore, a comparison will be made between the theoretical yield and the actual yield. The first and second H_2SO_4 reactions should have produced 2.7329 liters each. The third trial should have produced 5.4658 liters.

RESULTS

We were unable to collect any Hydrogen from the electrolysis of water laboratory experiment. However, we were able to see the production of Hydrogen inside the Erlenmeyer flask. The Hydrogen was forming as bubbles around the cathode. The cathode is negatively charged and the anode is positively charged. The reason that the Hydrogen formed around the cathode was because the Hydrogen was acting as a positively charged molecule. We also saw the formation of water droplets on the side of the flask. This indicates that the Hydrogen was rising to the top of the flask, but it was recombining with Oxygen and they reformed into water.

Figure 1 shows a comparison between the theoretical yield of the amount of hydrogen production and the average amount of hydrogen that was produced using

Sulfuric acid. Figure 2 shows a comparison between the theoretical yield of the amount of hydrogen production and the average amount of Hydrogen produced using 21ml and 42 ml of Hydrochloric acid.

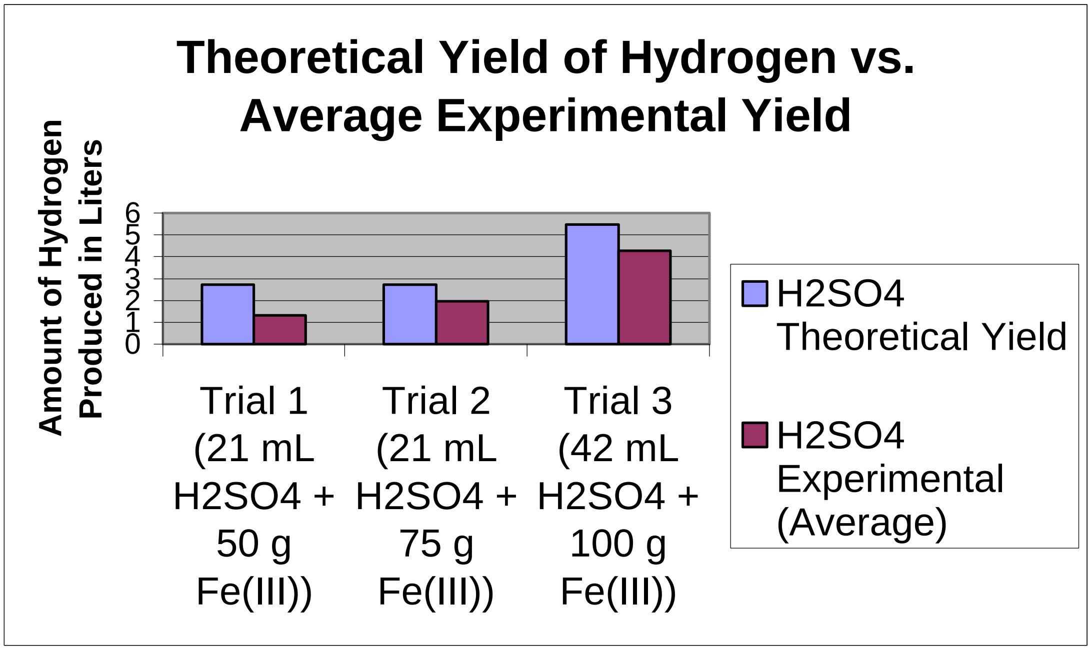

Fig. 1-This bar graph is used to show the difference between the expected theoretical yields of Hydrogen and the experimental results for the sulfuric acid labs.

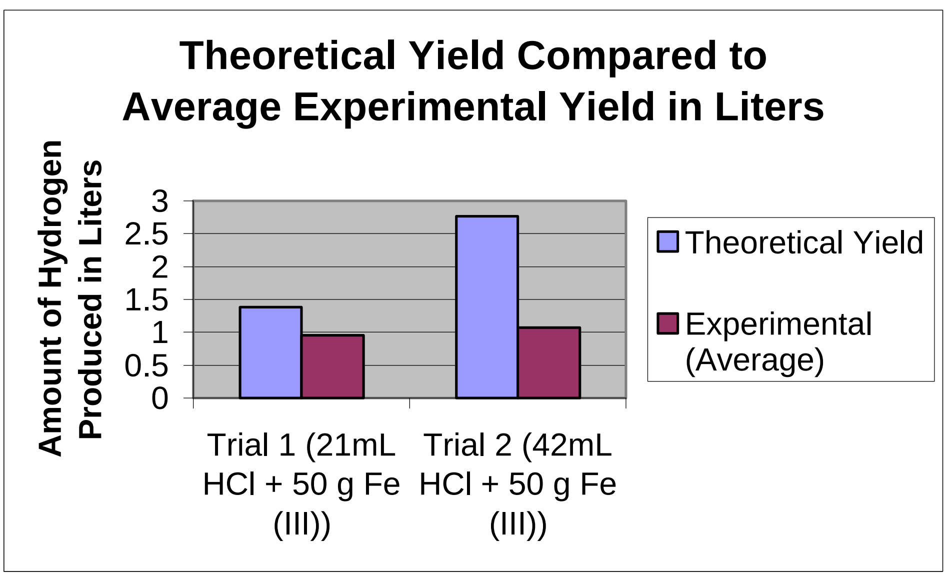

Fig. 2-This bar graph is used to show the difference between the expected theoretical yields of Hydrogen and the experimental results for the sulfuric acid labs.

In Figure 3 and Figure 4, the data shown is the average of the four lab groups' data. Figure 3 shows a comparison of trial one of the Hydrochloric acid lab and trial one of the Sulfuric acid lab. The first lab uses 21 milliliters of Hydrochloric acid and 50 grams of Iron (III) filings in trial one. The second lab uses 21milliliters of Sulfuric acid and 50 grams of Iron (III) filings in trial one.

Figure 4 shows a comparison of trial two of the Hydrochloric lab and trial one of the Sulfuric acid lab. The first lab uses 42 milliliters of Hydrochloric acid and 50 grams of Iron (III) filings in trial two. The second lab uses 21 milliliters of Sulfuric acid and 50 grams of Iron (III) filings in trial one.

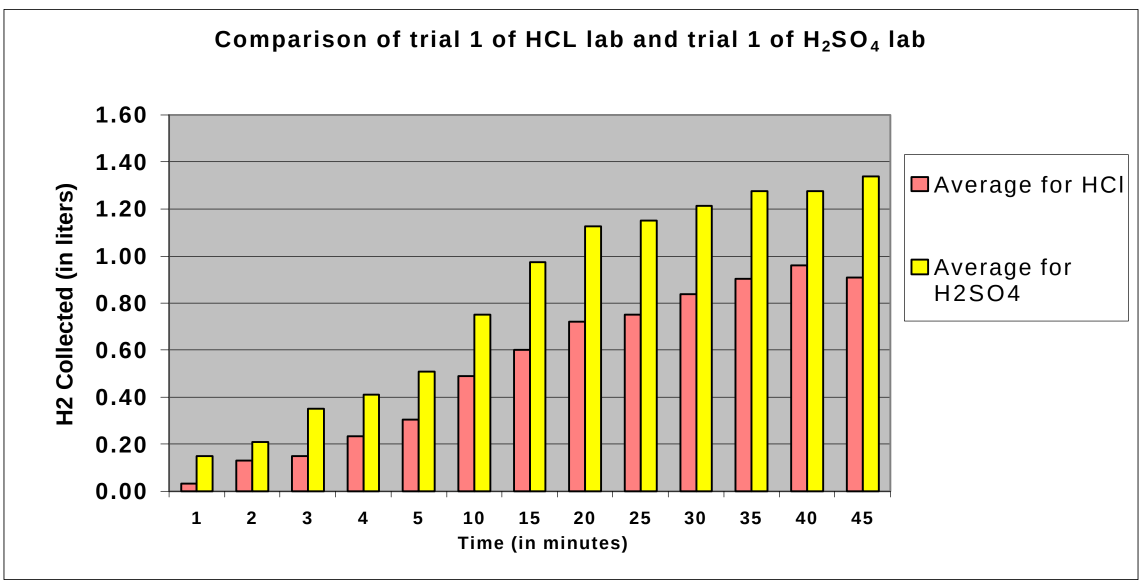

Fig. 3-This figure shows the comparison of trial one of the Hydrochloric acid lab and trial one of the Sulfuric acid lab.

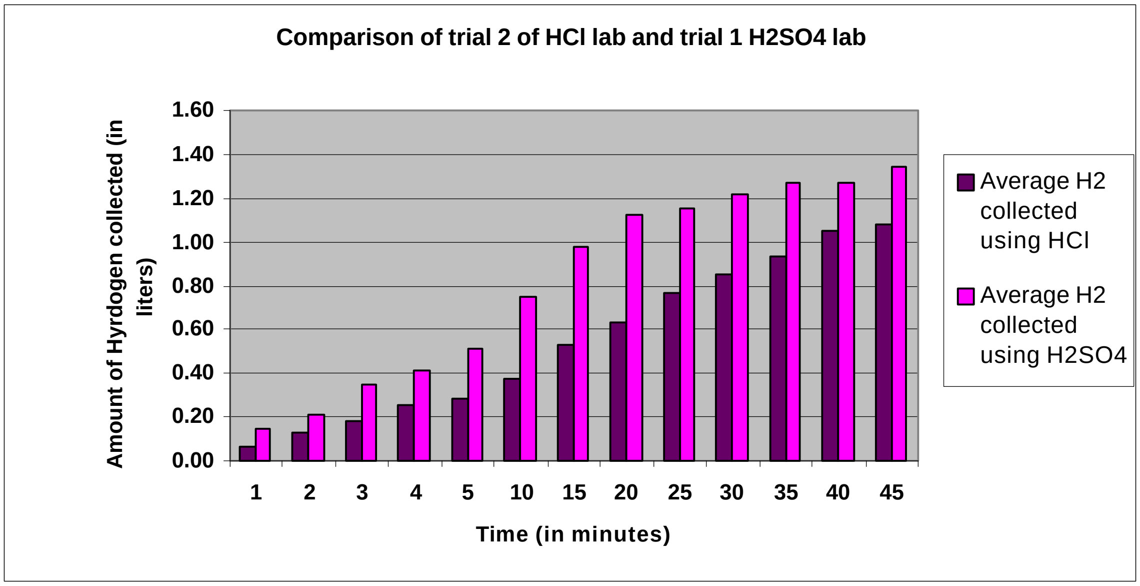

Fig. 4-This figure shows the comparison of trial two of the Hydrochloric acid lab and trial one of the and 50g of iron

Figure 5 shows the difference in collection rates of the Hydrochloric acid and Sulfuric acid using 21ml of each acid and 50g of iron filings.

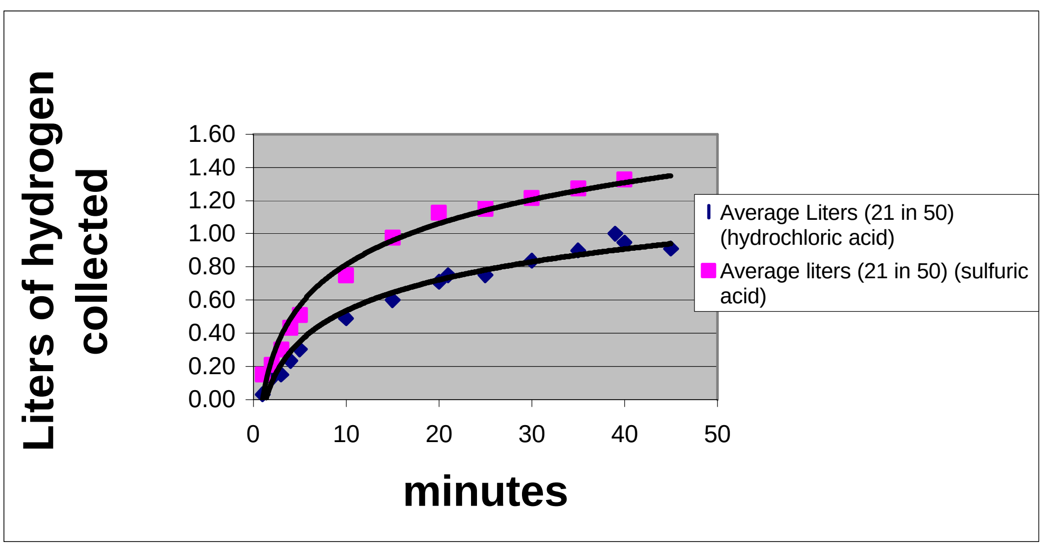

Figure 5: Difference in rate of Hydrogen collected using Hydrochloric acid and Sulfuric acid with 21ml of acid and 50g of iron

DISCUSSION AND CONCLUSIONS

The hypothesis of electrolysis states that more Hydrogen production will be observed at a higher voltage. More Hydrogen was observed at a higher voltage, but the observations were qualitative. Because the data was qualitative, not quantitative, the data was inconclusive. The hypothesis was neither rejected nor accepted.

Graphs in Figure 1 and Figure 2 show the amount of H_2 that was collected is less than the ideal theoretical amount of H_2 that was expected to be collected. The amount of H_2 that should have been collected, according to the theoretical yield calculations, was unable to be collected due to time restraints. If the reactions had been allowed to go to completion, the amount of H_2 collected may have more closely matched the ideal amount. In the HCl lab, the amount of reagents did not have an effect on the outcome of the experiment. Even though the first trial used 21 ml of hydrochloric acid, and the second trial used 42 ml of hydrochloric acid, little change occurred in the amount of H_2 collected. In the H_2SO_4 lab, the amount of reagents had an effect upon the amount of H_2 collected. Unlike the HCl acid metal lab, the H_2SO_4 lab came closer to the amount of H_2 that the theoretical yield showed. The percentage rates of the theoretical yields and the experimental yields were closer in the H_2SO_4 acid metal lab than in the HCl acid metal lab.

Figure 3 is created to find out if using the same amount of each acid, the amount of Hydrogen gas collected from the Sulfuric Acid lab would be double the amount collected from the Hydrochloric Acid lab. This hypothesis proved to be false because the amount of Hydrogen collected is less than double the amount collected from the Hydrochloric Acid lab. Figure 4 is created to find out if using 42 milliliters of

Hydrochloric Acid would equal the amount of hydrogen collected using 21 milliliters of Sulfuric Acid.

The hypothesis that states H_2SO_4 will produce double the hydrogen than HCl when combined with Iron (III) is rejected. The hypothesis is rejected because 21 milliliters of Sulfuric Acid did not produce double the amount of Hydrogen that 21 milliliters of Hydrochloric Acid did. Figure four shows that 42 milliliters of Hydrochloric Acid did not produce the same amount of Hydrogen as 21 milliliters of Sulfuric Acid. This result is mainly due to the reaction time of the different acids. Sulfuric Acid has a faster reaction time than Hydrochloric Acid. If the reactions are allowed to complete, the results could have been different.

Figure 5 shows that the Sulfuric acid produces more hydrogen than the Hydrochloric acid did. The sulfuric acid produced hydrogen at a faster rate at the beginning of the experiment than Hydrochloric acid, but they both slowed down to about the same rate after about 20 minutes.

The first H_2SO_4 trial, using 50g of Iron was not performed correctly. This lab was not properly executed because, as Figure 7 shows, 50g of Iron was insufficient to complete the reaction as compared to the H_2SO_4 reaction with 75g of Iron filings. However, the trial using 75g of Iron filings had an adequate amount of Iron filings to allow the acids and metals to react more completely. This resulted in more H_2 being produced, as represented on the graph. Therefore, as long as enough Iron is used, it will not be a limiting agent.

The environmental hazards are very important to consider when it comes to Acid Metal Reactions. The residuals of the reactions were Iron Chloride and Iron Sulfate.

Iron Chloride looks like a black crystalline powder. This iron chloride mixture is very bad to have after an experiment. On the UN Major hazard class rating on a scale from 1 (being lowest) to 10 (being highest), it has a rating of 8 (physchem, 2000). This rating was based on the information of the fact of getting burns, harmful inhalation, ingestion, and the contact with skin from mixing iron and Chloride. People may think that the iron sulfate would be more harmful than the chloride and the iron, but that is not the truth. The mixture of sulfate and iron looks light blue or light blue-green. It is a slight biohazard that could have affects on a person of being harmful if inhaled, ingested, and harmful if absorbed through the skin. Also, if five grams or less were ingested then it can start symptoms such as nausea, abdominal pain, and vomiting (maybe death). There is one use for iron sulfate, which is used for feed or fertilizer. Overall, these mixtures are harmful in many ways.

Many changes could have been done to improve the experiments. In the electrolysis lab, the students could have used copper electrodes rather than steel electrodes. The reason for using copper electrodes rather than steel electrodes is, because copper is a better conductor than steel. Another improvement would be the use of a standard electrolysis unit. This type of apparatus would have separated the Hydrogen and Oxygen, and kept them from recombining into water.

Another important improvement would have been to allow more time for the experiments to run to their completion. Increasing the time would have allowed the collection of more Hydrogen. Another complication is the inability to determine whether the students were using Iron (I), Iron (II), or Iron (III). The reason the students have to know this is so that they could balance their equations. They guessed that the iron filings were Iron (III) because it is the most abundant. During the HCl experiments, sulfur is detected as an impurity in the Iron Filings. The smell of rotten eggs is the indicator. The students needed access to purer regents.

During data collection, of data there were errors. Some errors came from the students. One group's information is invalid because they used 42ml of Sulfuric Acid and 75 grams of Iron Filings when the correct amounts should have been 21ml of Sulfuric Acid and 75 grams of Iron Filings. Also, another group's information was invalid because they had Iron Filings stuck between the stopper and the flask, which caused pressure to leak from the flask.

This experiment raised many different questions. For instance, does the amount of catalyst added to the reagents in the electrolysis lab affect the speed of the reaction? In addition, if a different electrolysis apparatus were used, would it create a variation in the results? Also, how did impurities in the Iron filings affect the reaction? If impurities do not affect the reaction, would the type of metal affect the reaction speed? Further, would additional time in the acid/metal labs help to complete the reaction? If more time does not facilitate a completion, then why will the acids and metals not finish reacting? In addition, how did the consistency of the procedures, such as shaking the flask, affect the results?

H_2 can be used as a fuel for fuel cells. For the most part, the public does not know the benefits of using H_2 for fuel cells because fuel cells are a developing technology. One of the benefits includes having an environmentally safe, portable source of electricity. Thus, investigating H_2 as an alternative energy source will be beneficial in the long run. H_2 production for use in fuel cells could be investigated worldwide as a possible alternative energy source. If fuel cell technology is further developed, H_2 production could be efficient on a large-scale basis. All that would be necessary is to use high-molarity acid with large quantities of Iron filings. However, other sources of H_2 production are possible. Under the right circumstances, the production of H_2 through an acid/metal reaction is viable and effective.

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