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ARTICLE

The Methane Recycler

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Currently, a large portion of the world relies on natural gas furnaces to heat their homes. However, they are harmful to the environment, and natural gas is non-renewable. The alternative to natural gas furnaces is electrical furnaces. However, due to the high financial cost, many people are unwilling to replace their current furnace with a new one that uses electricity. To help solve this issue, we have created a modification to these residential furnaces that allow for the recycling of the main ingredient in natural gas, methane. This innovation is able to recycle methane with no emissions and utilize only electricity. This allows our innovation to convert any natural gas furnace into an electrical furnace, at a much lower initial cost.

INTRODUCTION

Natural gas furnaces are cheap but emit greenhouse gasses, and electric furnaces are costly. We realized this issue when our families decided to look into ways for climate-friendly heating and discovered the high cost of electric furnaces.

To solve the issue, we came up with an idea to recycle the byproducts of burnt methane, which is the main component of natural gas. This would be much cheaper, as a new furnace would not need to be installed, only the modification of the existing natural gas furnace would be required. The reactions to recycle methane takes inspiration from commercial power-to-gas plants (Science Daily, 2020), which use electricity to produce gas via electrolysis. Electrolysis produces hydrogen and oxygen gas from water ($2H_2O \rightarrow 2H_2 + O_2$). The Sabatier reaction ($CO_2 + 4H_2$ $CH_4 + 2H_2O$) ("Sabatier reaction", 2021) is used to create methane and water from the hydrogen gas created during the electrolysis of water, and carbon dioxide, which is produced when methane is burned ($CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$) (Chapter 5.3.3 - Application of Hydrogen by Use of Chemical Reactions of Hydrogen and Carbon Dioxide, 2018).

The final product must be easy to install, have minimal environmental impact, be less expensive than other solutions, be adequately efficient, and not pose any hazard to the users of the product. Meeting these requirements would make it a potential alternative to electrical furnaces.

METHODS AND MATERIALS

As natural gas is composed of multiple gasses such as methane, ethane, and propane, we decided to only focus on recycling methane, as it makes up around 95% of natural gas and it would make it simpler. We believe the best way to do this would be to install this modification on the exhaust of our natural gas furnace, where the byproducts of burned methane are routed.

We took the byproducts of carbon dioxide and water from the combustion of methane and ran the byproducts through tubing into the electrolysis and Sabatier chamber (Figure 1). The electrolysis chamber runs direct current electricity through the water, separating water into hydrogen and oxygen gas. The oxygen is routed into the furnace to allow the fire to continue burning, while hydrogen is routed with the carbon dioxide to the Sabatier reaction chamber, where water and methane are created. The newly formed water is cycled back into the electrolysis chamber for future use, while the methane is returned to the furnace for burning.

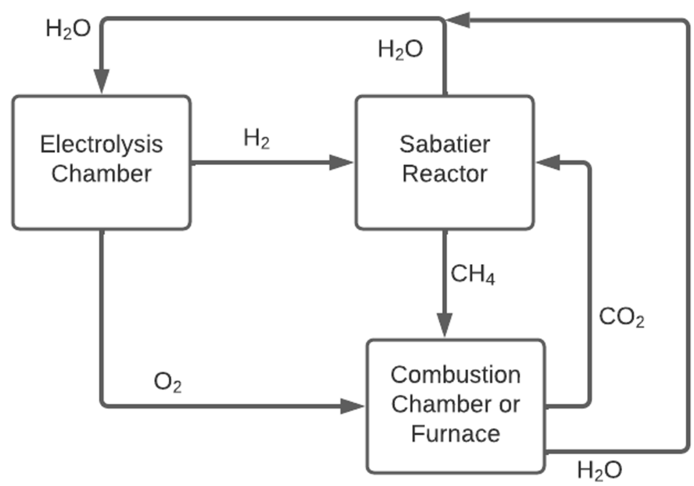

Figure 1: Diagram of our setup.

At first, we created a proof of concept of the reactions in a separate test to ensure our reactions worked. Then we designed and 3-D printed a prototype (Prototype 1) with a closed system as this would be required to make our product function properly. We then built a second prototype (Prototype 2) that improved on Prototype 1.

In our proof of concept, we used plastic bottles for the chambers, plastic tubing to connect the chambers, a DC car charger to run electricity for electrolysis, nickel as a catalyst for the Sabatier reaction, and a soldering iron which would provide the 450°C temperature required for the activation energy of the Sabatier reaction. The proof of concept is held together and sealed with hot glue and Flex Seal.

When building the proof of concept, we did not focus on build quality, as it only needed to prove that our reactions were possible in a real-world environment. We connected all the parts and had a separate bottle with water, baking soda, and citric acid to mix and produce the carbon dioxide necessary to start the reaction. At the other end, we produced hydrogen gas through electrolysis. Both the carbon dioxide and hydrogen were routed to the Sabatier chamber, where a soldering iron heats a strip of nickel to approximately 450°C as a temperature of around 400°C is needed for the reaction.

Next, we created our 3-D printed Prototype 1 and had the tube fittings built into it. Inside, we used various containers for the majority of the chambers. This prototype was relatively similar to our proof of concept, with a number of the parts being reused. We reused the plastic tubing to connect the bottles, the car charger, the soldering iron, and nickel.

We later built Prototype 2. This was made with a soldering iron, tubing, nickel, a car charger, a water bottle, and a metal can for the Sabatier reactor. One end of the Sabatier reactor connects to the furnace's exhaust, and the other to the furnace's intake. The car charger was also connected to an electrical outlet. To connect our plastic tubing, we used barbed hose connectors. We also added an exhaust tube to show how the water and carbon dioxide would separate. The exhaust connections had one input and two outputs. The input connects to the furnace; the output connects to the carbon dioxide exhaust that leads to the Sabatier chamber for the carbon dioxide. The second output was for the water formed. It was intentionally placed in the middle at the lowest point of the tubing so that when the water vapor condenses into a liquid, it will flow down to the lowest point, which is routed to the electrolysis chamber.

We then ran two tests and two control tests to measure the rate of methane produced. These control tests were done on the working setup with a desiccant in the cup, without a catalyst or electrolysis, and with the soldering iron and CO2 production on. We did not produce any methane or water, allowing us to measure the ambient water in the environment. To do this, we used anhydrous magnesium sulfate ($MgSO_4$), which we prepared by heating Epsom salt to 287°C. This is a desiccant, which means it absorbs water readily. We used this to find the amount of methane produced, as water is produced in a 2:1 molar proportion. The difference in weight of the desiccant before and after equals the weight of water produced. We then converted that weight into moles, and divided it by two, getting the amount of methane in moles. Then, we converted that to milligrams, yielding the amount of methane produced.

RESULTS

In Prototype 1, the soldering iron melted the 3-D printed body and was unsuccessful. However, in Prototype 2, we noted the condensation of water on the sides of our bottle chamber. We would have liked to ensure methane was present by igniting it, but due to the amount of methane produced, we were not able to.

The theoretical efficiency of our product can be measured by the amount of electrical energy converted into chemical energy, which is currently about 52 percent. The remaining 48 percent of electrical energy is converted to kinetic and thermal energy. This is calculated by combining the theoretical efficiency of both reactions. The theoretical efficiency of electrolysis is approximately 65 percent, and the theoretical efficiency of the Sabatier reaction is approximately 80 percent (Benjaminsson, G., Benjaminsson, J., & Rudberg, R. B., 2013)

Table 1 shows the amount of water detected in each test. In the first test of measuring the amount of methane produced, the weight of the $MgSO_4$ and cup before running our prototype was 45.345g. After running our prototype for 30 minutes, the weight was 45.375g, meaning we produced 30 milligrams of water in 30

Table 1: Amount of water detected and the difference between experimental and control tests.

Test Type	Water detected	Average water detected	Difference between the Average Test and Average Control
Test 1	30mg	32mg	17.5mg
Test 2	34mg		
Control 1	11mg	14.5mg	
Control 2	18mg		

$$\frac{0.0175g\ H_2O}{30\ minutes} * \frac{1\ mol\ H_2O}{18.015g\ H_2O} * \frac{1\ mol\ CH_4}{2\ mols\ H_2O} * \frac{16.04g\ CH_4}{1\ mol\ CH_4} * \frac{1000mg}{1g} = \frac{7.79mg\ of\ CH_4}{30\ minutes}$$

Equation 1: Equation for conversion between water and methane.

minutes. In test 2, the weight of the cup and $MgSO_4$ was 12.472g and became 12.506g after the test, meaning we made 34mg of water. Converting it to methane would be 15.14mg/30 minutes.

In the first control test, the cup was left in a closed container for 30 minutes and measured before and after the 30 minutes. The cup's weight was 12.075g, and the weight after was 12.086g, meaning it collected 11 milligrams of water in 30 minutes. In the second control test, the cup's weight was 11.621g, and the weight after was 11.639g, meaning it collected 18 milligrams of water after 30 minutes.

The average amount of water produced by the two tests was 32mg in 30 minutes, and the average amount of water collected in the two control tests was 14.5mg every 30 minutes. Therefore, the difference is 17.5 mg of water every 30 minutes. Converting that to mg of methane, we produced 7.79mg of methane in 30 minutes (Equation 1).

DISCUSSION

The condensation formed on the bottle during the tests could only have been caused by the water created by the Sabatier reaction, thus proving we produced methane and our reactions worked. These results show that a residential methane recycler can produce 7.79 mg of recycled methane in 30 minutes. Future work should be done to increase the speed and efficiency of our reactions. To do this, future work should use a catalyst with a larger surface area to increase the reaction speed and a ruthenium-based catalyst (Christian et al., 2011) to increase the Sabatier reactor's efficiency. It would be more efficient to heat the catalyst directly than the soldering iron. Using a strong base such as sodium hydroxide as an electrolyte for electrolysis would increase its efficiency (Benjaminsson, G., Benjaminsson, J., & Rudberg, R. B., 2013). The next steps would be to ensure everything is air-tight and improve the efficiency/speed of our product. Additionally, we should keep the variables the same when testing, as we could not run the control tests with all chambers active.

CONCLUSION

Prototype 2 demonstrates the way our final product would work. Everything is structurally sound. All the reactions, including the electrolysis and Sabatier reactions, worked, demonstrating the functionality of our prototype. Future studies should focus on improving the speed, efficiency, and safety of recycling methane.

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Hi, I am Farhan, a Grade 9 student at the Surrey Academy of Innovative Learning. I am interested in general science or anything that seems interesting, with my main interests being chemistry, mineralogy, and math. My secondary interests are engineering, astronomy, and physics. My post-secondary/career plans are to go to UBC and have a career in science, such as a chemist or physicist. Some of my achievements include finishing grade 11 math in grade 9, studying grade 12 chemistry in grade 9, and getting a bronze medal in the CWSF.

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I am a grade 10 student in Surrey, BC. I won a bronze medal in the Canada-wide Science Fair with my partner, Farhan Ahmed. I have an interest in computer technology and programming, along with interesting topics. When not learning about computers or participating in science fairs, I am usually playing the piano, video games or watching TV shows.