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Design Of A Methane-To-Methanol Conversion Device

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DESIGN OF A METHANE-TO-METHANOL CONVERSION DEVICE

by

Pankti Doshi and Jessica Garcia

SENIOR DESIGN PROJECT REPORT

Submitted in partial fulfillment of the requirements

for the degree of

Bachelor of Science in Bioengineering

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Santa Clara University

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Santa Clara University
DEPARTMENT of BIOENGINEERING

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY
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ENTITLED

Design of Methane-to-Methanol Conversion Device

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF

BACHELOR OF SCIENCE IN BIOENGINEERING



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ABSTRACT

The purpose of this project was to develop a device that will make natural gas, primarily methane, an efficient and economical fuel alternative as the world's petroleum supply is diminished. Presently, methane gas is too costly and dangerous to convert to methanol. The direct oxidation of methane can reduce the processing and transportation costs creating a competitive alternative to petroleum. This device will be marketable to companies interested in alternative fuel sources competitive with petroleum. Entrepreneurs are then expected step in and develop a global market.

With the development of our prototypes and running methane and oxygen (or atmospheric oxygen) through the systems, we were able to detect the presence of methanol. We worked with a porous ceramic pot, two tanks and pressure regulators for oxygen and methane, an ignition system, and a device that contained this experiment. Due to the volatile nature of the chemical reaction between the two gasses, three prototypes were designed. By varying the experimental parameters of time length of the reaction, voltage, gas flow rate, and pressure, we were able to draw conclusions for what the optimal criterion are for interacting the gasses. More specifically, running the experimental reaction for 2 minutes, setting a voltage of 14 volts (V), exposing the system to a pressure of 20 hertz (Hz) all contributed to the testing the methanol samples. Using gas chromatography and mass spectroscopy analysis, we observed methanol peaks, intermediate formaldehyde peaks, and methanol dimer peaks, successfully accomplishing the goal of this project.

By changing certain parameters for future experimentation and then testing the outcomes, the device can be modified to produce the cleanest methanol that can be used to power technologies that are used today. Using this device to spur the adoption of methanol as an alternative energy resource can conserve our existing petroleum reserves, increase competition among energy providers, and reduce cost. Also since methanol burns cleaner than petroleum-based fuels, developing automobiles, transportation, and power generation using methanol can grow existing technology companies, most likely start new ones, and deliver environmental benefits.

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TABLE OF CONTENTS

ABSTRACT.....	iii
ACKNOWLEDGEMENTS.....	iv
LIST OF FIGURES.....	vii
LIST OF TABLES.....	vii
INTRODUCTION.....	1
Device Overview.....	2
Customer Needs.....	4
Benchmarking Results.....	5
Challenges and Constraints.....	6
Budget.....	7
Design Process.....	7
Risks and Mitigations.....	7
Team Management.....	8
FUNCTIONAL ANALYSIS.....	9
Experimental Method.....	9
Sample Testing.....	9
PROTOTYPE 1.....	11
Introduction.....	11
Materials and Methods.....	11
Results.....	11
Discussion.....	11
PROTOTYPE 2.....	12
Introduction.....	12
New Approach and Expected Results.....	12
Materials and Methods.....	12
Results.....	13
Discussion.....	13
PROTOTYPE 3.....	14
Introduction.....	14
Results.....	14
Discussion.....	14
SUMMARY AND CONCLUSIONS.....	15

ENGINEERING STANDARDS AND REALISTIC CONSTRAINTS.....	17
Environmental.....	17
Political.....	17
Health and Safety.....	18
Manufacturability.....	18
Ethical.....	18
BIBLIOGRAPHY.....	19
APPENDICES.....	20

LIST OF FIGURES

A-1. Power System of Prototype 1.....	20
A-2. Design of Prototype 1.....	21
A-3. Design of Prototype 2.....	22
A-4. Design of Prototype 3.....	23
A-5. Schematic of Methane-to-Methanol Conversion Device.....	24
A-6. Prototype 2 - Inside Ceramic Pot.....	25
A-7. Control Methane Mass Spectrum.....	26
A-8. Control IPA Mass Spectrum.....	27
A-9. Control Methanol Monomer Mass Spectrum.....	28
A-10. Control Methanol Dimer Mass Spectrum.....	29
A-11. Prototype 3 - Inside Ceramic Pot.....	30
A-12. Prototype 3 – Inside Ceramic Pot (Magnified 1).....	31
A-13. Prototype 3 – Inside Ceramic Pot (Magnified 2).....	32
A-14. Prototype 3 – Outside Ceramic Pot (First Sample).....	33
A-15. Prototype 3 – Outside Ceramic Pot (Second Sample).....	34

LIST OF TABLES

A-16. Budget.....	35
A-17. Experimental Data.....	36
A-18. Gantt Timelines.....	37

INTRODUCTION

Natural gas is an abundant resource with significant benefits. Yet, petroleum still remains the world's main source of energy. This is because natural gas is usually found in isolated reserves, is challenging and expensive to transport, and sells for so little that suppliers find it difficult to make a profit. That said, this hydrocarbon gas mixture, primarily consisting of methane, accounts for 24 percent of the total energy consumed in the U. S., making it a vital component of the nation's energy supply [4].

Many of the problems of distributing volatile methane are overcome by adding a single oxygen atom to form methanol. The oxygen readily forms hydrogen bonds to strengthen the intermolecular forces and produce a liquid at standard temperature and pressure. Methanol is one of the most commonly produced chemicals in the petrochemical industry (21 million tons/year) and is used as a solvent, a gasoline component, and a chemical feedstock for producing other chemicals [4]. However, methanol is currently being produced by an expensive and energy intensive process.

The purpose of our project was to evaluate the possibility of competitively producing methanol through direct oxidation of methane. Rick Moody, in his 1998 dissertation "Methanol Production by Direct Oxidation of Methane in a Plasma Reactor", concluded that methanol production via a direct, single step method would be competitive with existing methanol production methods (steam reformation of methane followed by oxidation of syngas) if it achieved a single pass methane conversion of at least 5.5 %, with selectivity to methanol of 80%" [7].

This provides two very clear metrics for comparison, conversion (i.e.: how many non methane products are formed) and selectivity (i.e.: how much of the product are methanol). Many processes have been tried, but they all suffer from a serious chemical constraint: the energetics to oxidize methane to methanol is greater than the energetics needed to oxidize methanol all the way to carbon dioxide and water [2]. The goal of this project was to provide a way to gently react the oxygen and methane, rather than crash them together so hard that they inevitably oxidize all the way to their end products.

Our invention accomplishes this by using a separation mechanism first introduced in chemistry classes. Fuel cells can be made with two containers separated by a mechanism for exchanging charges. This mechanism can be a “salt bridge”, often a tube packed with a supersaturated salt solution, or porous ceramic containing myriad small spaces formed between clay particles partially fused in a kiln. The porous ceramic bridge efficiently separates neutral molecules; it takes a long time for them to diffuse through the long crooked tubes within the ceramic. This difference between charged and neutral diffusion through a ceramic channel formed by the fusing of clay particles separates charged gases. If a positively charged methane ion and a negatively charged oxygen ion meet inside a small tube, we hypothesized they might be separated from other oxygen molecules and react gently enough to form methanol a single molecule of methanol.

The invention we proposed involves a low-energy, high-volume process to convert methane to methanol that could conserve our existing petroleum reserves, increase competition among energy providers, reduce cost, and, because methanol burns cleaner than petroleum-based fuel, provide substantial environmental benefits.

In case the experimentation process did not proceed the way the procedure was established, the following back up plan was developed: determine the importance of a methane-to-methanol conversion device, discuss alternatives to energy sources that are currently waste products, redo research in terms of the chemical properties of methanol and oxygen, and redesign parameters to make an efficient, optimal reaction. However, it was not necessary to implement this protocol because the experiment followed the initial developed procedure.

Device Overview

Our device contained the following regions with each region holding a specific part of the reaction that ultimately oxidizes methane into methanol:

A region containing oxygen

1. A region containing methane
2. A porous membrane separating the first region from the second region

3. Conductors inserted into the first and second regions, and electronically connected to terminals outside the first and second regions
4. A potential applied to the terminals for the purpose of conducting electrons and ionizing oxygen and methane
5. A means of reacting ionized oxygen and methane molecules into methanol and extracting the methanol

As shown in Figure 1 (see Appendix), the ignition system causes the ignition coil to produce several thousand high voltage pulses per second. The pulses are always in the same polarity and are connected to aluminum conductors. The aluminum conductors are shown inside and around the insulator, which are displayed in this image as an unglazed fused silica pot containing small channels snaking between small clay particles melted and fused in a kiln.

As described in Figure 2 (see Appendix) the unglazed pot is placed into a sealable ethyl methacrylate container containing a number of gas switches. A gasket seal is interposed between the top surface of the container and the bottom of the container. Holes for electrodes (not shown) allow wires to conduct potentials from an electronic ignition system to electrodes placed within and without the container such that electrical conductivity is maintained and no gas molecules leak from one compartment to another. One or more barriers can be placed inside container, both inside and outside the pot, in order to construct additional compartments. Switches can be connected to the input of gas sources or the output (waste) and turned on or off to affect uncontaminated gas flow. The liquid product collected at the bottom and sides of a compartment may be caused to flow out of the compartment using valves or channels not shown.

The second prototype was designed and developed after the first prototype cracked due to the volatile nature of the methane and oxygen reaction. As seen in Figure 3 (see Appendix) the concept is the same but the prototype has a stronger encasement and protection for the experiment to occur.

Lastly, the third prototype was fabricated because of the crack that developed in the second prototype from sealing the device too hard. This is displayed in Figure 4 (see Appendix) and has the strongest design to run the optimal experimental reaction.

Customer Needs

A methane-to-methanol conversion device would be necessary to make use of the natural methane reserves around the world. With the turmoil surrounding the Middle East, it is not a surprise that President Barack Obama has devoted major resources to improving natural gas technology [5]. Shifting the world's view towards cleaner fuels sources will reduce the carbon footprint of energy. Also, using such gases can fuel the economies of many countries and make them energy independent.

One of the main goals of a methane-to-methanol conversion device is to alter the geopolitics of the world. The fossil fuel reserves of the world are concentrated in a few areas surrounded by constant political turmoil. All countries that are involved with the fossil fuel industry must be cautious of their energy security and safety. Fossil fuel production, exportation, and importation is necessary because every country uses fossil fuel energy, but only very few countries have political control over the reserves [1]. This situation makes many countries, including the United States, increasingly dependent on a foreign supply. In contrast to this dilemma, methane and other natural gas reserves are proven to exist throughout the world.

Natural gases, especially methane, are considered the cleanest fuel source [4]. With lower carbon dioxide emissions, natural gases are one of the possible solutions to significantly slowing down the rate of global warming and climate change. One problem with the use of natural gases is methane emissions. Methane emissions have been shown to contribute to greenhouse effects in the atmosphere but at much lower rates than all other types of fossil fuels, and preliminary research has shown that these levels outweigh the drastic effects of current fossil fuels [7]. As a new energy source to consumers, methane and other natural gases that could be converted efficiently to usable liquid forms is a preferred solution to the harmful effects of current fossil fuel sources.

Our invention will be widely operated by engineers, who will focus on developing the hardware and software of the technology; lab technicians, who will test the methanol production and eliminate any impurities involved in the experimentation process; energy production companies, who will figure out methods to optimize the device's efficiency and productivity; and consumers, who will use the final product as an energy source.

We determined that there is a substantial need for a device such as ours that would be able to make use of this methane. With a dwindling supply of petroleum in such an unstable geopolitical situation, the world must eventually turn to alternative fuel sources. Our solution makes use of the wide dispersion of natural gas reserves throughout the world. The evidence also shows that natural gases would be both economically and environmentally preferable. As noted earlier, the problem with using natural gases is that there is not an efficient way to convert these gases into a more usable liquid form that would be easy and less dangerous to transport. Our Senior Design Project focused on this problem, and we developed a reaction process that will cut the cost and risk of converting methane into methanol for industry use.

Benchmarking Results

The primary goal of our methane-to-methanol conversion device was to prove that our method would be able to drive down the production costs of natural gases and make their use an affordable and safe alternative to petroleum. A lot of research has been done to explore how natural gases can be transformed into alternative energy sources. As the world comes closer and closer to exhausting our fossil fuel supply, new technologies have explored the various routes of converting natural gases into usable energy fuels.

Methanol is a widely produced chemical worldwide and has many potential applications as a fuel. However, the many processes of producing methanol are very energy intensive and expensive. The primary method of producing methanol is a two-step process. The first step involves converting methane into a synthesis gas mixture of carbon monoxide and hydrogen. This step is extremely energy intensive and responsible for the high expense as it makes use of a selective catalyst. The stream must then be reformed to produce methanol. The problem with producing methanol is that it is highly reactive and it must be removed from the reaction once it is formed, preventing further oxidation of

methanol into carbon monoxide and carbon dioxide. The two-step industry process overcomes this issue but in a costly and inefficient way. The goal of our device was to bypass this two-step process and directly oxidize the methane into the methanol without the need for a catalyst or the pre-formation of a synthesis gas.

Over the past 40 years, two main additional approaches have been investigated to solve the problem of efficiently converting methane to methanol. The first involves homogeneous gas-phase partial oxidation [7]. Research in this field offers relatively low conversion rates (less than 10%) and low selectivity abilities. The second is heterogeneous catalytic partial oxidation with even less impressive results. New approaches have been considered that involve more direct methods. These liquid phase and supercritical reactor systems have also proved less than adequate in being able to competitively produce methanol.

Our closest competitor is research that makes use of the high levels of free radicals in plasmas [7]. Free radicals are known to play a major role in oxidation reactions such as the one we were trying to perform on methane. This method isolates the high energy plasma and allows the free radicals to react with methane at lower oxidizing conditions. This then promotes higher selectivity of methanol. Research continues in this field and our device was designed to be competitive with this method by increasing its yield and reducing its cost.

Challenges and Constraints

Environmental research on the effects of tapping into methane hydrates has shown that there are still many engineering concerns with getting the methanol out of these reserves, but our project is based off the assumption that this will one day be possible. There are also ethical concerns with the safety of sourcing methane from underground natural gas reserves [3]. Natural gas reserves are often isolated and difficult to access. If our device proves to be efficient, it would make the use of these remote reserves more economically attractive. Future developments in technologies may have to adjust to this new form of energy, but our project focuses on making the conversion process more efficient, thus determining whether or not sourcing methane will be worth further development.

Budget

This budget, as shown in Table 1 (see Appendix), contains our main project costs including the voltage source, electrodes, and gas tanks. Additional hoses, fittings, and hardware were also required throughout the process. The voltage source was donated to our project by Single Cell Technology. We received \$1000 from Santa Clara University Engineering Undergraduate Programs that we have used to purchase the gas tanks and electrodes, the main expenses of our project. We also competed in the SCEO Business Plan Competition with our Senior Design Project and won the \$1000 Grand Prize that was used towards the remainder of our project's expenses.

Design Process

Detailed engineering analysis was necessary to design our device. Figure 5 displays our conceptual thought process behind the experimental design. Our design describes the direct oxidation of methane to methanol using a separation mechanism and a salt bridge. This design was based on a conceptual schematic of fuel cells for the oxygen and methane gasses with a separation component to describe the interaction of the molecules. To develop the product, we starved the methane of oxygen, and did not form the final oxidized products (carbon dioxide and water). We used a potential difference (voltage) to form an electric field (dV/dx) that drove the chemicals through the long channels created by the ceramic clay particles. The goal of our reaction was to add a single oxygen per methane and let the (inevitable) extra kinetic energy dissipate into other molecules before the next oxygen is encountered. The resultant flow rate brought new methane and oxygen together for the next reaction. To test the efficiency and accuracy of our system we ran gas chromatography and mass spectrum analysis on both control methane and methanol and our final product methanol.

Risks and Mitigations

There were a few safety risks to consider as we worked on this project. As with any electrical device dealing with varying voltages, there was a significant risk of electrocution or shock. To avoid this occurrence, we took all possible precautions to be aware of the device and where the potential was dissipating when it was in operation.

Also, there was the risk of having two medium sized gas tanks that could potentially have fallen over and caused a dangerous explosion. To avoid this we made sure that the tanks were secured and regularly checked that they were in place. Gas leakage from the device into the room was another potential risk. At high concentrations, the methane could cause fainting. We dealt with this issue by constructing a long system of tubing to transport excess gas outside where it had no effect. Finally, methanol has the potential to be extremely toxic if not handled properly. We were aware of these potential risks and actively kept them in mind when proceeding with our project.

Team Management

To keep our project professional, we had to work effectively as a team and distribute the work and credit evenly. It was our responsibility to each other to do our share in an accurate and timely manner. All results were delivered honestly. Keeping records and evidence of our work kept us responsible for our progress and helped us to make accurate and informed conclusions about our work. Weekly team meetings and biweekly advisor meeting helped up move along on our timeline, and adjustments were made accordingly.

The Gantt Timeline described in Table 2 (see Appendix) portrays the week-to-week performance in designing the prototypes and developing the device in order to obtain methanol samples for testing purposes.

FUNCTIONAL ANALYSIS

Experimental Methods

When running the first prototype of the methane-to-methanol conversion device, the applied power to the inverter was around 13.5V, and the oxygen and methane flowed into the reaction chamber for one minute at a pressure of 20 psi. The two gases were allowed to interact within the acrylic box and ceramic flower pot for around 1 minute for round 1 and 2 minutes for round 2. However, because the second experiment ran for 2 minutes, it caused bright plasma arcs on the inside where there was no oxygen to make ozone. Due to issues with the volatile nature in the reaction between oxygen and methane, a second prototype was built to deal with the system level issues. Instead of using methane and pure oxygen, atmospheric oxygen was used (78% nitrogen, 21% oxygen). Consequently, there was much less energy in case of catastrophic mixing. The atmospheric oxygen was sufficient and the nitrogen should help reduce the reactivity if necessary. The tradeoff of using the second prototype over the first is the material that was used. Instead of using the same materials and gas container as shown in Prototype 1, we purchased a set of Vacucraft containers to build the Prototype 2. The resources used for the device were changed to ensure safety especially if the device cracked or exploded. Prototype 3 was fabricated due to human error in cracking the lid of Prototype 2. The experimental run involved designing controls for methane and methanol, and running the reaction between atmospheric oxygen and methane. An Infrared (IR) Spectroscopy was utilized in order to analyze the desirable methanol samples.

Sample Testing

In order to test the samples of the control methane, the control oxygen, and the reaction of the two gasses (methanol), we used a mass spectroscopy. The interpretation of the spectra involves the relationship of absorption bands in the spectrum of an unknown compound, in this case, methanol with the known absorption frequencies of bonds. The identification of the source of an absorption band involves intensity, shape, and position in the spectrum.

We were originally going to use a gas chromatography, a method for separating the components of a solution and measuring their relative quantities. This technique involves a sample that is rapidly heated and vaporized at the injection port. The sample is transported through the column by a mobile phase consisting of an inert gas. Sample components are separated based on their boiling points and relative affinity for the stationary phase, which is most often a viscous liquid within the column. The higher a component's affinity for the stationary phase, the slower it comes off the column. The components are then detected and represented as peaks on a chromatogram.

Samples were obtained by running the oxygen and methane gasses through our fabricated methane-to-methanol conversion device. Small amounts of the liquid (1-5 μL) were aliquoted in the designated vials and transferred them safely and carefully to the laboratory. After the initial steps are taken, the actual testing process takes about 10 minutes. It takes 5 minutes to set up the machine, from powering it on to manually entering the values for temperature and running time, and another 5 minutes for the liquid to evaporate and produce a chromatogram. It takes another 5-10 minutes to analyze the peaks, which will show oxygen, nitrogen, carbon, methane, and most importantly the sample we are testing: methanol. If methanol is detected, we took the time and intensity of the peak to help us understand how to repeat the process for more ideal results that match with prior research.

PROTOTYPE 1

Introduction

The container of Prototype 1 was fabricated with TAP Plastics materials to seal the gasses and chemical reaction of methane and oxygen. A ceramic pot was placed in the middle of the container with gas switches and tubing set for the regulation of the experiment.

Materials and Methods

The procedure for Prototype 1 involved 5 microliters (μL) of isopropyl alcohol (IPA) added to the inside of the ceramic pot and 5 μL inserted on the outside of the pot before putting the lid of the TAP Plastics container. The oxygen and methane tank was set at 2000psi, releasing around 20psi into the system. The gas flow ran for one and a half to two minutes with the voltage set to 12V. Observations were recorded.

Results

The experimentation did not produce any retrievable amounts of liquid for testing purposes. However, there was a scent of methanol in the device when opening the lid of the container.

Discussion

Running the concentrated oxygen and methane gasses into the system did not produce any liquid. This experiment was repeated three separate times fluctuating the time from one and a half minutes to 2 minutes, and making observations on the overall reaction inside the device. Because there was a scent of methanol in the system after the reaction, there was confirmation that the experiment did produce some product. We concluded that due to the improper rubber sealing and tightening of the TAP Plastics device along with a lack of a proper protocol to prevent the liquid from evaporating we needed to design a new procedure for the experiment.

PROTOTYPE 2

Introduction

Due to the volatile nature of the reaction between methane and oxygen along with the fact that we had been experimenting with the time of applied potential, a large crack resulted in our initial prototype. Instead of recreating Prototype 1 by ordering new TAP Plastics materials and reassembling the device, we decided to order Vacucraft containers. These containers are able to be vacuum sealed tight which we hypothesized would help us maintain the desired pressure of our reaction. Similar tubing, ceramic pot, and aluminum foil were used as in Prototype 2.

New Approach and Expected Results

We decided to use Vacucraft containers in order to better seal in our reaction and control for the pressure in the reaction. However, we decided that based on the high energy of the reaction between methane and the concentrated oxygen that was emitted from the oxygen tank, that atmospheric oxygen would be a safer alternative for the parameters of our project. If we had had access to a larger, better safety-equipped area, concentrated oxygen most likely would have given us better results overall but without these criteria we did not feel comfortable taking the risk. Since we were able to see some methanol in the bottom of our device before it cracked, we expected to see methanol again with Prototype 2 although with more impurities from the atmospheric air conditions. Since the gas chromatography and mass spectrum devices that were to be used to analyze the samples needed at least 1-2 μL of fluid, for this Prototype we added IPA to each chamber of the device to absorb any liquid or gas that was produced by the reaction. IPA has very distinct peaks and properties from methane, methanol, and formaldehyde (the key intermediate in the reaction) and would not interfere with the testing of our samples.

Materials and Methods

The procedure for Prototype 2 was similar to that of Prototype 1. About 5 μL of IPA were added to the inside and the outside chambers of the device before it was sealed shut. The chambers of the device were evacuated to reach atmospheric pressure. Oxygen was released into the system at atmospheric pressure. Methane was then released into the

system for one and a half minutes. The potential was applied in the same manner through the ignition system and coil for one and a half minutes. The whole device was placed into a freezer in order to condense the products of the reaction and encourage liquid formation. The samples were collected into vials and transported on dry ice for testing.

Results

Unfortunately, due to unforeseen complications with the gas chromatography machine, we were unable to test our samples the following day as planned. While we waited two weeks for repair on the machine, the samples were kept frozen on dry ice. When we returned to test our samples the machine was still down and we opted to use the mass spectrum instead. The results of our mass spectrum are shown in Figure 6 (see Appendix). Although magnified, there is clearly a formaldehyde peak around 60 mass per charger (m/z) and a smaller methanol dimer peak as 62 m/z . The methanol monomer is expected at approximately 30 m/z .

Discussion

One of the main reasons that there is a large formaldehyde peak in our results and a small methanol monomer peak is the fact that we used atmospheric oxygen instead of the pure, concentrated oxygen that we had used for Prototype 1. The volatile nature of this reaction and the space we had to experiment in were not compatible, and we opted for impure, atmospheric oxygen. If we had been able to collect samples from our first prototype, we hypothesize that the results would have shown this. With fresh samples, we hoped to eliminate or lessen this appearance in further testing. Also, although the samples we left frozen on dry ice, the fact that they were not tested for two weeks before testing led to the formation of methanol dimers in our samples. Dimers, hydrogen bonds between two of the same molecules occur easily in methanol and do not typically affect chemical activity. We were interested to see if fresher samples would have the same phenomenon.

PROTOTYPE 3

Introduction

Through transportation of our device and repeated tight sealing with clamps, eventually the plastic Vacucraft containers gave out, and we needed to build another prototype for our final round of testing. Due to time and budget, we used additional Vacucraft containers that we had bought previously and reconstructed Prototype 2. The materials and methods remained the same from Prototype 2 to Prototype 3 except that the samples were tested the following day and not two weeks later.

Results

From this round of testing, we have results for control methane, control IPA, control methanol in a monomer form, and control methanol in a dimer form, found in the appendices for Figures 7, 8, 9, and 10 respectively. We also have results from the samples that were taken from both the inside and outside cavities of the device.

Consistent with the results from Prototype 2 we still have a significant formaldehyde peak and methanol dimer peak as shown in Figures 11, 12, 13, and 15. The methanol monomer peak is more apparent here at approximately 31 m/z as seen in Figure 14 (see Appendix).

Discussion

Again we see the formaldehyde intermediate peak primarily due to the impurity of atmospheric oxygen. The methanol dimer peak is still significantly more apparent than the monomer peak, which shows how reactive methanol is. Even in the control, lab-grade methanol, the methanol dimer is more apparent than the monomer. The reaction could be optimized with purer oxygen and a longer time of applied potential, but due to safety constraints, our results show the impurities of the reaction. However, clearly the reaction did occur to some extent, which means that proceeding with further research could potentially have huge results given more time and safety precautions.

SUMMARY AND CONCLUSIONS

The U.S. goes through about 29 million of barrels of oil per day and we use resources such as coal, oil, and these finite resources as if they are going to last forever [5].

However, we have to face facts: smog, carbon emissions, and climate change, are all reasons why we have to switch from fossil fuels to alternatives, and those reasons are getting more urgent as time goes on.

Because we safely and efficiently produced methanol from the experimental reaction, as observed by graphs and data from the Infrared Spectroscopy analysis, we can take this project to the next level by determining methods to deliver pure methanol samples and obtain quantitative amounts of the fuel. It can also be utilized in oil fields that regularly burn off natural gas as an unwanted by-product and in small factories and homes to convert natural gas into methanol, potentially as a transportation fuel. This device also can play a role in chemical factories needing methanol feedstock.

With the ability to supply energy to the machines and technologies we own today, this invention has risks that need to be considered. Due to the volatile and explosive nature of the methanol, the chemical needs to be safely transported and contained. By researching the dangerous features of these liquid and finding techniques to make the device user-friendly and safe for users, we can illustrate how methanol can provide a greener atmosphere. With the adaptable, affordable nature of this low-energy, high-volume process, the current petroleum reserves and finite resources can be conserved; also, it can make remotely located natural gas reserves more usable and economically attractive.

With the innovation of this idea, we have filled for the Provision Patent Application (PPA) and will submit our final results to patent this process. We would like this efficient device to have a huge influence in addressing human needs for products in emerging, underdeveloped nations.

The future steps we plan to take with this project are to continue testing the device in order to quantify the results of the methanol sample. In addition, we plan to develop further prototypes that will optimize the efficiency, cost and production of the device. We also would like to model and simulate the reaction. The goal is to find the interaction

between the theoretical and experimental values; by mathematically modeling the reaction between methane and oxygen, we can alter the parameters (such as temperature, time, pressure, or gas flow) to develop a stronger understanding on how to maximize the system productivity. After achieving the patent, we can continue exploring routes that can modify our technology, establish partnerships with researchers involved with sustainable energy, and examine funding opportunities to further our goals with the project.

ENGINEERING STANDARDS AND REALISTIC CONSTRAINTS

Following are the factors that we have taken into consideration in developing our device:

Environmental

Although there is substantial evidence that using methanol as a fuel source would reduce carbon emissions into the atmosphere, there are other environmental concerns with the sourcing of methane. Methane is one of the most emitted greenhouse gases from both natural sources and human activities [4]. The prevalent sources of methane emissions are livestock and the production of crude oils. One of the ultimate uses for our device would be to harness this excess waste and use it as a further fuel source instead of letting it emit into the environment [6]. However, this poses more difficult engineering challenges that will need to be addressed by future projects. In addition to recycling a common waste product, methanol burns cleaner than petroleum and will result in a smaller carbon footprint.

Political

Many political relationships and contracts exist between countries that rely on the exportation of crude oil. Since a minority of countries has direct access to petroleum reserves, there tends to be conflict surrounding the distribution of this resource. The ultimate end-goal of our project is to change these geopolitics by creating a device that will be able to give countries fuel self-sufficiency [5]. By providing a reliable energy supply that is resistant to the highs and lows of worldwide trade, more political focus can be spent on other issues such as world hunger, poverty, and environmental policy.

Health and Safety

The main health and safety concerns that constrict our device are the volatility of the materials and methanol's toxicity. Methane, although nontoxic, can be highly reactive and flammable. It is important to address these issues when doing any experimental work with methane because of its reactive tendencies. In addition, to methane's potential for explosions on a large scale, methanol, the final product, is toxic to humans. In small quantities, if ingested, methanol can cause permanent nerve damage or death if not

immediately treated with antidotes. To overcome this, a potential solution could be to dilute the methanol before distribution to the consumers as is currently done with petroleum.

Manufacturability

The future of our device could be to create a portable version that could be transported with a large vehicle to directly oxidize methane sources on site and then transport the formed methanol. Further engineering will have to be done in order to make this concept a reality. The manufacturability of our device and its connections to the methane source and a storage container must be considered. There are many components to deliberate with the future manufacturability of our device if it were to ever reach market. In its primary stage of development, we were able to produce three separate prototypes for under \$2000 which is of little consequence when the potential benefits are in the millions.

After we gain experience with a large unit, we anticipate building a smaller unit that can be operated by a family or individual within the confines of a home or apartment. This would allow individuals or small groups to tap available natural gas as a realistic replacement for gasoline.

Ethical

As bioengineering students from Santa Clara University, we had many ethical responsibilities to address in the development of our Senior Design Project. Our project is designed to help our future generations who will have to deal with a dwindling supply of petroleum oil and resources. The goal of our device was to begin the inevitable transition away from petroleum and make use of an underused resource. The success of the device could potentially resolve global issue of the need for an alternative fuel source.

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APPENDICES

A-1. Power System of Prototype 1

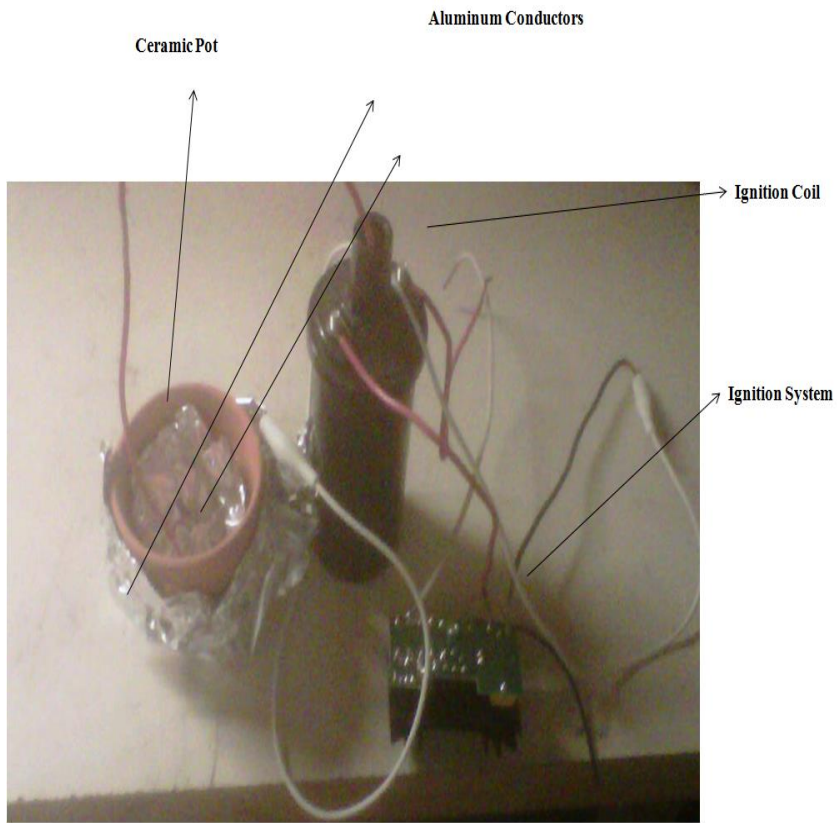


Figure 1. Design of the power system used for the first prototype with the ignition coil, ignition system, ceramic pot, and aluminum conductors.

A-2. Design of Prototype 1

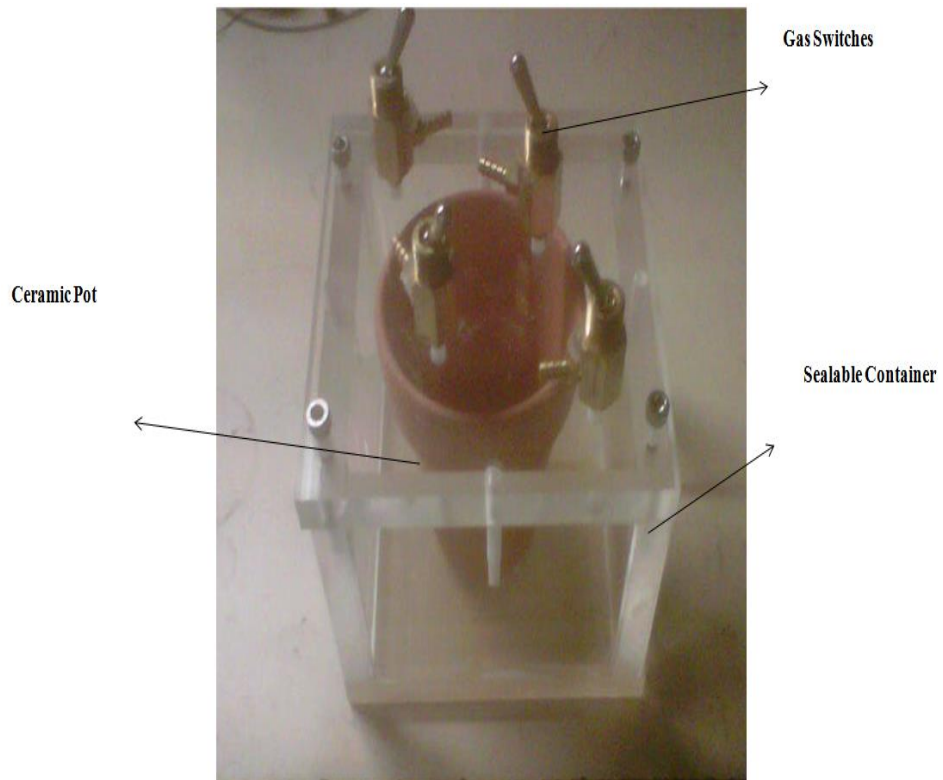


Figure 2. Design of first prototype with the ceramic pot, sealable container, and gas switches.

A-3. Design of Prototype 2

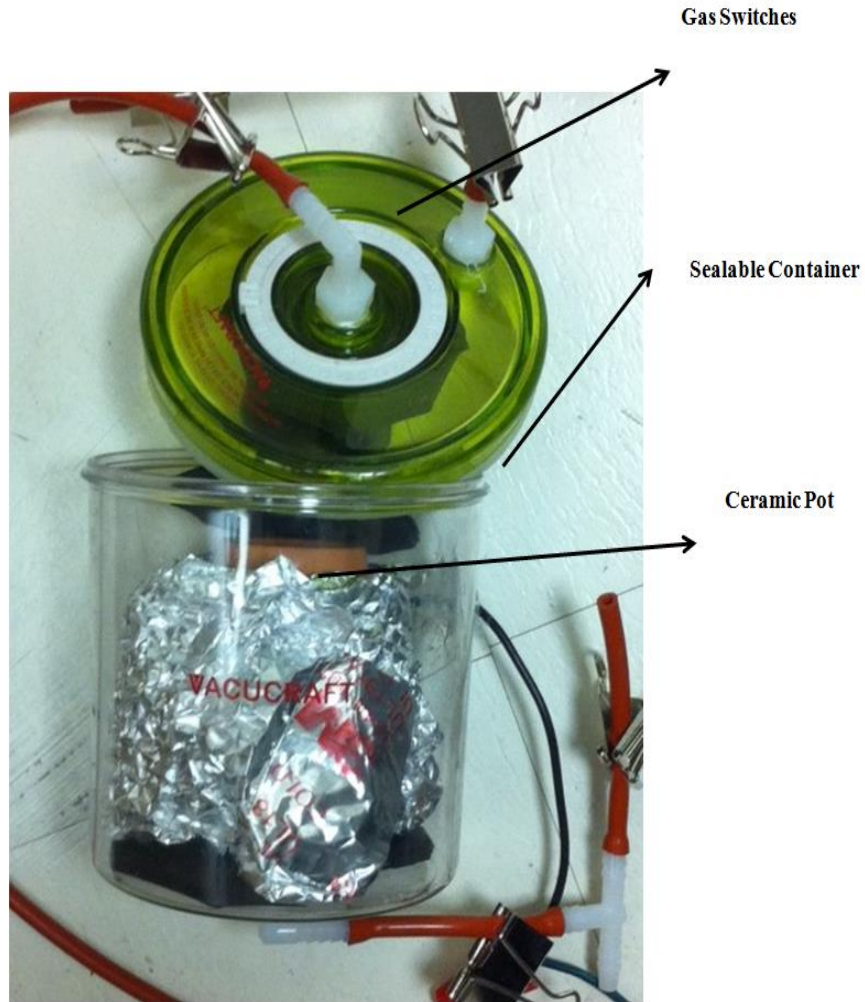


Figure 3. Development of second prototype with ceramic pot, sealable container, and gas switches similar to Prototype 1.

A-4. Design of Prototype 3



Figure 4: Development of third prototype with ceramic pot, sealable container, and gas switches.

A-5. Schematic of Methane-to-Methanol Conversion Device

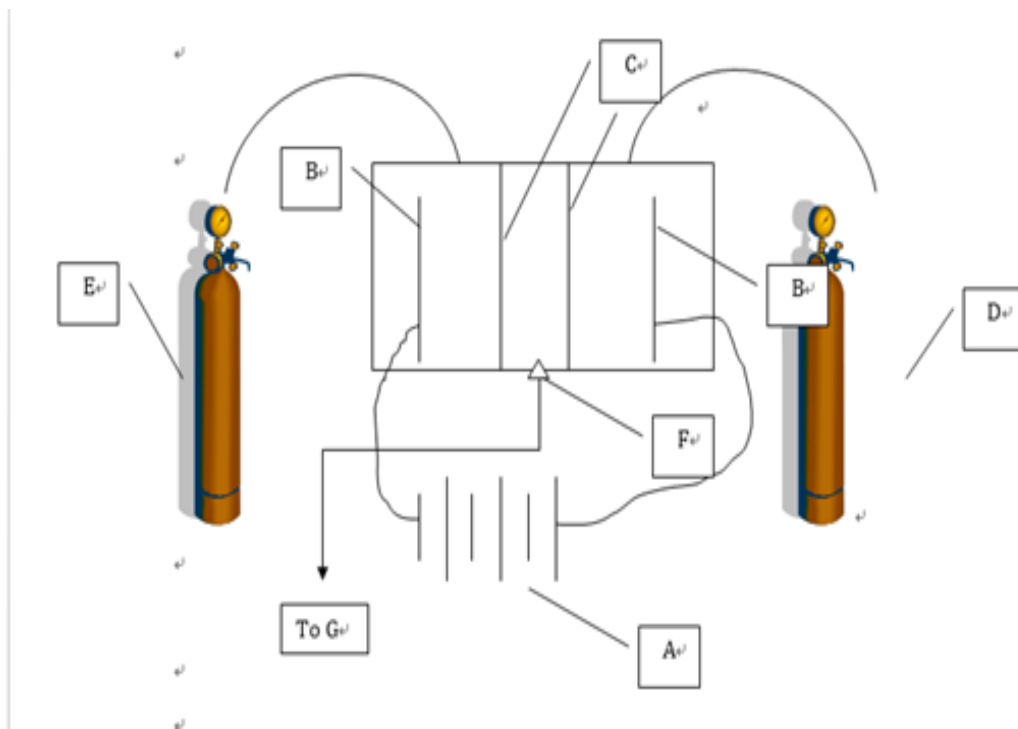


Figure 5. Schematic of the experimental design and function, where A represents the voltage source, B are the electrodes to establish an electric field, C is the dielectric barrier containing many small channels, D is the source of O_2 gas, E is the source of CH_4 gas, F is the means of extracting liquid products of the reaction, and G is the means of testing said products for their chemical composition.

A-6. Prototype 2 – Inside Ceramic Pot

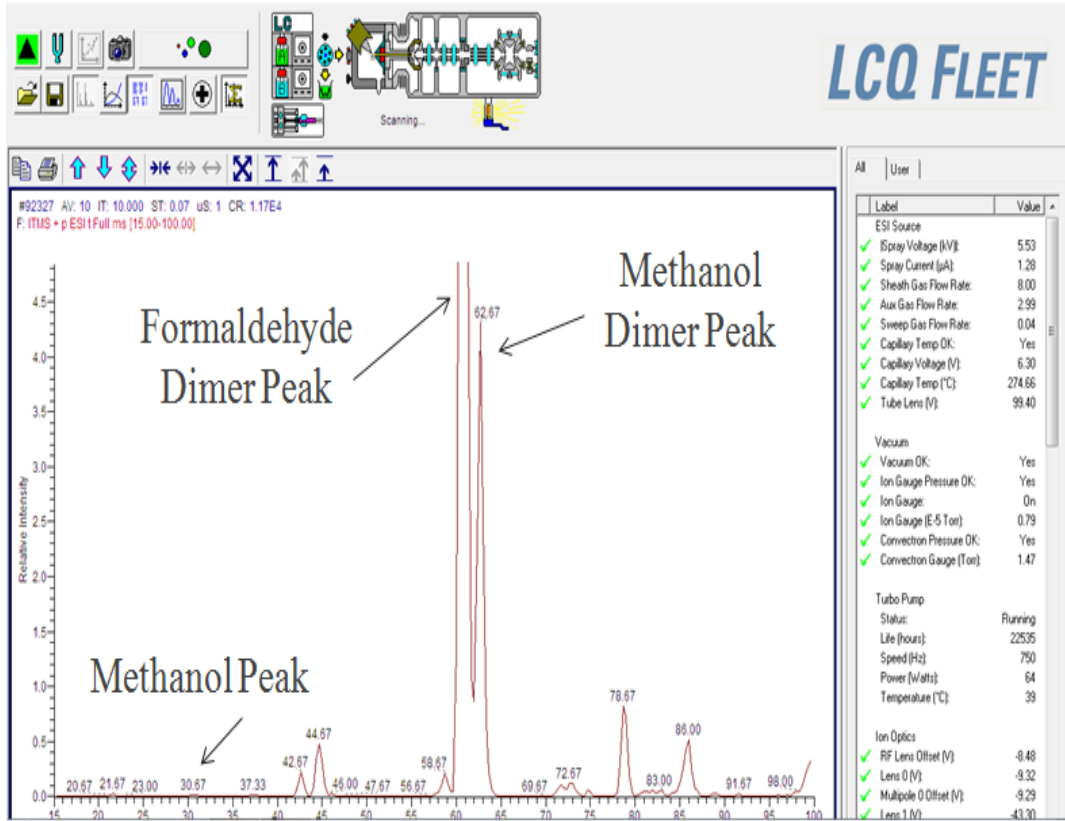


Figure 6. IR Spectroscopy graph displaying the three peaks: methanol peak, formaldehyde dimer peak, and methanol dimer peak in Prototype 2.

A-7. Control Methane Mass Spectrum

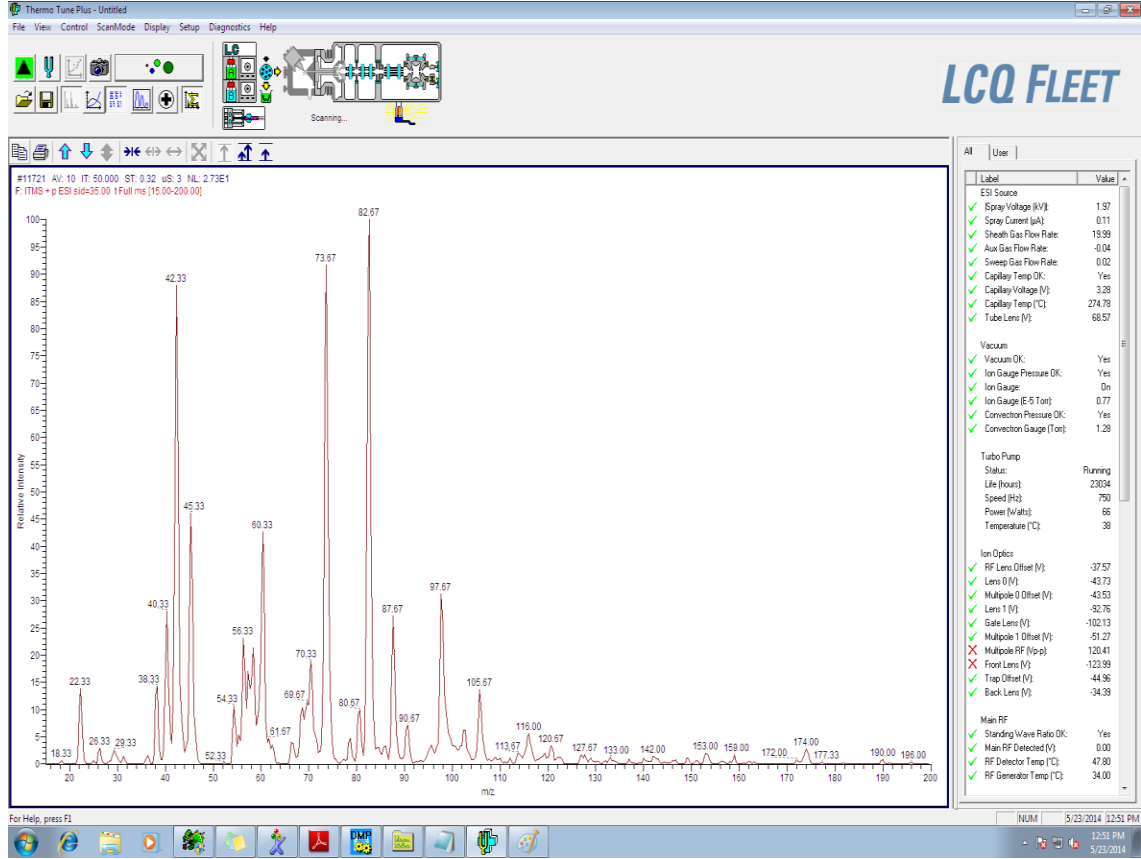


Figure 7. Control methane mass spectrum.

A-8. Control IPA Mass Spectrum

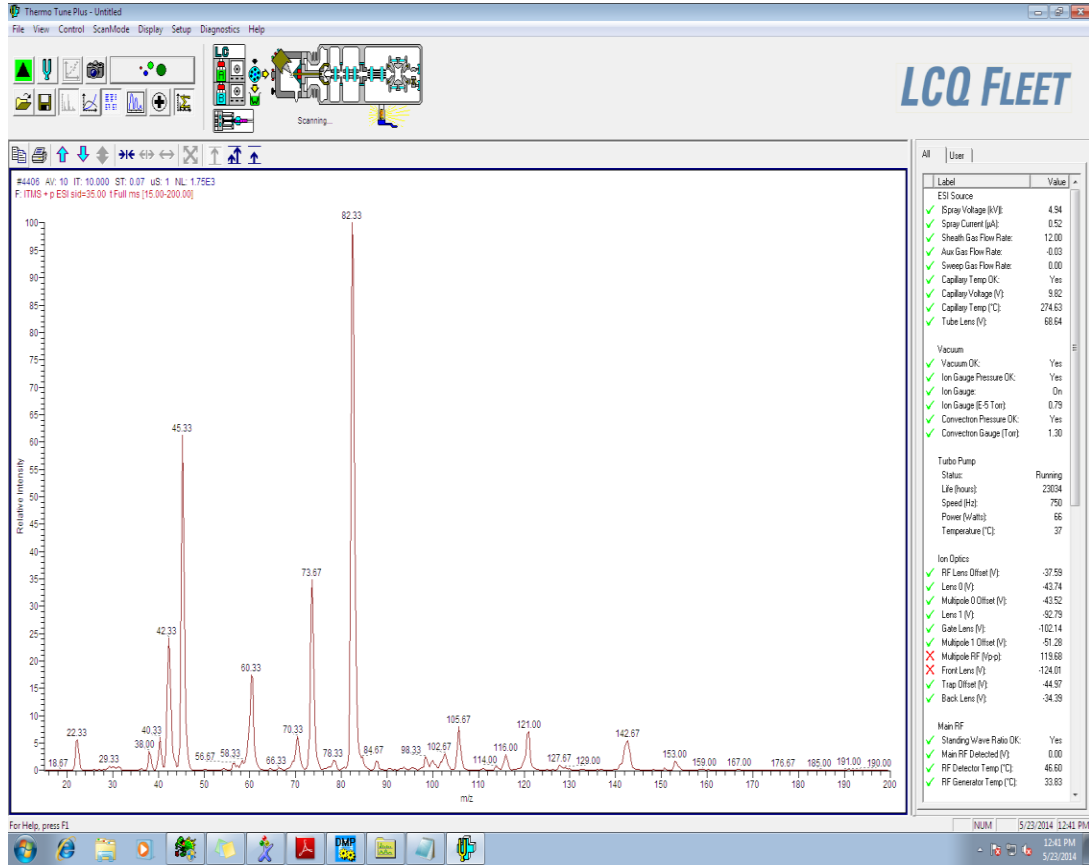


Figure 8. Control IPA mass spectrum.

A-9. Control Methanol Monomer Mass Spectrum

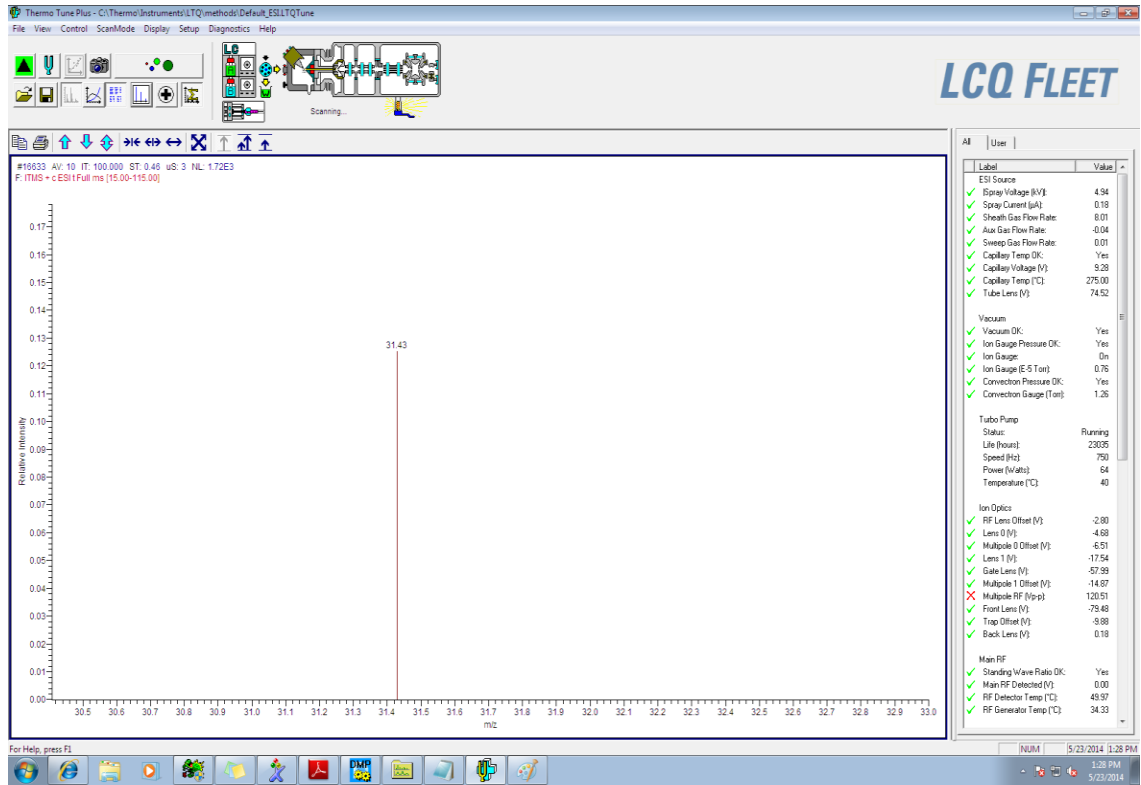


Figure 9. Control methanol monomer peak.

A-10. Control Methanol Dimer Mass Spectrum

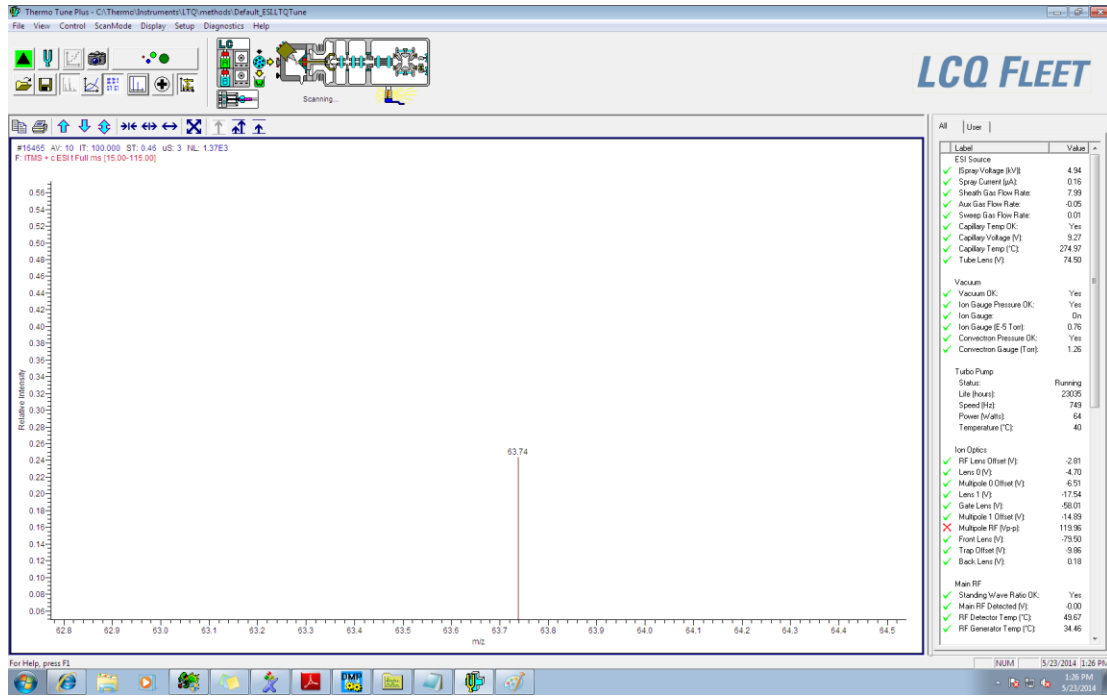


Figure 10. Control methanol dimer peak.

A-11. Prototype 3 – Inside Ceramic Pot

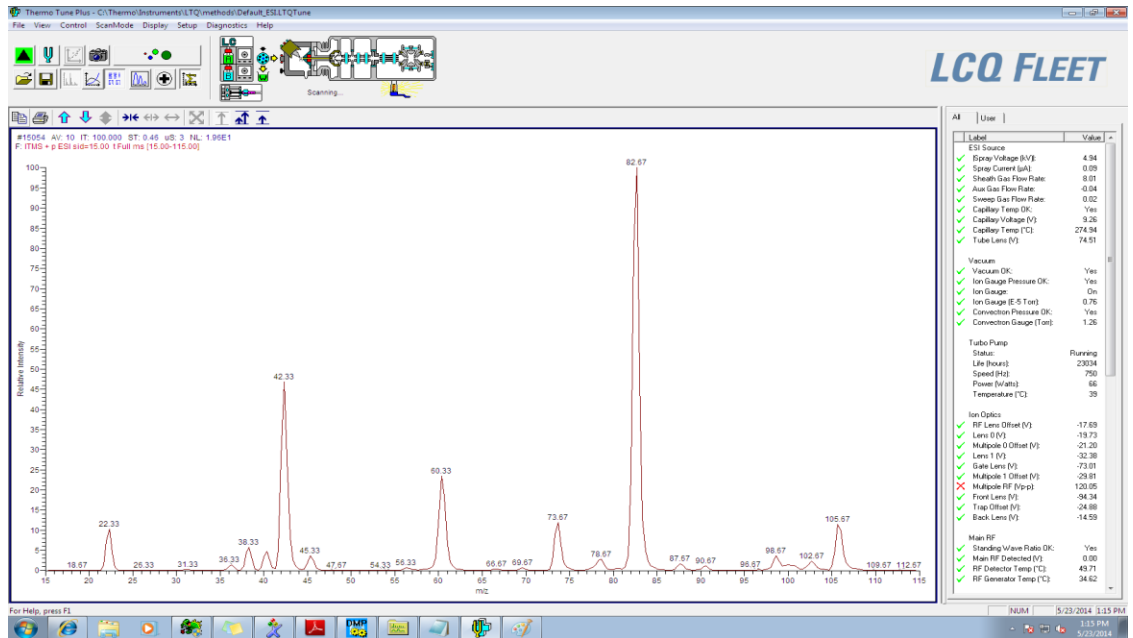


Figure 11. Prototype 3 results displaying methanol dimer at 62 m/z and formaldehyde peaks at 60 m/z inside the ceramic pot.

A-12. Prototype 3 – Inside Ceramic Pot (Magnified 1)

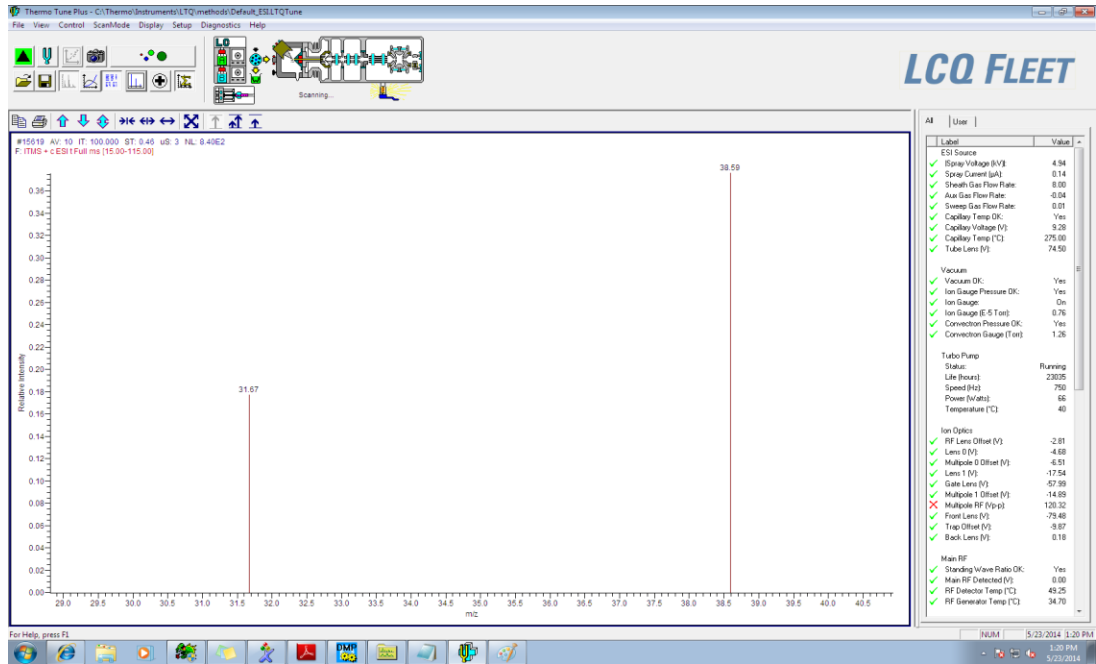


Figure 12. Prototype 3 results displaying the methanol monomer peak at 31 m/z and 36 m/z. Sample obtained from inside of ceramic pot.

A-13. Prototype 3 - Inside Ceramic Pot (Magnified 2)

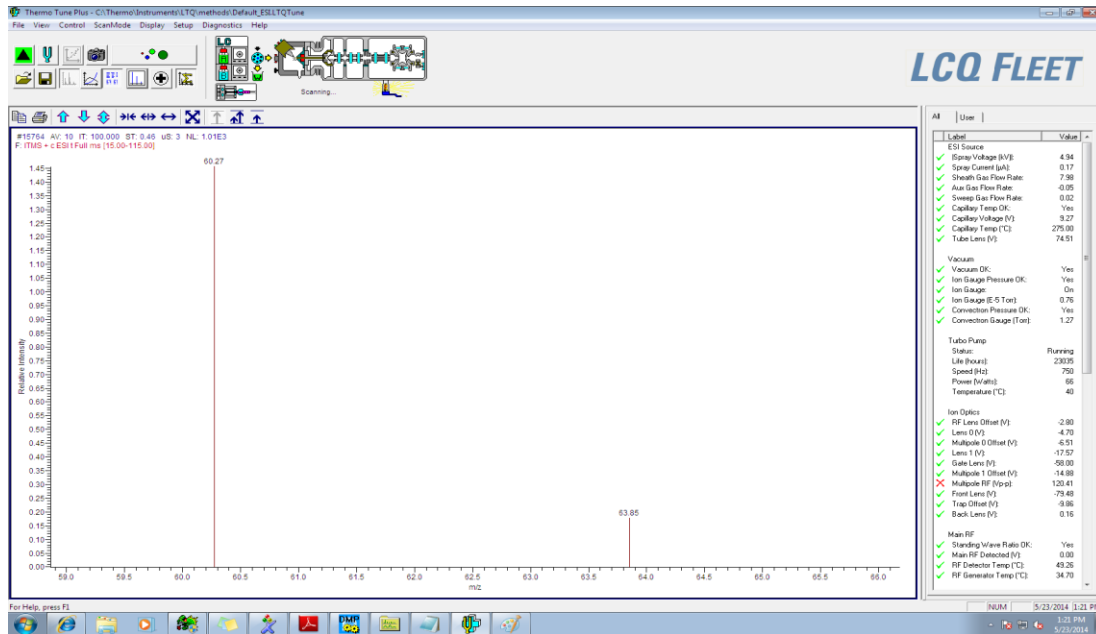


Figure 13. Prototype 3 results displaying methanol dimer (64 m/z) and formaldehyde peaks (60 m/z). Sample obtained from inside of ceramic pot.

A-14. Prototype 3 - Outside Ceramic Pot (First Sample)

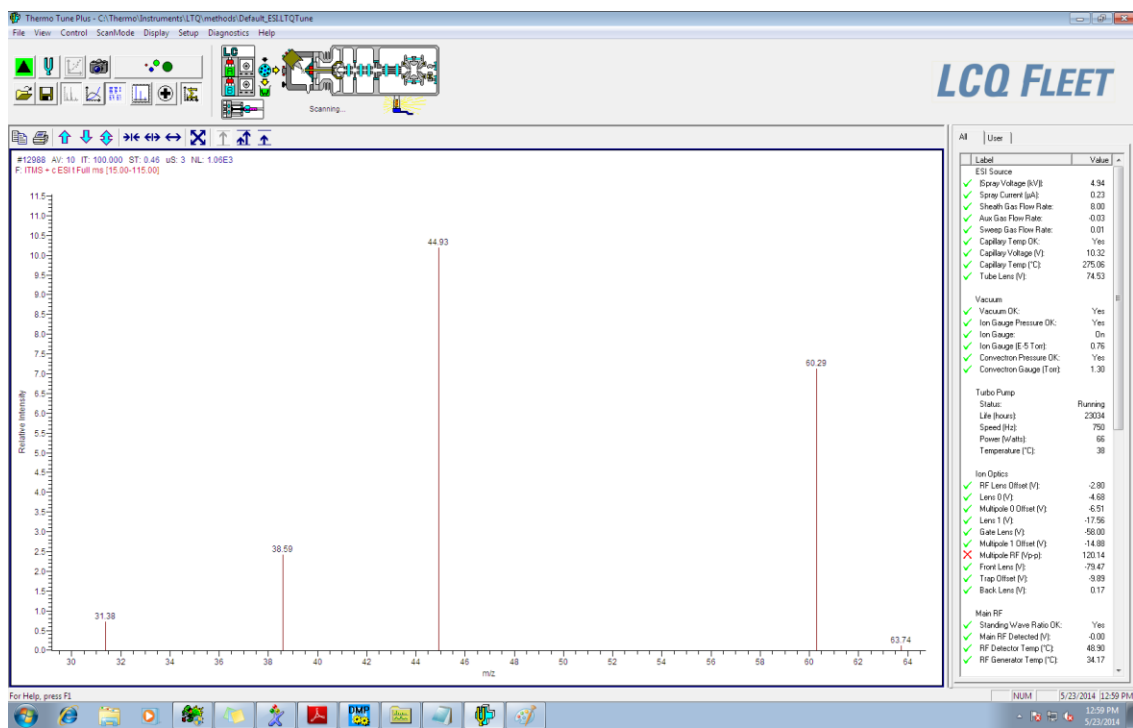


Figure 14. Prototype 3 results displaying methanol monomer at 31 m/z and 34 m/z, methanol dimer at 64 m/z, and formaldehyde peaks at 60 m/z outside of the ceramic pot. The large peak 44 m/z is another intermediate or impurity.

A-15. Prototype 3 –Outside Ceramic Pot (Second Sample)

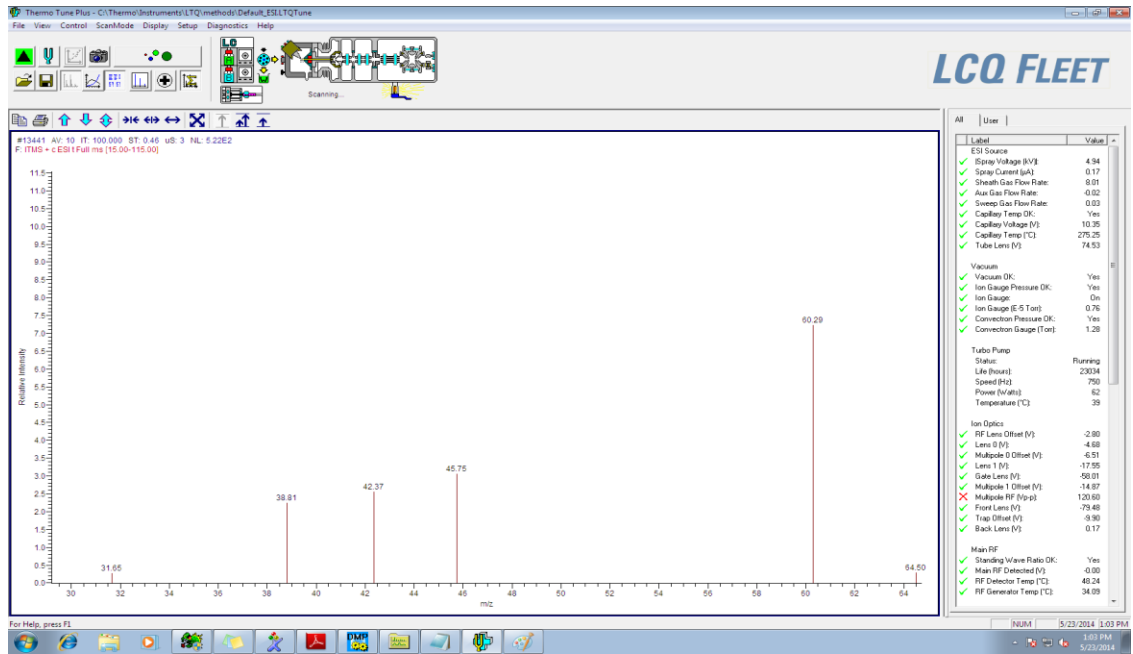


Figure 15. Prototype 3 results displaying methanol monomer at 31 m/z, methanol dimer at 63 m/z, and formaldehyde peaks at 60 m/z outside of the ceramic pot. All other peaks are potential intermediates or impurities.

A-16. Budget

Table 1. Budget for Methane-to-Methanol Conversion Device Project

Items	Purchase History	Cost (\$)
High current voltage source	Single Cell Technology	300
Oxygen: tank and regulator	Praxair	400
Methane: tank and regulator	Praxair	450
Hardware, Syringes, Miscellaneous	NA	150
Provisional Patent	Nolo.com	200
Total Estimated Cost		1500

Funding Organizations	Amount Received (\$)
Santa Clara University's School of Engineering Senior Design Grant	1000
Santa Clara Entrepreneurship Organization	1000
Total Funding Received	2000

A-17. Experimental Data

Table 2. Experimental Data for Prototypes 1, 2, and 3.

Experiment Number	Gas Flow Time (min)	Methane and Oxygen Regulator Pressure (psi)	Voltage Applied to Ignition System (V)	Injection Volume (μL)
Trial 1 (Prototype 1)	2	10	12	3
Trial 2 (Prototype 1)	3	10	12	3
Trial 3 (Prototype 2)	1	20	12	5
Trial 4 (Prototype 2)	2	20	12	5

A-18. Gantt Timelines

Table 3. Gantt Timelines Winter and Spring Quarters.

