A Review of the Gasoline Engine Vortex Tube Retrofit Waste Heat Recovery and Exhaust Reforming System

By: Nykyta Vovk

In collaboration with Bob Greenyer and the Martin Fleischmann Memorial Project

Table of Contents

1.0 Introduction

2.0 Background

3.0 Unit Operations In Depth

- **3.1 Pre-Ionizer**
- **3.2 Diffuser/Bubbler**
- **3.3 Vortex Tube**

4.0 Conventional Means to Achieve Claimed Results and Routes of Possible Results Manipulation

5.0 Proposed Experimental Replication

- **5.1 Materials and Components**
- **5.2 Data Acquisition**
- **5.3 Experimental Protocols**
  - **5.3.1 Mass Spectrometer Characterization**
    - **5.3.1.1 Response Time Characterization Protocol**
  - **5.3.2 Craftsman 5000-Watt Gasoline Generator Tests (without retrofit system)**
    - **5.3.2.1 Generator No Load**
    - **5.3.2.2 Generator Loaded**
  - **5.3.3 Retrofit System With Generator Experiments**
  - **5.X.X.X Preliminary data/results to guide discussion/suggestions**
- **5.4 Results and Discussion**

1.0 Introduction The Vortex Generator Retrofit (VGR) system, developed by Malcolm Bendall, represents a groundbreaking approach to improving the environmental and operational efficiency of various combustion engines, including those in vehicles and power generators. This technology is particularly effective for gasoline engines. The VGR's innovative design aims to lower harmful emissions like CO_2 and CO, increase O_2 output, and enhance overall engine performance. This is achieved by utilizing the engine's waste heat and emissions in a unique "plasmoid" process. Our analysis provides a comprehensive review of the VGR system, focusing on its unit operations, the viability of its underlying mechanisms, and a critical evaluation of its effectiveness based on existing data and theoretical principles.

This paper scrutinizes the VGR system in detail, exploring its operational components and the science behind its claimed benefits. Through a mix of experimental examination and theoretical analysis, we aim to determine the validity and reproducibility of the VGR's performance enhancements. This includes an assessment of the system's compatibility with existing engine designs and its potential for widespread implementation in various industries. Ultimately, our goal is to provide a balanced and rigorous review, shedding light on the efficacy of the VGR system in real-world applications.

In addition to examining the technical aspects of the VGR system, this paper also delves into its environmental implications. With the growing emphasis on sustainable technologies, it's crucial to understand how innovations like the VGR can contribute to reducing the environmental footprint of combustion engines. We also explore the economic and practical aspects of retrofitting existing engines with the VGR system, considering both the immediate and long-term benefits and challenges. This comprehensive review aims to provide a multi-faceted perspective on the VGR system, making it a valuable resource for both industry professionals and environmental scientists.

2.0 Background The Vortex Generator Retrofit (VGR) system is an innovative technology designed to reduce the environmental impact and improve efficiency of combustion engines. At its core, the VGR system utilizes a unique combination of three unit operations: the pre-ionizer, the diffuser/bubbler, and the vortex tube. The pre-ionizer's role is to energize electrons in the intake air, preparing it for the subsequent stages. The diffuser/bubbler then introduces the energized intake air into the vortex tube, creating 'plasmoids' through a process of bubble cavitation. Finally, the vortex tube completes the system, maintaining a continuous flow of this treated intake air into the engine. This section elaborates on each unit's function and their collaborative synergy, which is central to the VGR's potential for enhancing engine performance and reducing emissions.

Figure 1 presents a process flow diagram of the VGR system. It includes three main units: the UV pre-ionizer (Unit Operation #1), the diffuser/bubbler plasmoid generator (Unit Operation #2), and the vortex tube (Unit Operation #3), each enclosed in a dotted box and labeled accordingly. Throughout this document, these components will be referred to by their designated 'Unit Operation' number for clarity and ease of discussion.

Gas flows ("hot" exhaust and "cold" intake air) are regulated and driven by the action of the

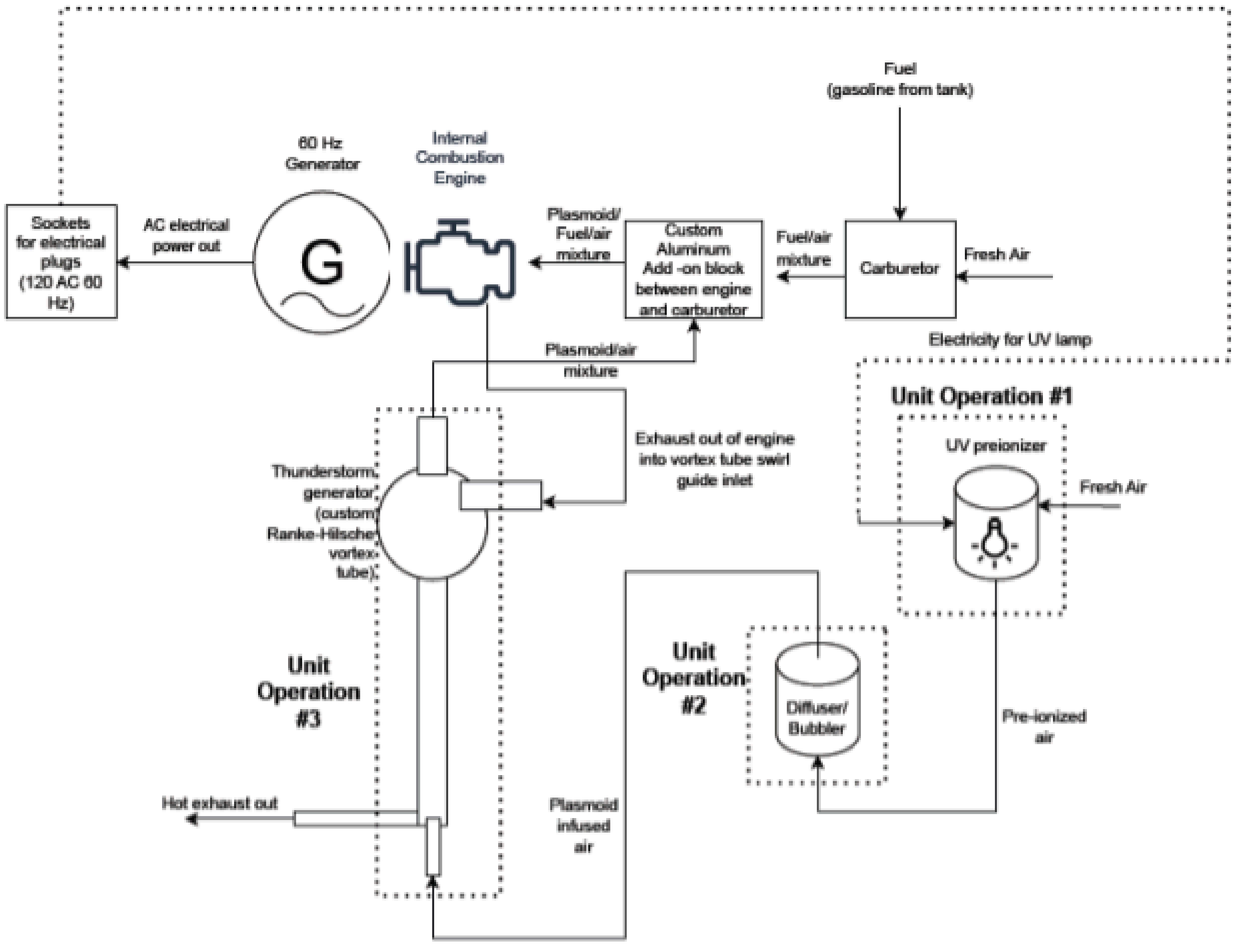


Figure 1. A process flow diagram of the VGR system attached to a portable gasoline engine electric generator. This flow diagram was created based on the system the author inspected during the live demonstrations witnessed on 8/13/2023 and 8/14/2023.

gasoline internal combustion engine. A Firman portable generator was used for the retrofit.

The gasoline internal combustion engine was a **439cc engine. **need more info about generator here (make and model, #of pistons, rated wattage, yada yada), get make and model info, everything else will follow**** Cold intake air is pulled into the system during the compression part of the engine piston stroke, hot combustion exhaust is pushed into Unit Operation #3 (vortex tube) during the expansion part of the engine piston stroke. Due to this, the gas flows inside the system are pulsed in nature. Implications of this pulsation will be discussed in greater detail further on in this work.

Figure 2 offers a front view of the VGR system. Central to the image is the vortex tube, identifiable by its elongated shape and a spherical component near the top. Hot exhaust, depicted by red arrows, enters this sphere via a side-mounted pipe, indicated by a left-pointing red arrow. After circulating through the vortex tube, exhaust exits at the bottom through an elbow fitting. The system also features an intake air line from Unit Operation #3, positioned between the engine and carburetor (see Figure 1 for flow details). This line carries air treated with plasmoids from Unit Operation #2 through the vortex tube, moving counter-current to the hot exhaust.

Figure 2. Frontside view of the VGR system depicting the internal combustion engine, thunderstorm generator, and carburetor. Cold intake air flow is depicted with blue arrows, hot combustion exhaust is depicted with red arrows.

Upstream of the VGR's vortex tube (Unit Operation #3), are Unit Operations #1 and #2. The engine's piston stroke creates a partial vacuum between the carburetor and fuel/air intake, drawing air through these unit operations. Fresh air is continuously pulled into Unit Operation #1, which is exposed to the atmosphere. This unit, featuring an ultraviolet light source, pre-ionizes atmospheric air. Constructed from aluminum alloy 6061, it houses an ultraviolet lamp (specifics to be determined). Pre-ionized air then flows into Unit Operation #2. Further details of this arrangement can be seen in Figure 3, presenting a side view of the system.

As the pre-ionized air continues through to unit operation 2, it is subjected to bubble formation, shear, and collapse inside the water contained in unit operation 2. In the system witnessed by the author, unit operation 2 was constructed using clear PVC pipe housing, PVC end caps, rubber sleeves, and clamping collars. Inside the unit there was water, a diffusor at the inlet side to promote bubble formation, and steel scouring pads to promote bubble shear and collapse. By the inventor's own admission, this was a rather crudely assembled version of this unit. Under optimal conditions the inventor employs a ceramic diffusion stone which serves all three purposes of bubble formation, shear, and collapse. Unit operation 2 is filled with water via the funnel teed off the line between unit operation 1 and 2 as can be seen in Figure 3. During normal operating conditions the valve below the funnel is always closed, water does not need to be continually added as the system runs. Theoretical considerations and various attempts at explaining physical phenomena that may be responsible for the system's claimed capabilities are discussed further into this work.

The piping used on the demonstration unit was copper tubing obtained off the shelf at a hardware store. It should be noted that this entire unit was constructed along with the required modifications to the engine in a period of about 48 hours by three people. Such a relatively fast construction time speaks to the relative simplicity of the system, but also reflects the crude nature of the demonstrated unit. It is also important to note that the vortex tube (unit operation 3) was fabricated in the UK and brought with the inventor ahead of time. Due to the relative complexity of the vortex tube geometry, it would contribute heavily to a longer construction time of the entire system if unit operation 3 needed to also be fabricated from scratch. Design and fabrication of all three unit operations will be discussed in depth further on in this work.

Figure 3. A side view of the TGR system depicting the air pre-ionizer (#1), bubbler/diffusor unit (#2), water feed funnel (#3). Intake air is pulled into the pre-ionizer, travels down through the pipe, and enters the bottom of the bubbler/diffusor unit.

3.0 Unit Operations in Depth There has been a certain amount of confusion involved with the details of how the TGR system operates. Information is somewhat scattered piecemeal between the inventor's website strikefoundation.earth, HowTube, and various other sources. For example, the system presented on the inventor's website displayed below in Figure 4 is technically not what was witnessed by the author at the demonstration. As can be seen by comparison in Figure 1, the demonstrated system was much simpler than the system depicted on the inventor's website. (1) Because of discrepancies like this, it is worthwhile to go into detail about the exact workings of each piece of the demonstrated TGR system as well as conventional theoretical background of how each unit operation may accomplish the claimed results.

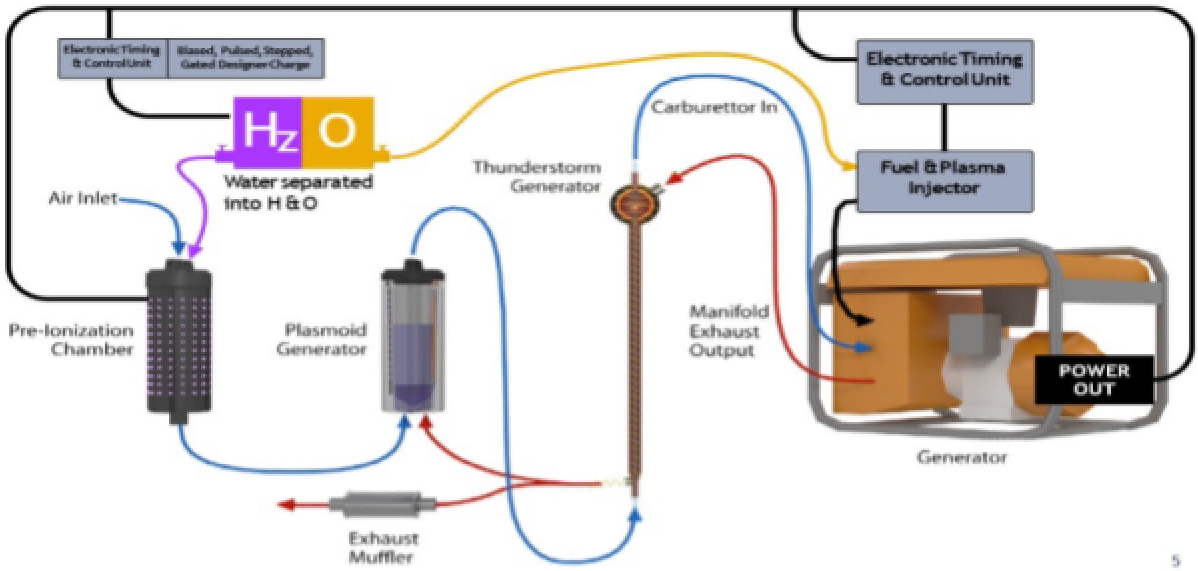


Figure 4. TGR system flow diagram presented on the inventor's website strikefoundation.earth. *(1)*

3.1 Pre-Ionizer (Unit Operation #1) The pre-ionization unit is arguably the simplest unit operation in the TGR system, although some intricacy seems to be involved in operating parameters, namely the wavelength/frequency of light inside the chamber. During operation, the pre-ionization chamber is responsible for energizing electrons inside the passing air molecules. The claimed function of this unit operation is to precondition the air for subsequent bubble collapse and plasmoid formation inside unit operation #2. It appears that the emphasis here is on O_2 electron energization for proper plasmoid formation downstream. Energized nitrogen electrons may play a role as well, but this is currently unknown to the author.

An ultraviolet lamp is used inside the chamber as an electron excitation source. It is claimed that there is some kind of resonance that is required at this step, which is achieved by using the correct wavelength/frequency of UV light. ****resolve the 100 um question, UV wavelength will fall below 400 nm, 100 um as a frequency designation does not make sense. So was this simply a typo, and a UV wavelength of 100 nm was meant instead of 100 micrometers?**** Depicted below in Figure 5 is a cross-sectional view of a mock 3-D model of the intake air pre-ionization unit. The unit demonstrated consists of cylindrical aluminum housing, and a spiral UV light bulb. The intake air inlet is located to the side of the UV lamp on the cylinder flat. The pre-ionized air outlet is located on the opposite cylinder flat side.

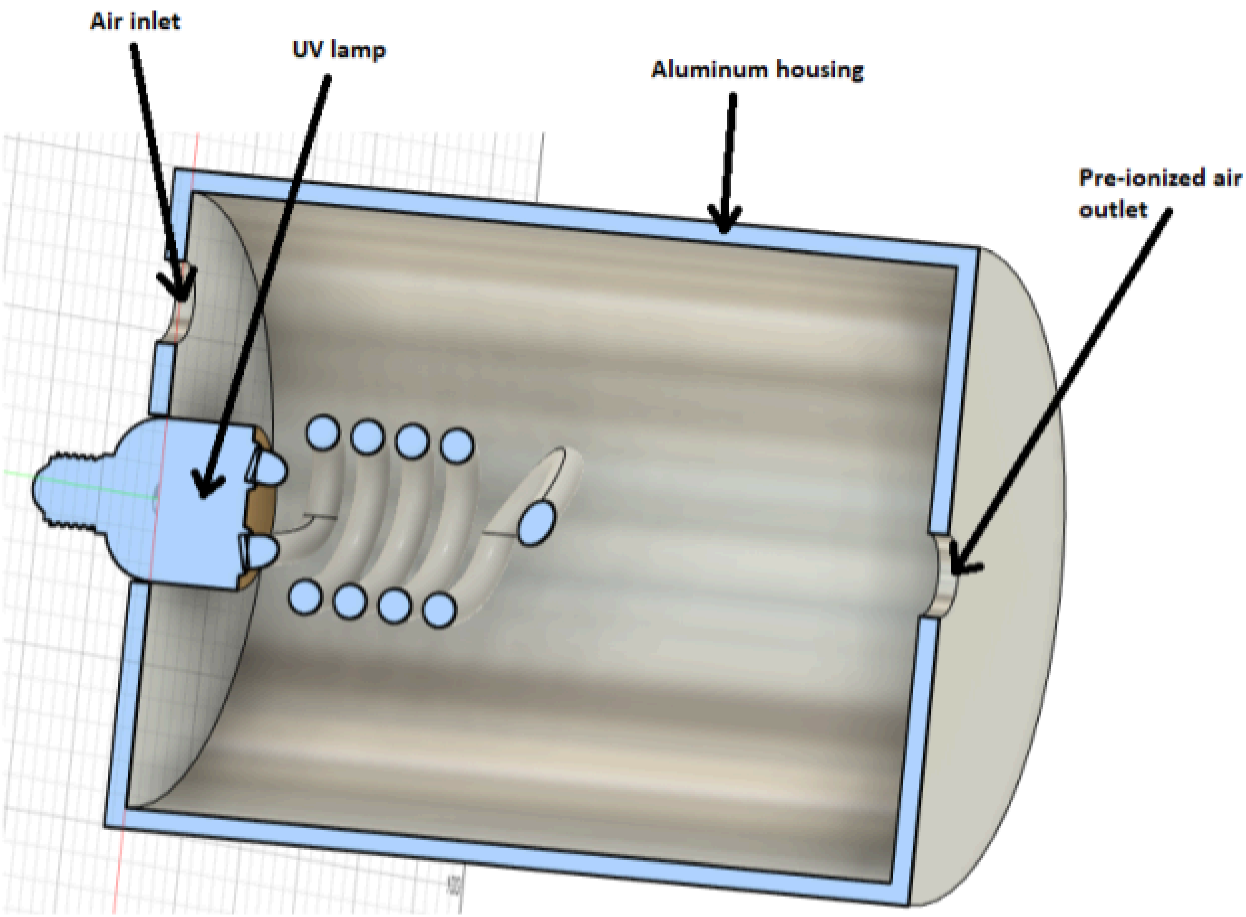


Figure 5. Cross sectional view of the pre-ionizer unit labeled #1 in Figure 3.

3.2 Diffusor/Bubbler (Unit Operation #2) Although simpler in its design, the action inside the bubbler unit is on par in complexity with the action inside the vortex tube unit. Plasmoid formation is claimed to take place inside the bubbler unit through the action of bubble formation and collapse via cavitation. In the demonstration unit witnessed by the author, the air inlet employed a fish tank diffusor stone to promote formation of microbubbles as air enters the bubbler. According to the inventor, it is optimal to have 50 micrometer pores inside the diffusor for forming very spherical bubbles. It is claimed that during collapse, spherical bubbles promote plasmoid formation. This leads to another question of how small the bubbles can be and still function as intended. Perhaps even smaller pore sizes would lead to increased plasmoid generation and performance. Shear was promoted in the demonstration unit bubbler by using steel wool kitchen scrubbers that were directly inserted into and above the water. This may not be needed with the use of a proper diffusion stone that has sharp edges along its pore structure such as ceramic porous pucks.

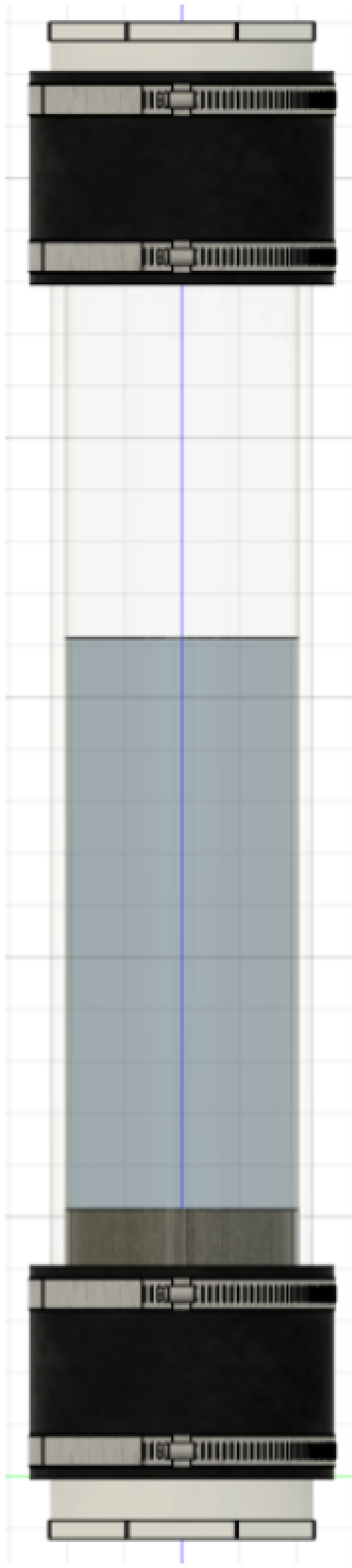


Figure 6. Model depiction of the bubbler unit. Air enters through the bottom PVC cap and diffuses through the porous stone into the water. Steel wool is located inside and above the water.

As claimed by the inventor, sound waves and shockwaves produced by the combustion inside the engine may promote and intensify the cavitation and shear phenomena taking place inside the bubbler unit. Energy levels of the acoustic waves and shock waves produced and their ability to couple into the bubbler water will be explored in the theoretical section of this work. It is worth keeping in mind that one of the claims of the inventor is essentially that wasted energy in the forms of heat, acoustic waves, and shock waves is recovered in the form of useful work for running the retrofit system. Two of the waste energy vectors, acoustic waves, and ****shock waves is likely the wrong terminology here, conventional combustion engines should not produce actual shock waves, they would quickly tear the engine apart**** shock waves are taken advantage of inside the bubbler unit.

Depictions of the bubbler unit are presented as a side on view in Figure 6, and a cross sectional view in Figure 7. The bubbler unit that was witnessed by the author on the demonstration TGR system was constructed using 4" nominal pipe size PVC pieces. As can be seen in Figure 7 below, the unit housing was made using clear PVC pipe, the top outlet and bottom inlet was made using standard PVC caps, caps were secured to the housing using clamped rubber sleeves. Inside the bubbler unit, a 4” diameter aquarium diffusion stone was installed inside the bottom PVC cap. Stainless steel wool was added to be located partially submerged inside the water, and in the air head space above the water level. The bubbler unit was filled roughly halfway up with tap water during the demonstration witnessed by the author.

In Figure 6, the path of pre-ionized intake air enters at the bottom, rises, and exits the top of the diagram. In the cross-sectional view of the bubbler in Figure 7, pre-ionized intake air enters at the right end of the diagram, travels left, and exits at the left end of the diagram.

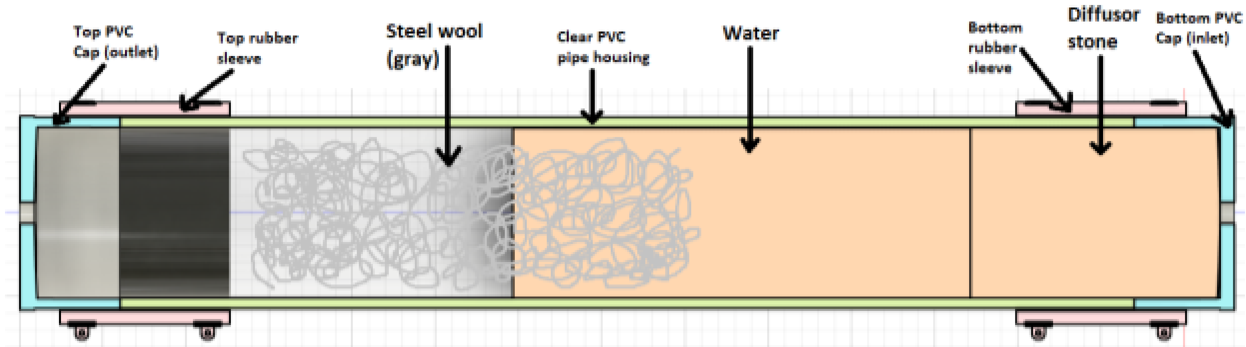


Figure 7. Cross sectional view of the bubbler unit labeled #2 in Figure 3.

The diffuser action of creating bubbles for cavitation and collapse purposes is presented as the main purpose for incorporating it into the bubbler unit. There is likely a secondary overlooked action, which is to keep the water rich with oxygen via oxygenation through the micro bubble formation, allowing for efficient diffusion of oxygen into the water. This may be an important aspect of the plasmoid formation and transport process. The subject of plasmoid transport via the paramagnetic action of O_2 will be discussed in the theoretical section of this work.

3.3 vortex tube (Unit Operation #3) The vortex tube is fundamentally based on the Ranque-Hilsch vortex tube. A Ranque-Hilsch vortex tube is a unique piece of hardware that can separate a compressed gas inlet stream into “cold” and “hot” outlet streams. These vortex tubes do not incorporate any moving parts and can generate a temperature difference up to 230°C between the hot and cold ends. The vortex tube may be classified as a counter-flow vortex tube. Generally, in a counter-flow vortex tube, the hot end can release 30% to 70% of the input gas with the rest being released from the cold end. (5)

To better understand the way a counterflow Ranque-Hilsch vortex tube functions, a diagram is presented below in Figure 8. Compressed gas is injected through the inlet of the tube into a swirl guide. A free “hot” vortex is generated running through the length of the tube down to the hot end outlet. The free “hot” vortex is partially let out through a conical control valve while the rest of the flow is reflected generating a forced “cold” vortex. The “cold” vortex travels back rotating counter through the center of the “hot” vortex and is let out through a diaphragm on the cold side. (6)

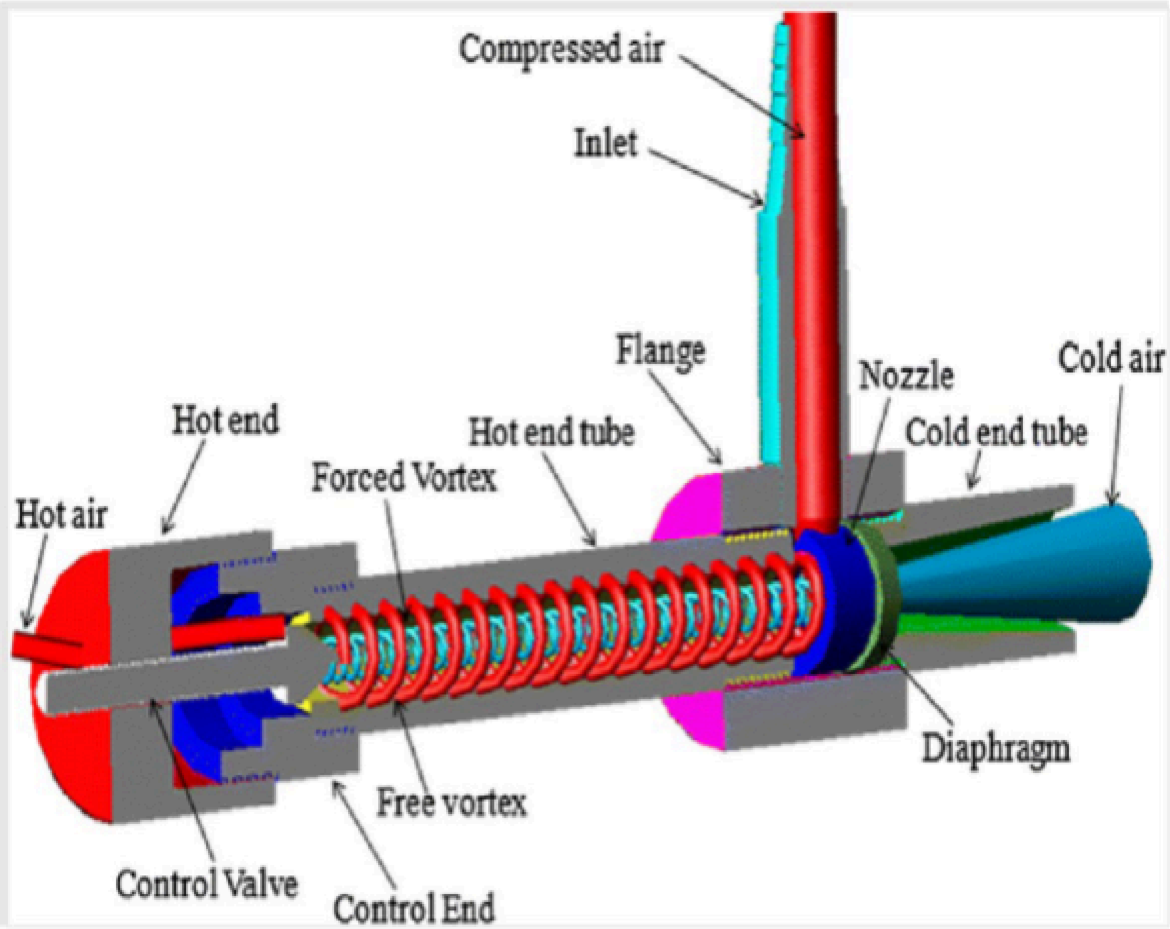


Figure 8. Sectional view of a conventional Ranque-Hilsch vortex tube. Compressed air is fed through the inlet into the swirl guide, forming a free "hot" vortex. A fraction of the free "hot" vortex is let out through the hot end of the tube via the control valve, the rest of the vortex is reflected forming the forced "cold" vortex circulating opposite of the free "hot" vortex. The forced "cold" vortex exits the tube through the cold end, opposite the hot end. *(6)*

Two major differences of the vortex tube design used in the demonstration from a counter-flow type Ranque-Hilsch vortex tube design is that gas is also injected at the "hot end" directly into the "cold" vortex, and the inner concentric pipe runs the full length of the outer pipe, physically separating the inner and outer vortex flows. These are major deviations from the way a standard Ranque-Hilsch vortex tube is operated and has implications for the flow dynamics inside the tube. A computational fluid dynamics (CFD) model of the flows inside the vortex tube is needed to test for potential disruption of vortical flows inside the tube. The vortex tube design that was implemented in the TGR system demonstration is depicted in Figure 9 below.

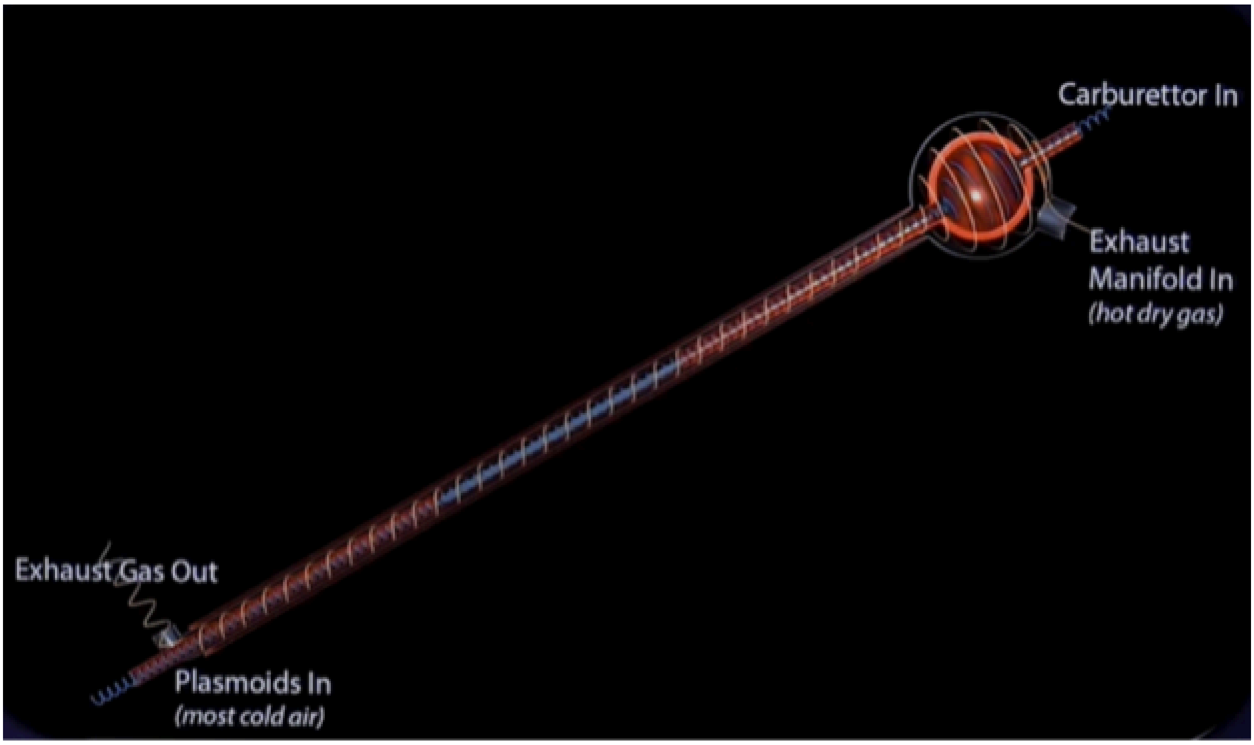


Figure 9. The inventor's depiction of the Thunderstorm Generator used on the demonstration system witnessed by the author. Notice the additional air inlet at the bottom left of the tube. CITATION Mal23 \l 1033 *(11)*

It is worthwhile to discuss the assumed flow characteristics inside the vortex tube depicted in Figure 9. A not-to-scale but geometrically similar model created in CAD software will be used to visualize flow regions. The two outer most concentric spheres at the hot inlet side of the vortex tube are used as a swirl guide to initiate the "hot" vortex. Depicted below in Figure 10 is a cutaway top-down view of the CAD model vortex tube. Exhaust gasses exiting the engine enter the outer sphere of the vortex tube perpendicular to the vortex tube.

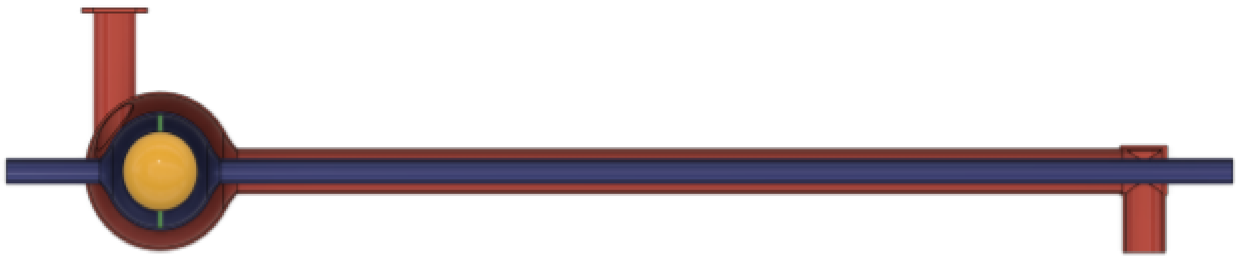


Figure 10. A CAD model representation of the Thunderstorm Generator used during the TGR system demonstration witnessed by the author. Red regions are the "hot" exhaust flow areas. Blue regions are the "cold" intake air flow areas. Exhaust gases travel from left to right, cold intake air travels from right to left.

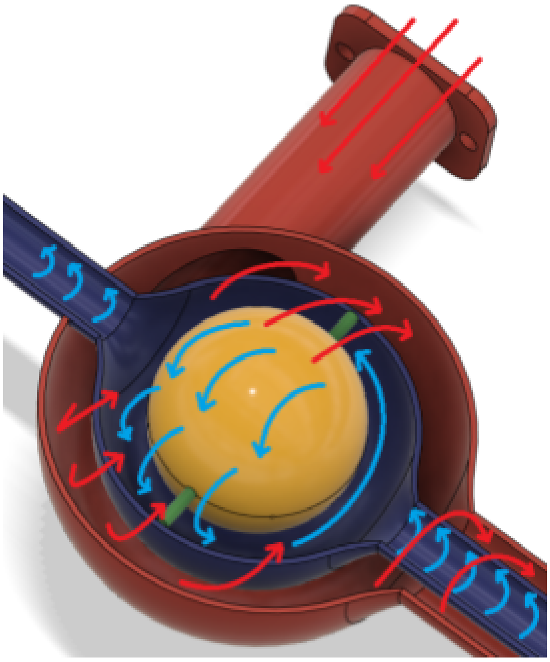


Figure 11. Exhaust (red arrows) and intake air (blue arrows) idealized fluid flows in the spherical region of the vortex tube.

Intake plasmoid treated air enters the vortex tube through a tee located at the opposite end from the sphere exhaust intake.

Three concentric spheres are used as a swirl guides for the incoming exhaust gasses and exiting treated intake air. Exhaust gasses (red arrows) can be seen flowing counterclockwise between the outer (red) and inner (blue) sphere in Figure 11 to the left. Intake air treated with plasmoids travels from the opposite side of the tube rotating in a clockwise vortex. The illustrated flows in Figure 11 are an idealized depiction of the claimed fluid flows inside the vortex tube. Whether or not this flow regime persists even with the additional intake air flow from the bottom of the vortex tube is a matter of question.

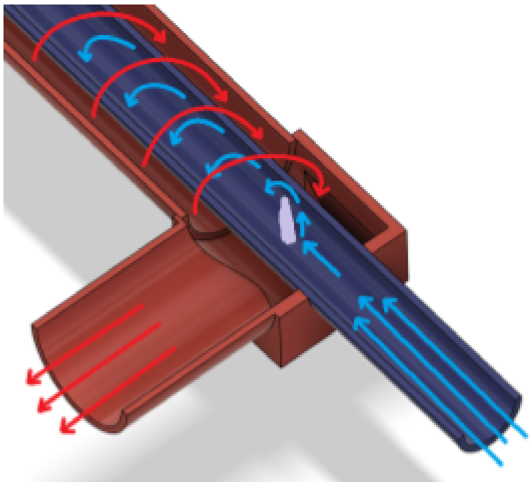


Figure 12. Exhaust (red arrows) and intake air (blue arrows) idealized fluid flows in the bottom region of the vortex tube. The blue inner tube extends all the way up to the spherical region.

Connecting the spherical top region of the vortex tube and the bottom intake air inlet/exhaust outlet region are two concentric tubes shown below in Figure 13. The two vortex flows have a physical separation in the form of the inside concentric tube, which consequently does not allow them to directly interact. This physically non-interacting feature of the flows inside the vortex tube ensures that exhaust gas is not diluted with fresh intake air. Consequently, the exhaust analysis readings will not be falsified by this part of the process, assuming this is the actual design architecture present inside the demonstration vortex tube. The bottom portion of the vortex tube idealized flows is depicted above in Figure 12. Exhaust gas enters the small annular region between the outer (red) and inner (blue) tube and then exits through the elbow. Intake air is pulled through the central blue tube and proceeds into the central region where it continues towards the

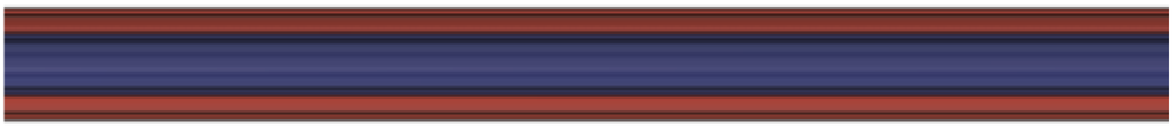


Figure 13. The central region of the Thunderstorm Generator tube where the exhaust "hot" vortex flow and intake air "cold" vortex flow counter-current to each other. The smaller inside concentric tube runs the full length of the larger outer tube, ensuring no direct interaction between exhaust and intake occurs.

spherical region of the vortex tube. A swirl guide depicted in gray inside the inner tube in Figure 12 is employed at the intake air inlet side to induce a vortex flow to form inside the inner pipe. The type and geometry of the treated intake air swirl guide is unknown to the author of this work. For example, a twisted ribbon metal piece may be used to initiate vorticular flow, one or multiple baffles could also be used. It is the author’s speculation that whatever method is used to induce vorticular flow, must not induce turbulence due to inherent downstream instabilities that would likely arise if turbulence is introduced at the inlet.

4.0 Conventional Means to Achieve Claimed Results and Routes of Possible Results Manipulation

**Water vapor injection into carburetor for improved engine performance

**CO_2 and CO adsorption via the use of a compound like an amine solution or calcium hydroxide may be used to scrub the exhaust prior to analysis

> This was also not observed, unless something like calcium hydroxide is packed into the vortex tube….this is unlikely.

**Flows within the vortex tube may also be set up in such a way to simply mimic an exhaust gas recirculation (EGR) system (2)

> This would require the exhaust flow to not be physically separated from the air intake flow inside the vortex tube. Designs indicate a physical separation, during replication, helium tests will need to be done to show that no gas crossover is taking place between exhaust and air intake sides.

**Plumbing and vortex tube flows may be used in a way to allow the inlet air to partially mix into the exhaust gas prior to the exhaust gas analysis point

> No plumbing inconsistencies were observed.

**Running the engine lean and increasing temperature of combustion via preheating intake air/lean combustion

> Rich to lean operational graphs showing gas percentages in exhaust. Discuss lean operation effects on combustion temperature. Combustion temperature effects on engine efficiency, preheating air intake effects on combustion temperature blah blah blah.

5.0 Proposed Experimental Replication (**proposed will be removed once the replication is done by the author)

Replication and testing of the retrofit system are to be done at a laboratory space generously made available by (**** *****insert name after permission is obtained from the individual in question). A retrofit system replication constructed by the author and Robert Hutchings (others involved will need to consent to names being put here) is to be studied in detail to provide independent experimental verification. Replication of the system layout described by the process flow diagram in Figure 1 is planned. A double sphere top and bottom vortex tube fabricated by Robert Hutchings will be employed on the replication retrofit system. This deviation is due to the original vortex tube design including spheres on both the exhaust inlet/intake air outlet and exhaust outlet/intake air inlet sides.

A schematic of the process flows in the retrofit replication experiment is presented below in Figure 14. Four ball valves are used to prepare and maintain the system as well as shut intake air on/off. One ball valve (normally closed during operation) is used to fill the bubbler unit with water before operation. One ball valve (normally closed during operation) is used to drain the bubbler unit and may be used in conjunction with a secondary valve to take water samples during operation. One ball valve is used to enable or disable treated intake air flow through the retrofit system to the engine during operation. One ball valve is used to drain any water collected in the treated intake air line between the bubbler and vortex tube.

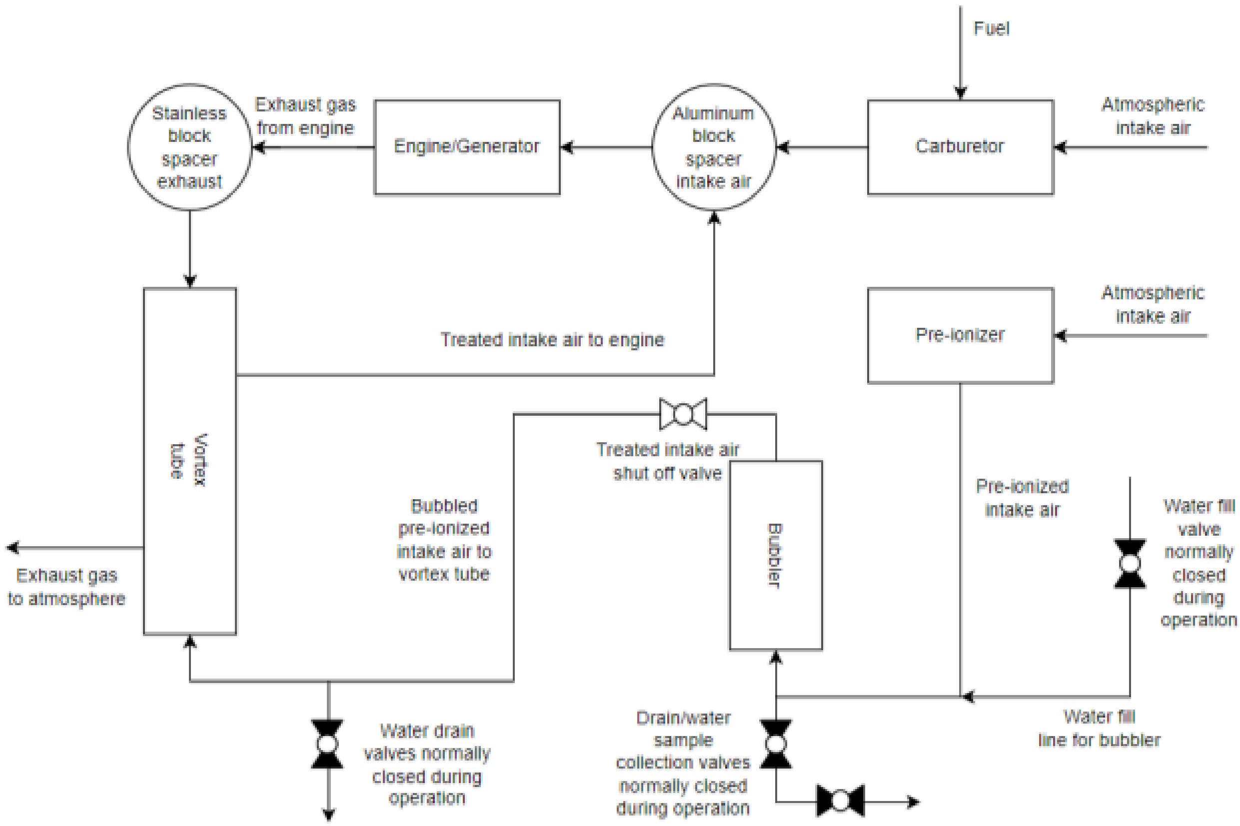


Figure 14. Process flow schematic of retrofit replication experiment.

5.1 Materials and Components

A Craftsman model CMXGGAS030731, 5000-Watt Gasoline Portable Generator will be used as the retrofit basis. The generator engine is a 306cc displacement engine. Modifications made to the engine will be the exhaust port being connected to either a control tube or

*Figure **XX***. Engine side view of the Craftsman model CMXGGAS030731 generator used for the experiments in this work. The only modifications in this setup are a custom fuel dispenser, and removal of the flame arrestor screen from the muffler. Bottom left depicts where the exhaust port temperature is sampled. Bottom right depicts the insertion of the continuous gas sampling line into the muffler exhaust outlet.

vortex tube and an extra intake air connection will be added between carburetor and engine. The original fuel tank will be completely removed from the generator to allow for incorporation of the retrofit units. A venturi inlet aluminum block piece to fit between the carburetor and engine is to be machined by Robert Hutchings. The original carburetor mounting studs will need to be replaced with longer studs to accommodate the extra length required by the aluminum insert. A flange connection and spacer will be included on the vortex tube exhaust inlet to connect to the exhaust output of the engine.

Figure ***XX.*** Aluminum intake air inlet to be placed between engine and carburetor. The bore is a 1" diameter. The connection is threaded ½" NPT. Fabricated by Robert Hutchings.

The fuel tank connection to the carburetor is bypassed in favor of using a smaller ~ 1 L volumetrically marked transparent container. The 1 L container is placed on a scale to record the weight of the fuel. This is for the purpose of tracking fuel consumption, and running experiments/tests with small 350 gram (~500 mL) gasoline increments. A schematic representation of the modified fuel dispensing system is presented to the right in Figure **XX**. This system will also allow for the ability to not run the engine dry during every experiment. Due to the container volume being about 1 L, a fuel level can always be maintained in the generator system even after completing an experiment that consumes 350 grams (~500 mL) of gasoline. Refraining from running the engine dry between experiments will enable more consistent engine behavior, minimizing engine start-up and shut-down aberrations.

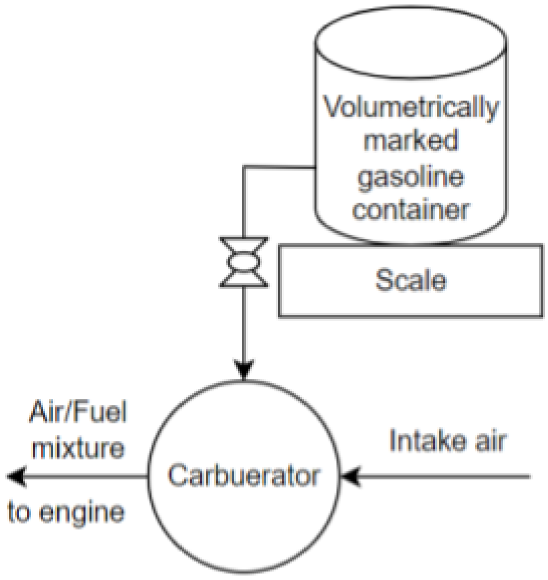


*Figure **XX***. Schematic of custom fuel dispensing system allowing for gasoline consumption tracking.

*Figure **XX***. Metered fuel dispensing system used during experiments. Gasoline weight is recorded once per second.

The vortex tube is to be fabricated with ½’’ I.D., 5/8’’ O.D size tubing for the center internal intake air line and a 1’’ I.D., 1 ⅛” O.D. size tubing for the center external exhaust gas line. To keep all intake air tube sizes consistent with the size of the central intake air line in the vortex tube, 5/8’’ compression fittings will be used along with 5/8’’ O.D., 1/2’’ I.D. copper tubing. This will allow for smooth treated intake air transitions into and out of the vortex tube.

The first replication bubbler unit is to be constructed of 4.0’’ O.D., 3.75’’ I.D. clear acrylic pipe as housing, two 4’’ rubber coupling sleeves with stainless steel clamp on connectors, and two 4’’PVC x3/4’’FNPT PVC reducer bushings. Brass ⅝’’ compression to ¾’’NPT fittings will be used to provide copper tube connections from the PVC reducer bushings. An extra hole will be drilled and tapped into the bottom bushing to provide for a thermocouple inlet for tracking water temperature.

5.2 Data Acquisition

**include a data acquisition panel picture

**include planned and wanted measurements list (temperatures, pressures, gas analysis points, flow meters)

**Radiacode 102 for radiation spectrum analysis (Gamma, X-ray, hard beta radiation)

**Continuous weight recording of fuel using Ohaus scale Valor7000 through RS232 and Simple Data Logger software

**physical data acquisition system, thinking to try and use my NI 4 slot chassis with thermocouple inputs, mA inputs, will have to see, going to first start with my 4 K-type thermocouple recorder, especially for preliminary generator characterization tests

Figure ***XX***. Four channel type K thermocouple temperature logger.

Heat gun for temperature differentials.

5.3 Experimental Protocols

Experimental procedures and protocols are presented in detail for consistency and ease of replication. Unless explicitly stated, protocols are followed exactly for each experiment/test.

5.3.1 Mass Spectrometer Characterization

Prior to any tests involving the use of the residual gas mass spectrometer to analyze gasses at various points in the system, the response time of the continuous gas sampling system is characterized using helium tracer gas injected at the inlet of the sampling system. The mass spectrometer used in this work is a Stanford Research Systems QMS 100 amu quadrupole Residual Gas Analyzer. For an improved response time, a diaphragm pump is used to speed up the transport of gasses from the gas sampling system inlet to the tee where the mass spectrometer capillary is connected.

Helium will be used as the tracer gas to characterize the response of the continuous gas sampling system. Although helium will diffuse more quickly than the gasses of interest to be analyzed, this will be a good indicator of the system's response time to changing gas compositions. The sample inlet line leading to the diaphragm pump and mass spectrometer has a 1/16'' I.D., and ⅛'' O.D.. The sample inlet line length from sampled gas inlet to the tee where the mass spectrometer capillary inlet is connected is **XX feet XX inches**. The first **6** feet of the sample inlet line is stainless steel tubing to allow for the high temperatures of exhaust gas entering the tube. Exhaust gasses traveling through the stainless steel tube decrease in temperature, allowing for a transition to PTFE tubing. The PTFE tubing is connected directly to the tee where a majority of the sampled gas flow is pulled through the diaphragm vacuum pump, and a small fraction enters the mass spectrometer.

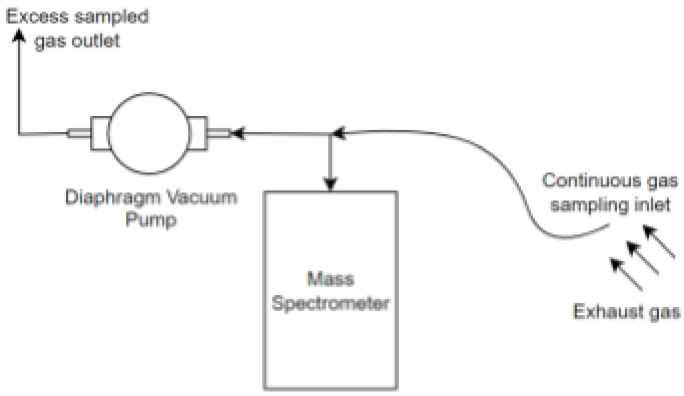


Figure ***XX***. Diagram of continuous gas sampling and analysis system.

5.3.1.1 Response Time Characterization Protocol

1. Power on mass spectrometer and associated computer, wait 15 minutes to allow for turbomolecular pump spin-up and vacuum stabilization
2. Power on diaphragm pump for pulling gas stream from sampling system inlet
3. Using SRS software, enable mass spectrometer ionizer and begin recording continuous analysis of gas entering the sampling system
4. Making note of the time on the mass spectrometer computer, enable 50 SCCM of helium flow injected into gas sampling system inlet, let helium flow for 120 seconds, then shut helium off
5. Wait 2 minutes to allow the helium mass peak to disappear, and repeat step 4
6. Repeat steps 4 and 5 until this cycle has been completed at least three times

7. Turn off recording to save analysis data

Response time will be the length of time from the moment helium gas flow is enabled, to when the helium mass 4 peak appears above noise level on the analysis software. ****how to define "above noise level"? maybe use something along the lines of how signal pulses beginning gets defined on an oscope? 10% of plateau value?**

5.3.2 Craftsman 5000-Watt Gasoline Generator Tests (without retrofit system)

A Craftsman 5000-Watt gasoline generator will be used to drive the retrofit system. Prior to using the generator integrated with the retrofit system, tests are to be carried out to characterize the behavior of the generator itself. Gas analysis is done using a 100 amu quadrupole mass spectrometer for every generator test. Temperatures of the exhaust port on the engine are recorded using a model 88598, 4 channel type-K thermocouple logger. All characterization tests are to be done in 350 grams (~500 mL) octane rating 86 gasoline increments, and the time to use the full 350 grams (~500 mL) of gasoline will be recorded for each test. Loaded and unloaded as well as muffled and non-muffled tests are conducted to characterize the generator. Different levels of fuel rich to lean operations will also be tested under load for both the muffled and non-muffled conditions. Rich versus lean conditions will be defined by the position of the choke lever on the generator engine carburetor, the richest corresponding to choke fully on, leanest corresponding to choke fully off.

Due to the generator being brand new and unused, the engine will first be started with 1,000 mL gasoline. The generator will be unloaded and the engine allowed to run until 350 grams (~500 mL) of gasoline is consumed. This is to ensure more consistent steady-state results for all tests to follow. Gas analysis and exhaust engine outlet temperatures will be recorded for this initial startup of the generator. Time to consume the 350 grams (~500 mL) of gasoline will also be recorded.

Upon completion of the unloaded "priming" of the generator, the process will be repeated under 3 kW load. Two space heaters will be used to provide the load for the generator. Actual power consumption of the space heaters will be measured using a wall outlet. Voltage of the wall outlet is measured and an ammeter is used to measure the amperage draw of each space heater at full power. True power consumption of each space heater is calculated by multiplying the wall outlet voltage by the amperage draw of each space heater.

$$P_{heater}\,(Watts) \;=\; V_{outlet}\,(Volts) \;\times\; V_{heater}\,(Amps)$$

5.3.2.1 Generator No Load

Generator No Load With Muffler Protocol

1. Power on mass spectrometer and associated computer, wait 15 minutes to allow for turbomolecular pump spin-up and vacuum stabilization
    a. If mass spectrometer already running and stabilized, proceed to next step
2. Power on diaphragm pump for pulling gas stream from sampling system inlet
3. Using SRS software, enable mass spectrometer ionizer and begin recording continuous analysis of gas entering the sampling system

4. Power on temperature logger, set logging interval to 1 second and enable automatic temperature logging
    a. Make sure SD card is inserted into temperature logger
5. Load the engine fuel dispensing container to the 1,000 mL mark octane 86 gasoline
6. Enable weight data logging through Simple Data Logger software
7. Begin recording of a new radiation spectrum on the Radiacode 102
8. Record the time, start a timer and start up the engine on the generator following instructions in generator user manual
9. Allow the engine to run 120 seconds to allow engine temperatures to stabilize
10. After the initial 120 seconds of engine stabilization, record the time
11. Allow engine to run until about 350 grams of gasoline is consumed
12. Once 350 grams of gasoline is consumed, record the time, stop the timer, and shut down the engine
13. Save radiation spectrum recorded on the Radiacode 102
14. Wait another five minutes, then stop the temperature logging, mass spectrometer logging, and weight data logging

Generator No Load Without Muffler Protocol

Remove the muffler from the engine exhaust port. Attach continuous gas sampling inlet to the engine exhaust port. Due to potential issues with exhaust valve warping, unmuffled tests will be done with a control tube attached, ****include drawing of control tube**

Repeat protocol steps listed in **Generator No Load With Muffler Protocol**.

5.3.2.2 Generator Loaded

Generator Under Load With Muffler Protocol

1. Plug two 1500W space heaters into the generator outlets, and ensure the space heaters are set to full power
2. Ensure the generator switch is set to **OFF**
3. Power on mass spectrometer and associated computer, wait 15 minutes to allow for turbomolecular pump spin-up and vacuum stabilization
    a. If mass spectrometer already running and stabilized, proceed to next step
4. Power on diaphragm pump for pulling gas stream from sampling system inlet
5. Using SRS software, enable mass spectrometer ionizer and begin recording continuous analysis of gas entering the sampling system
6. Power on temperature logger, set logging interval to 1 second and enable automatic temperature logging
    a. Make sure SD card is inserted into temperature logger
7. Load the engine fuel dispensing container to the 1000 mL mark octane 86 gasoline
8. Enable weight data logging through Simple Data Logger software
9. Begin recording of a new radiation spectrum on the Radiacode 102
10. Record the time, start a timer and start up the engine on the generator following instruction in generator user manual

11. Allow the generator to run unloaded 120 seconds to allow engine temperatures to stabilize
12. After the initial 120 seconds of engine stabilization, record the time
13. Record the time, and turn the generator switch to **ON** to begin the loaded part of the test, record the wattage displayed on the power meters, and keep track of the wattage every two minutes (**depending on stability, this may not be needed**)
14. Once 350 grams of gasoline is consumed, record the time, stop the timer, turn the generator switch to **OFF** and allow engine to run for another 120 seconds
15. After running the additional 120 seconds, shut down the engine
16. Save radiation spectrum recorded on the Radiacode 102
17. Wait another five minutes, then stop the temperature logging, mass spectrometer logging, and weight data logging

Generator Under Load With Muffler, Varying Choke Protocol

Repeat protocol steps listed in **Generator Under Load With Muffler Protocol,** in **STEP 8**, keep the choke at the desired setting to be tested after the engine is running.

****there is a big if here, engine may not really run smoothly with generator loaded through the entire choke range (choke fully on —> fuel rich operation, choke fully off —> leaner operation)**

Generator Under Load Without Muffler Protocol

Remove the muffler from the engine exhaust port. Attach continuous gas sampling inlet to the engine exhaust port.

Repeat protocol steps listed in **Generator Under Load With Muffler Protocol**

Generator Under Load Without Muffler, Varying Choke Protocol

Remove the muffler from the engine exhaust port. Attach continuous gas sampling inlet to the engine exhaust port.

Repeat protocol steps listed in **Generator Under Load With Muffler Protocol**, in **STEP 8**, keep the choke at the desired setting to be tested after the engine is running.

5.3.3 Engine/Generator Control Experiments With Straight Concentric Tube

While conducting the generator baseline tests to characterize the engine and generator system without any retrofit attachments, it was noted that the exhaust tube area coming from the engine is larger than the annular area through which exhaust gasses travel inside the vortex tube. The exhaust diameter at the exhaust exit of the engine is about 1’’, resulting in a ~0.79 in^2 area. The annular area of the vortex tube is ~0.47 in^2. This roughly a 40% reduction in area from the engine exhaust exit to the vortex tube annular area between the central concentric tubes. Because of this area restriction, additional control experiments will be done incorporating a straight concentric tube that will emulate the concentric exhaust flow area of the retrofit system vortex tube. A model drawing of the concentric tube is depicted below. The tube was fabricated by Robert Hutchings.

Figure XX. Tube to be used for control experiments.

Another advantage of implementing this control tube is it will allow the use of the central tube as a secondary air intake, just like in the retrofit system. A secondary air intake between the engine and carburetor may have serious effects on the combustion behavior inside the engine and the proceeding exhaust gas composition.

Figure XX. Control exhaust tube fabricated by Robert Hutchings. The tube was constructed using mild steel for ease of welding. The outside exhaust tube (in red on the model above) is 0.995" I.D. and 1.125" O.D. The inside intake air tube (in blue on the model above) is 0.495" I.D. and 0.625" O.D. Flanges were custom made to match the exhaust connection on the generator engine. Flanges were added to both sides of the control tube to allow for connecting the muffler.

The above loaded and unloaded, muffled and unmuffled protocols will be followed with the control tube. First, only the exhaust portion will be attached to the engine to test the exhaust restriction effects. After the exhaust only tests, the central tube will be used to provide a second intake air path which will be injected between the carburetor and engine.

5.3.4 Retrofit System With Generator Experiments

****Testing with just a straight concentric tube in place of where vortex tube would be, keep annular area and intake tube area the same as it would be with the vortex tube**

****Staged experiment implementation….first only with vortex tube attached, then with bubbler and vortex tube, then with ionizer/full retrofit system, bubbler only, ionizer only, bubbler and ionizer only, vortex tube and ionizer only**

5.X.X.X Preliminary data/results to guide discussion/suggestions

Sunday, October 8th, 2023

Baseline engine/generator characterization tests. **NO retrofit attachment.**

The first characterization of the continuous gas sampling system was done following the **Response Time Characterization Protocol**. A 50 SCCM flow of helium was enabled and disabled using a Sierra SmartTrak® 100 mass flow controller. The rise and fall time of the helium peak is correlated with the mass flow controller's valve speed and gas sampling response time. Although all mass peaks from 0 to 50 amu were continuously recorded, only significant mass peaks of carbon dioxide (44 amu), diatomic oxygen (32 amu), diatomic nitrogen (28 amu), water (18 amu), hydrogen (2 amu), and helium (4 amu) are reported in the recorded graphs. ****may be worthwhile to check the peaks for things like methane/other light hydrocarbons** Unfortunately carbon monoxide can not be investigated due to its 28 amu peaks directly overlapping with diatomic nitrogen which is in the atmospheric background. The elevation at the location of testing is 1,730 meters (~5,676 feet).

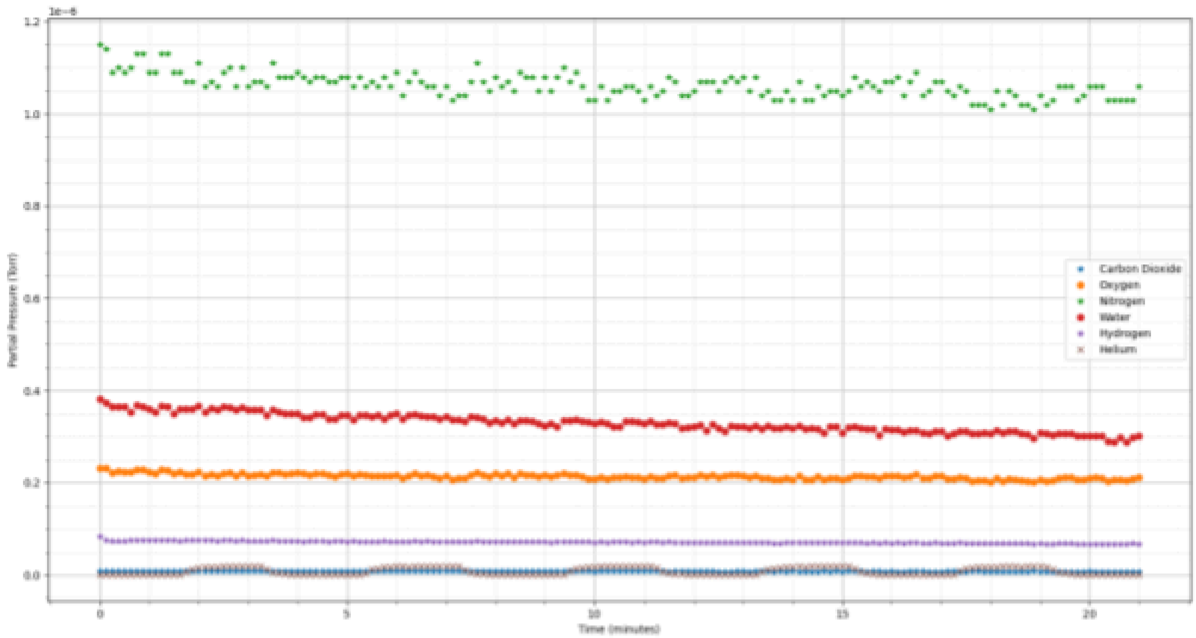


*Figure **XX***. Gas sampling characterization test. Response to flowing 50 SCCM helium gas into the sampling inlet for 120 seconds at 120 second intervals.

Based on the results obtained during the continuous gas sampling response time characterization, the response time to 50 SCCM incoming helium is less than or equal to about 15 seconds.

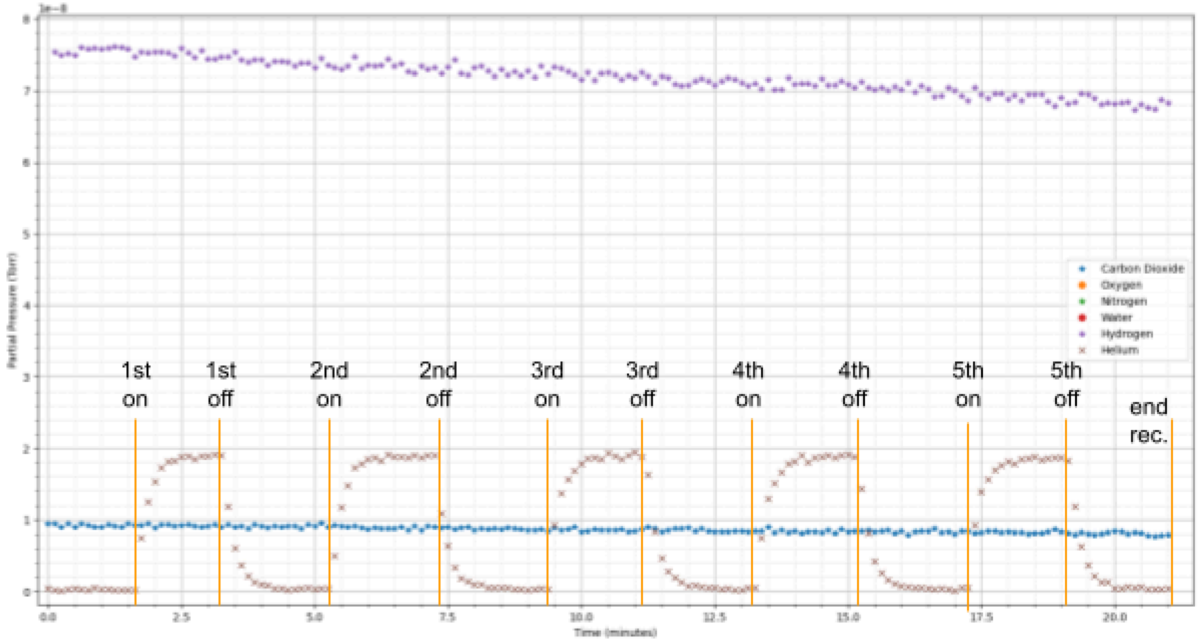


Figure ***XX.*** Gas sampling characterization test. Response to flowing 50 SCCM helium gas into the sampling inlet for 120 seconds at 120 second intervals. The graph is zoomed in to highlight the helium mass peaks. Orange vertical lines roughly indicate on and off times of helium flows, and end of record.

The first no retrofit unloaded generator start up priming test began at 15:57, and the engine was shut down at 16:21. Around this time, the weather conditions were as follows: 79 F, 36 F dew point, 21 % RH, 24.72 in pressure. Roughly 350 grams (~500mL) of gasoline was consumed in 24 minutes during this test. Mass spectrometer gas analysis showed a sharp response to the exhaust gasses exiting the muffler. As was expected from combustion, gas

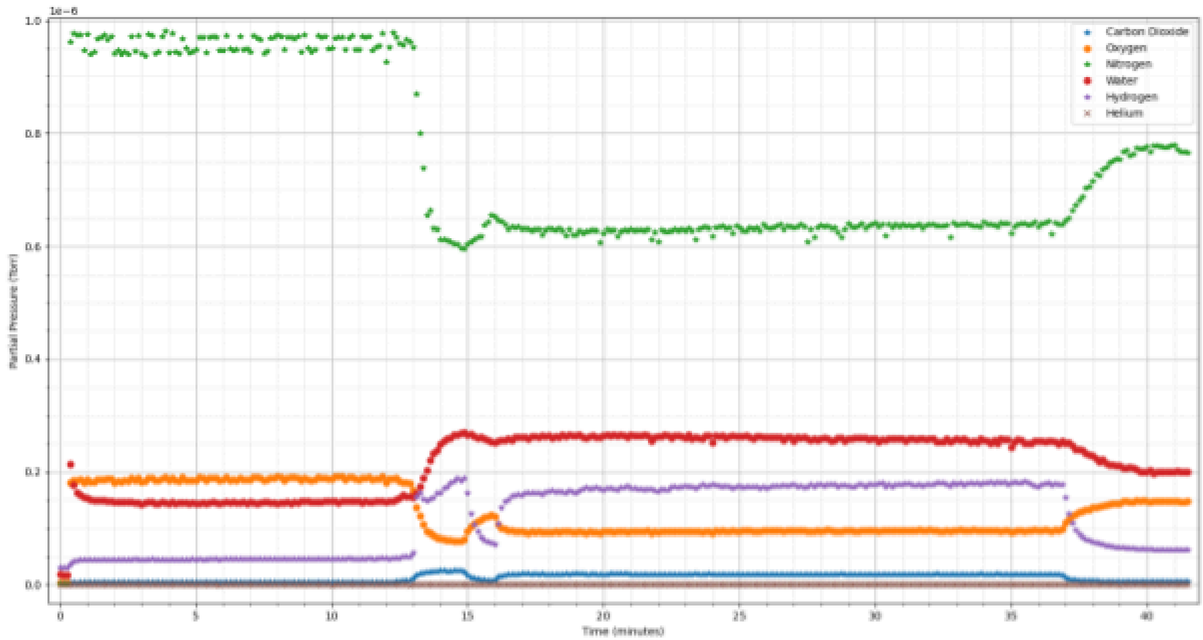


Figure ***XX.*** Mass spectrometer gas analysis of first unloaded generator start-up/priming run. Peak disruptions beginning around 15 minutes are due to the sampling inlet disconnecting from exhaust outlet. The sampling inlet was reconnected around the 16 minute mark on the graph.

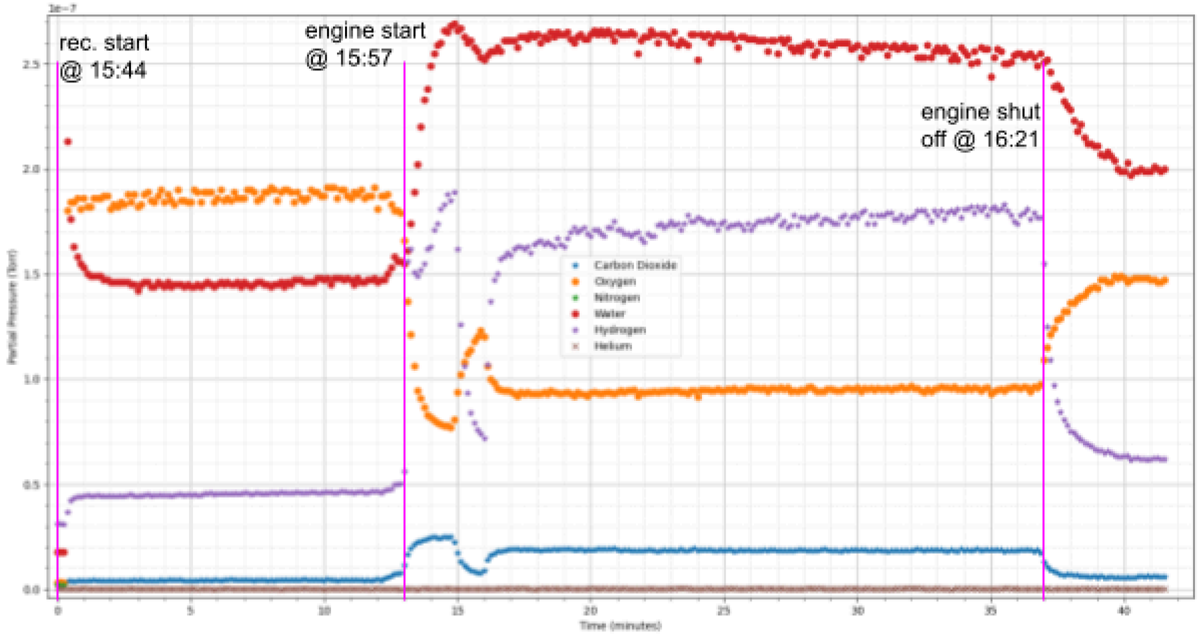


*Figure **XX**.* Mass spectrometer gas analysis of first unloaded generator start-up/priming run. Peak disruptions beginning around 15 minutes are due to the sampling inlet disconnecting from exhaust outlet. The sampling inlet was reconnected around the 16 minute mark on the graph. This is a zoomed in view excluding the nitrogen signal to show better resolution of carbon dioxide. Pink vertical lines are used to roughly indicate relevant times during the experiment.

compositions indicated relative increases of water, and carbon dioxide, and relative decreases in oxygen and nitrogen. Interestingly, the exhaust also contained a surprising amount of hydrogen gas. The exhaust port where temperature was being recorded plateaued at about 290℃. During the test, about two minutes after engine start, the exhaust gas sampling line became dislodged due to the vibration of the engine. This can be seen on the gas analysis graph where hydrogen and carbon dioxide sharply drop off. The

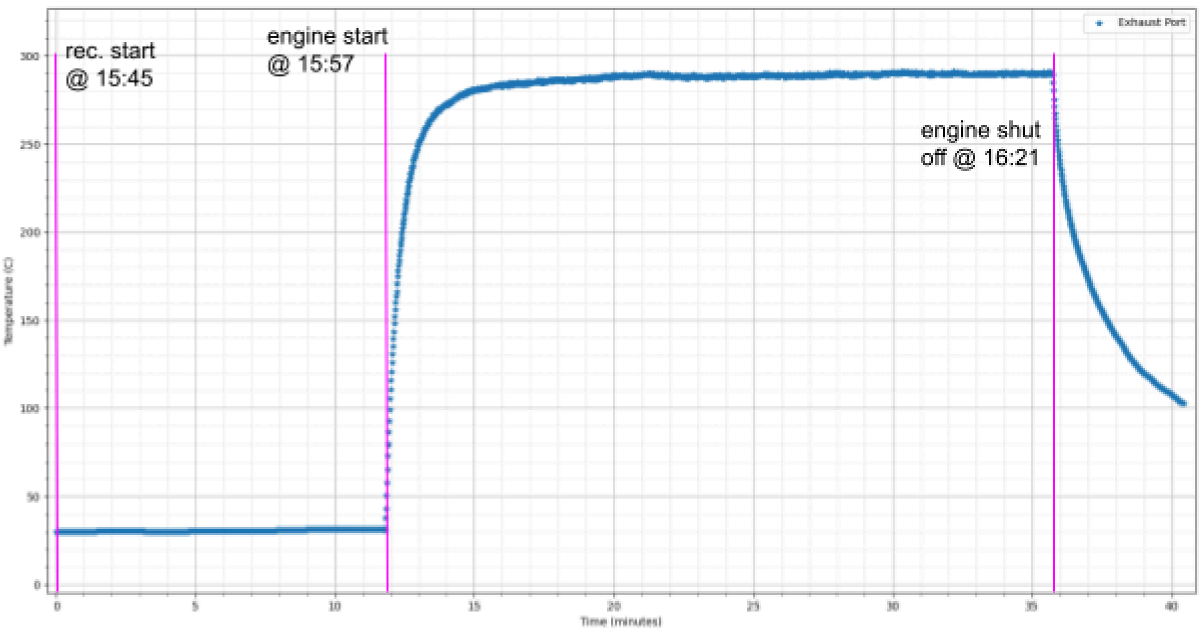


*Figure **XX**.* Exhaust port temperature during first unloaded generator startup/priming test. Pink vertical lines are used to roughly indicate relevant times during the experiment.

sampling line was returned to the exhaust exit of the muffler at which point the hydrogen and carbon dioxide increased once again.

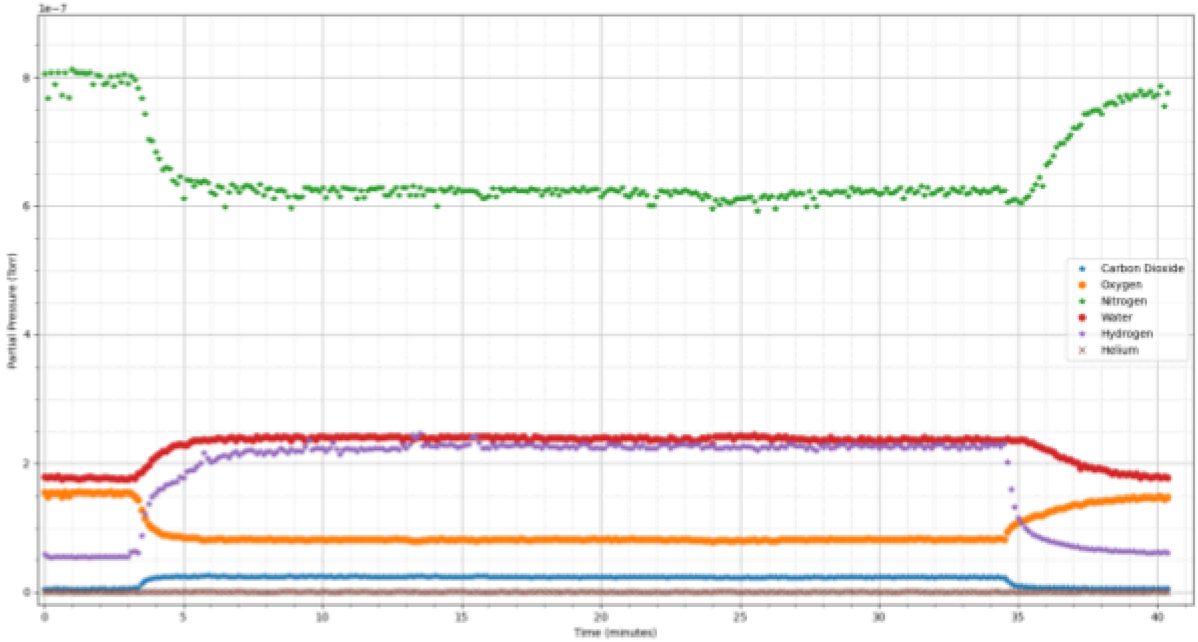


Figure ***XX***. Mass spectrometer gas analysis of first attempted loaded generator start-up/priming run.

The first attempt to perform a no retrofit loaded priming of the generator and engine failed due to a safety shutoff feature on the space heaters used as loads. Due to the temperature outdoors, where the generator was being run, the space heaters would only run for a few seconds before automatically shutting off. For the next attempt of a loaded priming run of

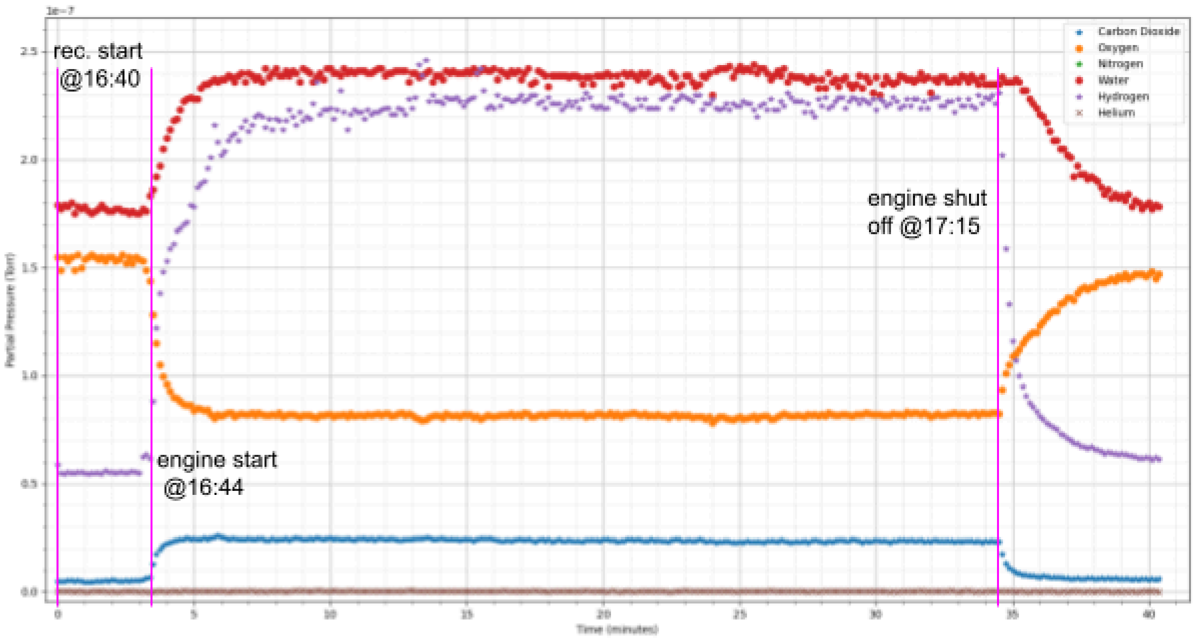


Figure ***XX***. Mass spectrometer gas analysis of first attempted loaded generator start-up/priming run. This is a zoomed in view excluding the nitrogen signal to show better resolution of carbon dioxide. Pink vertical lines are used to roughly indicate relevant times during the experiment.

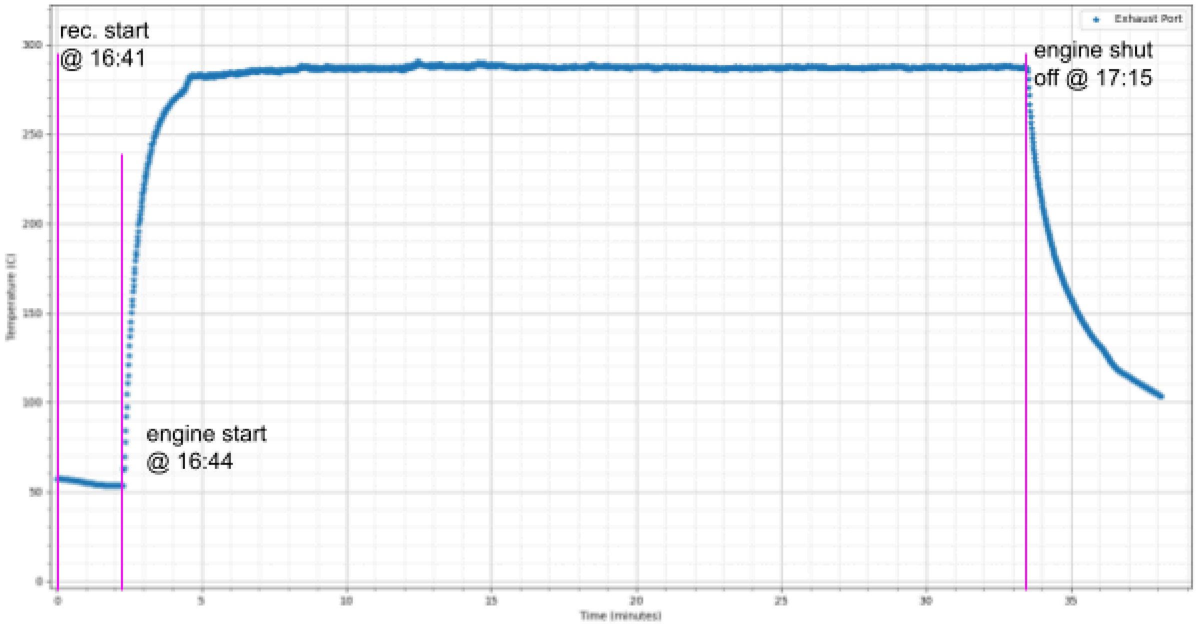


Figure ***XX***. Exhaust port temperature during first attempted loaded generator startup/priming test. Pink vertical lines are used to roughly indicate relevant times during the experiment.

the generator, hot plates will be used as loads. Although the loads failed to operate during this run, the run was carried out for a prolonged time to acquire more unloaded data. The engine was started at 16:44 and shut off at 17:15, fuel weight was recorded at 16:46 to be 570 grams, and then again at engine shut off to be 140 grams. Around this time, the weather conditions were as follows: 77 F, 36 F dew point, 23 % RH, 24.71 in pressure. Roughly 430 grams of fuel was used in 29 minutes during this test.

Ideas to implement before next tests/experiments attempts

**Plumb in an extra tee/drain valve in the fuel line right before the carburetor connection line to allow for ease of draining gasoline at end of testing

**Implement continuous (every 1 sec) recording of weight by reading data from the scale onto a computer

got the RS232 communication working with laptop, ready for implementation

**Add Radiacode 102 radiation spectrometer recording during tests, get a good radiation baseline to compare against when retrofit is being tested

**Add another thermocouple for continuously tracking ambient temperature (the cheapos I brought with me first day were very inconsistent, which is why they were not used)

ordered a nice thermocouple, equivalent to the one being used for the exhaust gas port temperature tracking

**May be a good idea to add a cold trap to the gas sampling line, all that water could burn out filament in mass spec a bit faster, but cold trap will reduce response time….still need to keep the mass spec in working order

**Order power meters to track wattage on loads

**Hot plates to be used as loads instead of space heaters, look into resistive wire, may be a good long term plan for making custom loads for cheap

Sunday, October 22nd, 2023

More baseline engine/generator characterization tests. **NO retrofit attachment.**

On this day, the first loaded and unloaded baseline tests of the Craftsman engine/generator were performed. Although all mass peaks from 0 to 65 amu were continuously recorded, only significant mass peaks of carbon dioxide (44 amu), diatomic oxygen (32 amu), diatomic nitrogen (28 amu), water (18 amu), hydrogen (2 amu), and helium (4 amu) are reported in the recorded graphs. ****may be worthwhile to check the peaks for things like methane/other light hydrocarbons, check for hydrogen cyanide (main peak @ 27 amu, secondary peak @ 26 amu), hydrogen sulfide (main peak @ 34 amu, secondary major peaks @ 32 and 33 amu)** Unfortunately carbon monoxide can not be investigated due to its 28 amu peaks directly overlapping with diatomic nitrogen which is in the atmospheric background. All weather data was pulled from Kirtland Air Force Base weather archive. A mini weathervane will be used for future tests to get a more accurate representation of local conditions in the test area.

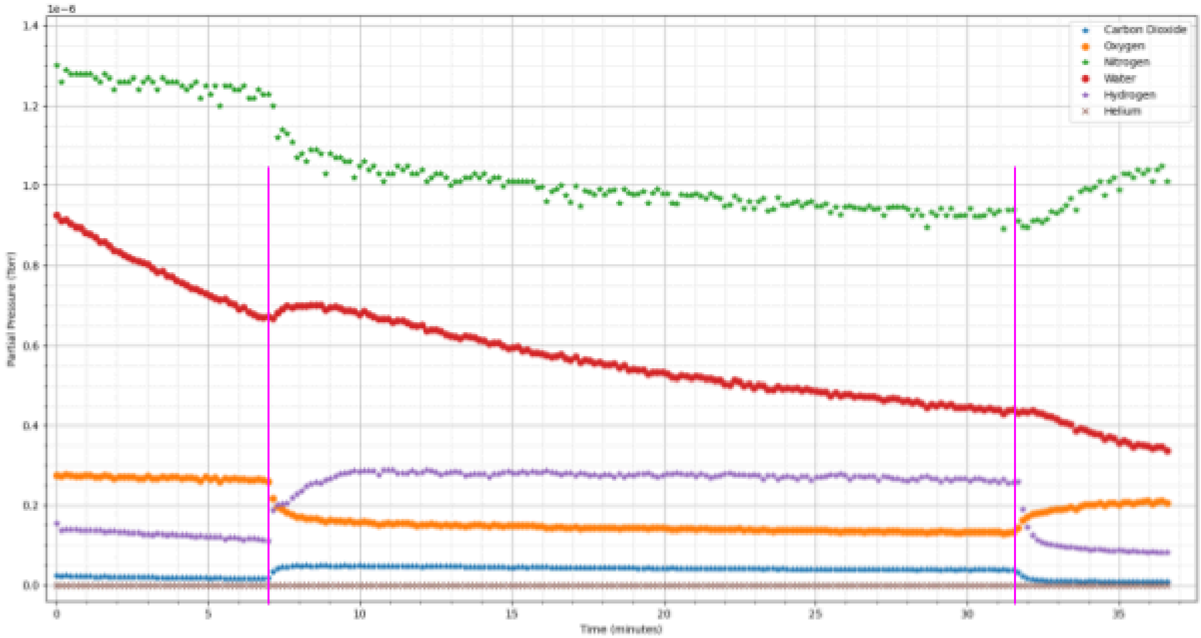


Figure ***XX.*** Mass spectrometer gas analysis of Unloaded#1 generator test. The large decreasing water peak is due to water condensate trapped inside the sampling line, as can be seen in the following tests, the water behaviour returned to normal after the line was vacuum purged.

The first no retrofit unloaded generator test titled Unloaded#1 began at 12:18, and the engine was shut down at 12:43. Around this time, the weather conditions were as follows: 74 F, 31 F dew point, 21 % RH, 24.63 in pressure. Roughly 364 grams of gasoline was consumed in 24 minutes during this test. As can be seen on the mass spectrum data, there is some anomalous water behavior due to water condensate having built up inside the gas sampling line. This issue was resolved as the line was purged with vacuum. Exhaust port and

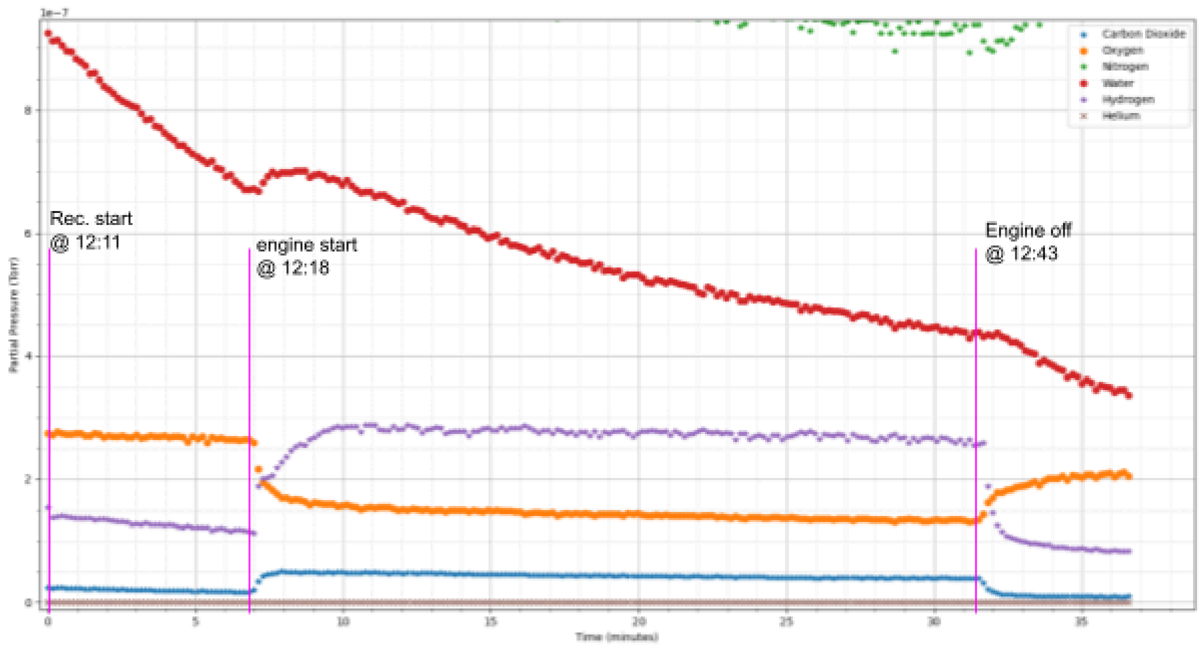


Figure ***XX.*** Zoomed in mass spectrometer gas analysis of Unloaded#1 generator test. The large decreasing water peak is due to water condensate trapped inside the sampling line, as can be seen in the following tests, the water behaviour returned to normal after the line was vacuum purged.

ambient temperatures were also recorded for the duration of the test and can be seen in the temperature graph presented. Exhaust port temperature plateaued around 290 C.

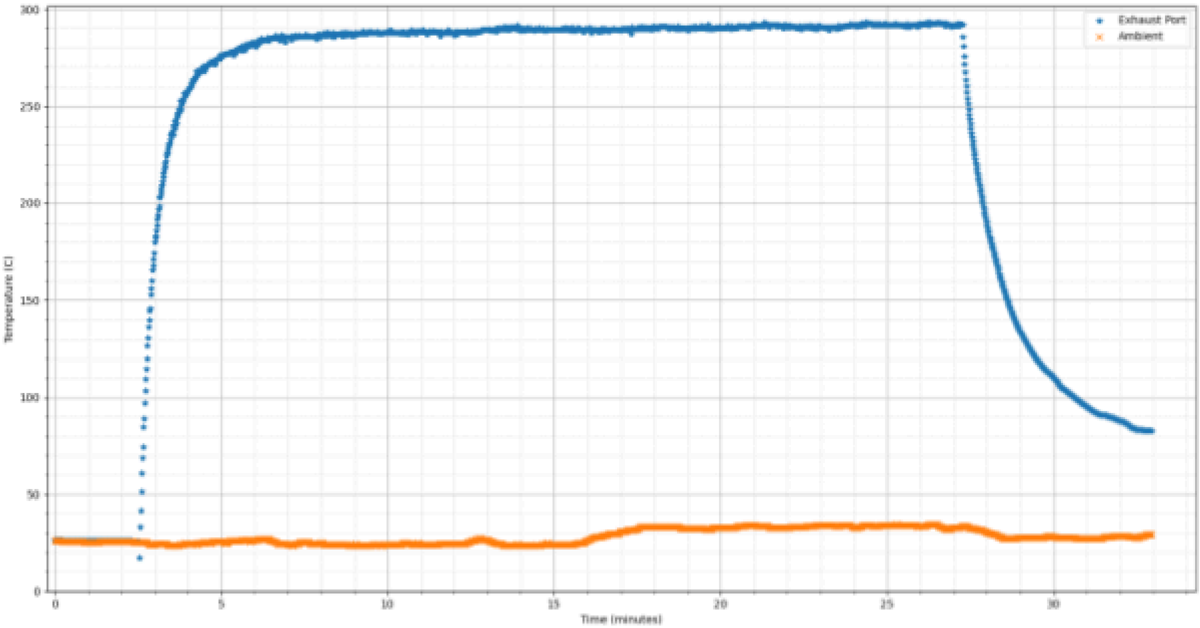


*Figure **XX***. Exhaust port and ambient temperatures during Unloaded#1 generator test. Pink vertical lines are used to roughly indicate relevant times during the experiment.

Gasoline weight data was continuously recorded at a rate of about 1 sample/second. The linear negative slope region of the graph was used for linear regression to obtain a fuel consumption rate. A fuel consumption rate of 0.247 grams gasoline/second (0.889 kg gasoline/hr) was obtained with an R^2 value greater than 0.99.

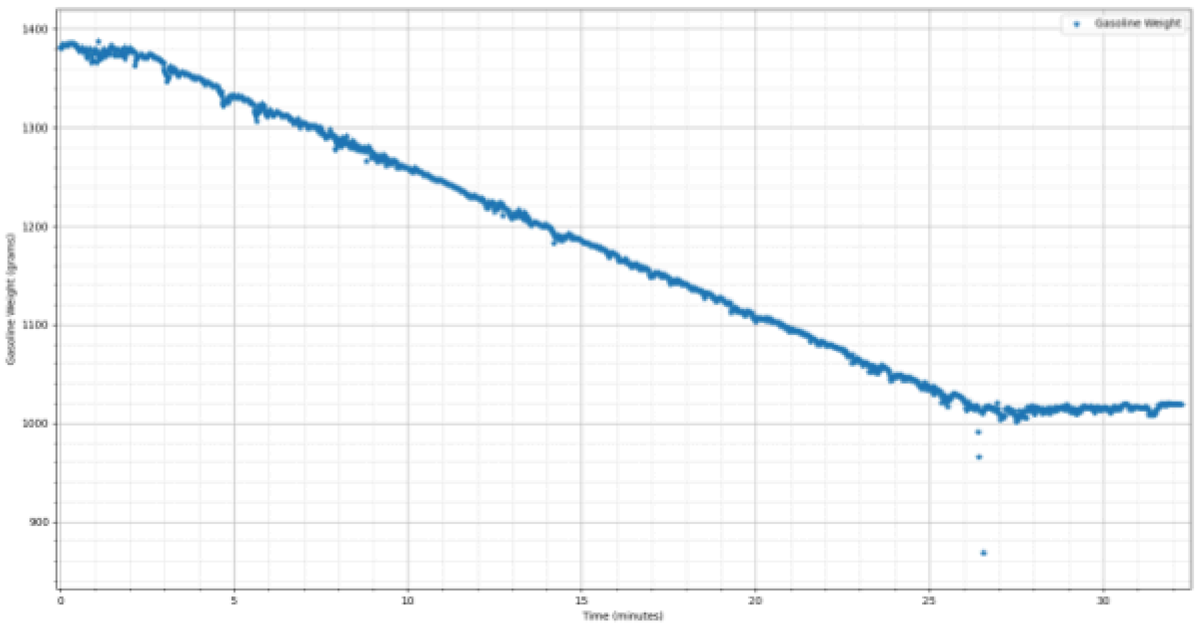
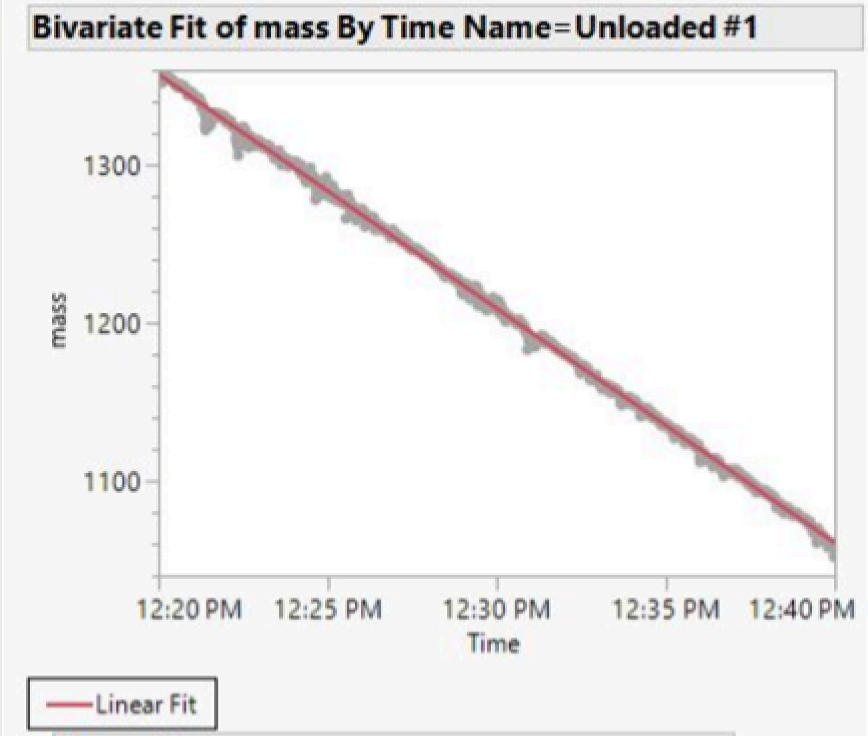


*Figure **XX***. Weight of graduated cylinder containing gasoline during Unloaded#1 generator test. The linear decline middle portion was regressed to obtain fuel consumption rate. A rate of 0.247 grams/second (0.889 kg/hr) was obtained. Pink vertical lines are used to roughly indicate relevant times during the experiment.



Linear Fit

mass = 12331.788 - 0.2471692*Time

Summary of Fit

RSquare	0.998976
RSquare Adj	0.998975
Root Mean Square Error	2.603686
Mean of Response	1208.905
Observations (or Sum Wgts)	1016

Figure ***XX***. Linear regression of Unloaded#1 test. A slope of -0.247 grams fuel/second is obtained with a coefficient of determination (R^2) value of 0.998976.

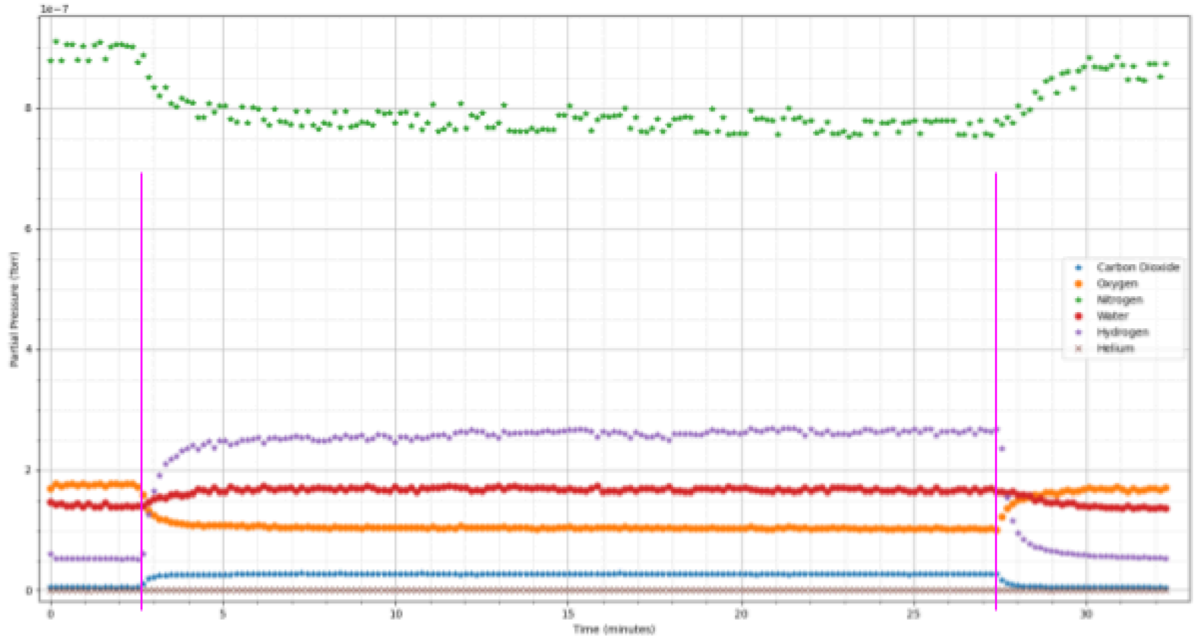


Figure ***XX.*** Mass spectrometer gas analysis of Unloaded#2 generator test.

The second no retrofit unloaded generator test titled Unloaded#2 began at 15:12, and the engine was shut down at 15:37. Around this time, the weather conditions were as follows: 80 F, 24 F dew point, 13 % RH, 24.55 in pressure. Roughly 365 grams of gasoline was consumed in 25 minutes during this test. Exhaust port and ambient temperatures were also recorded for the duration of the test and can be seen in the temperature graph presented. Exhaust port temperature plateaued around 293 C.

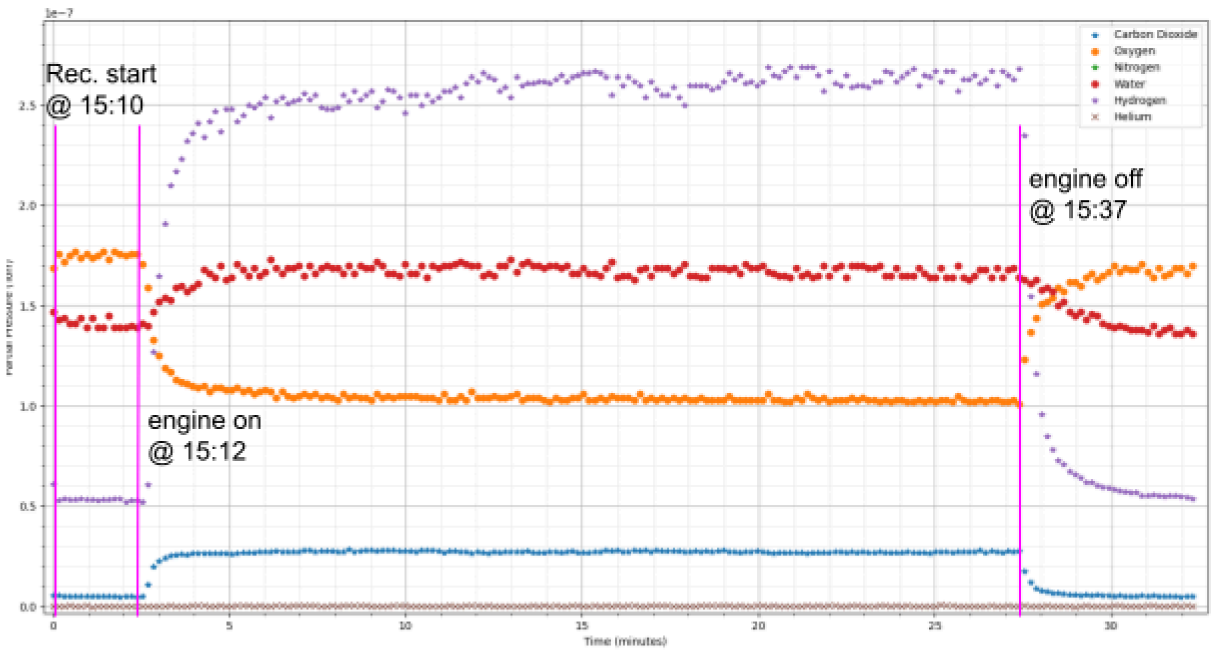


Figure ***XX***. Zoomed in mass spectrometer gas analysis of Unloaded#2 generator test.

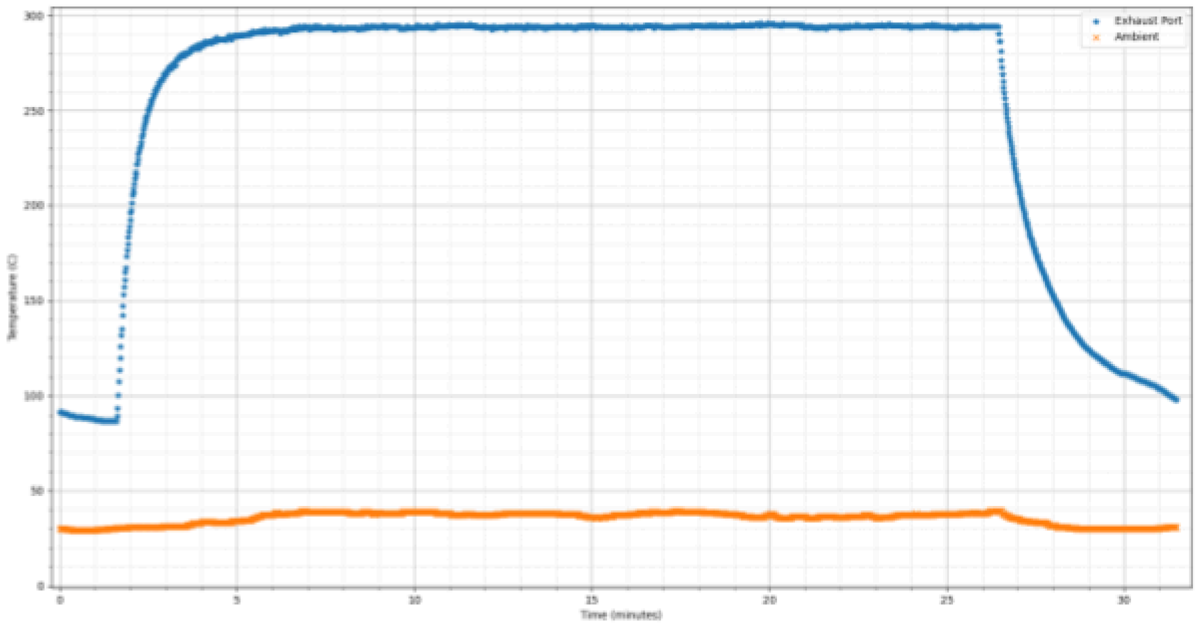


*Figure **XX***. Exhaust port and ambient temperatures during Unloaded#2 generator test. Pink vertical lines are used to roughly indicate relevant times during the experiment.

Gasoline weight data was continuously recorded at a rate of about 1 sample/second. The linear negative slope region of the graph was used for linear regression to obtain a fuel consumption rate. A fuel consumption rate of 0.244 grams gasoline/second (0.878 kg gasoline/hr) was obtained with an R^2 value greater than 0.999.

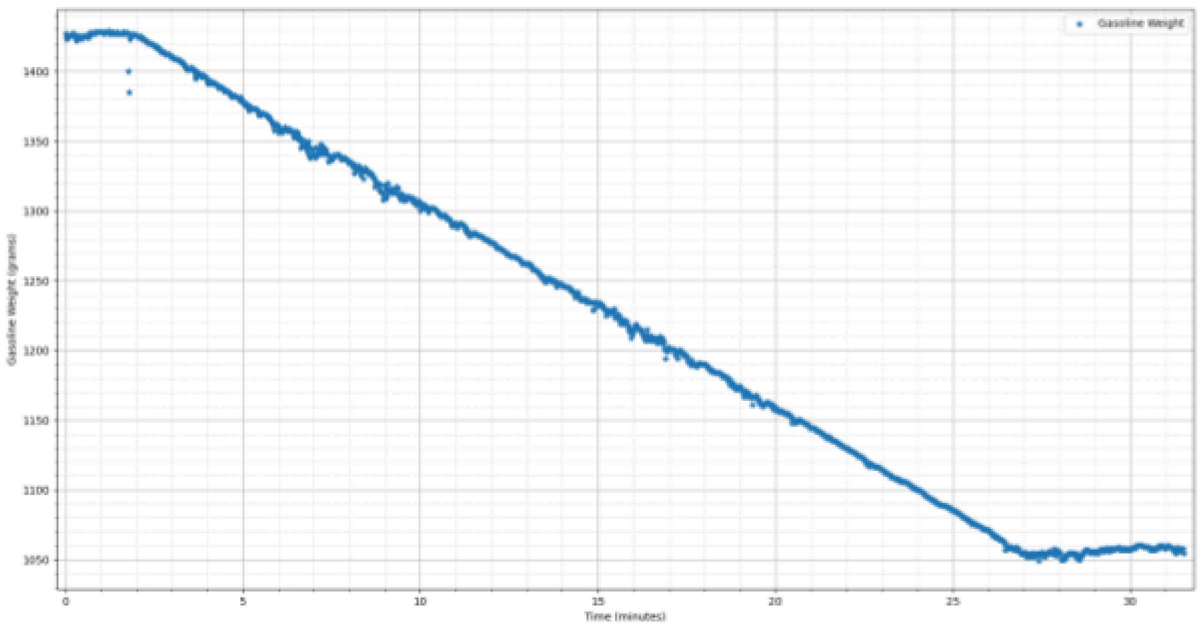
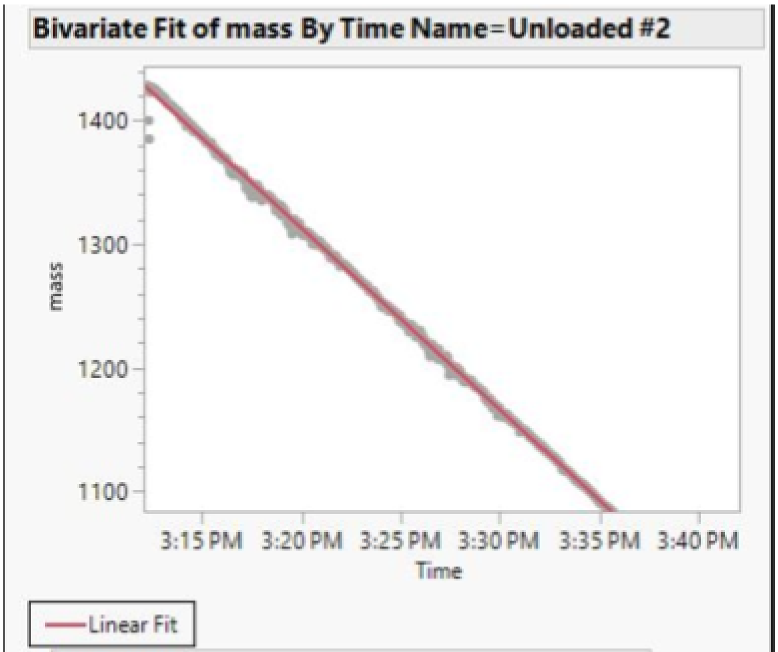


*Figure **XX***. Weight of graduated cylinder containing gasoline during Unloaded#2 generator test. The linear decline middle portion was regressed to obtain fuel consumption rate. A rate of 0.244 grams/second (0.878 kg/hr) was obtained. Pink vertical lines are used to roughly indicate relevant times during the experiment.



Linear Fit

mass = 14780.427 - 0.2439806*Time

Summary of Fit

RSquare	0.999532
RSquare Adj	0.999531
Root Mean Square Error	2.181823
Mean of Response	1239.82
Observations (or Sum Wgts)	1274

Figure ***XX***. Linear regression of Unloaded#2 test. A slope of -0.244 grams fuel/second is obtained with a coefficient of determination (R^2) value of 0.999532.

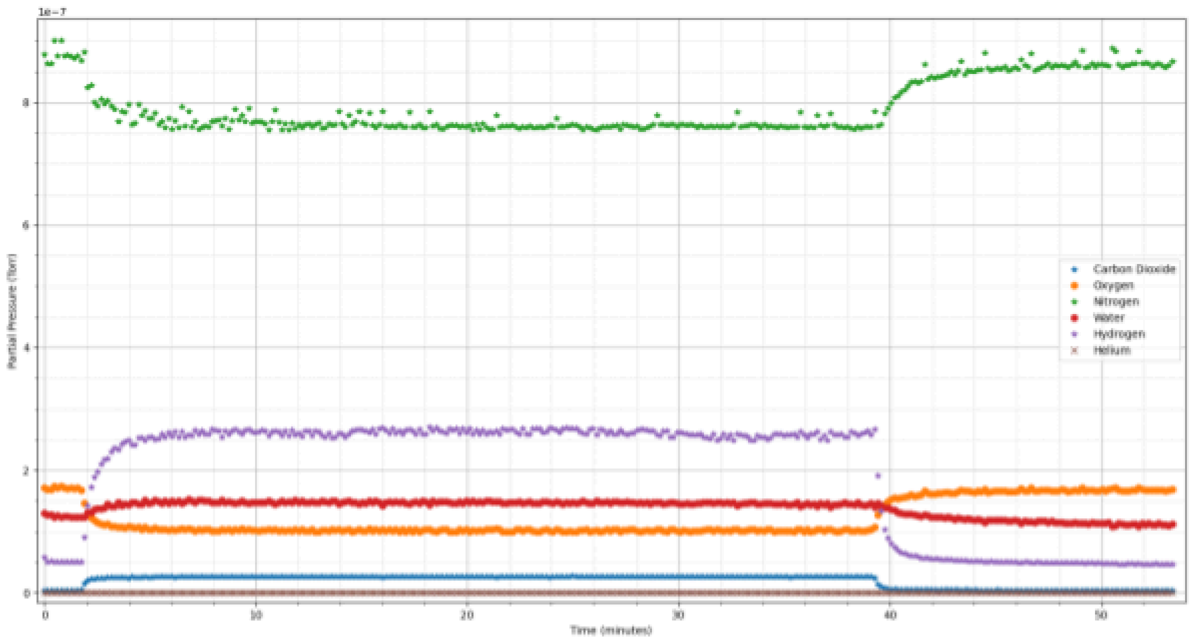


*Figure **XX***. Mass spectrometer gas analysis of Unloaded#3 generator test.

The third no retrofit unloaded generator test titled Unloaded#3 began at 16:15, and the engine was shut down at 16:53. Around this time, the weather conditions were as follows:80 F, 25 F dew point, 13 % RH, 24.54 in pressure. Roughly 548 grams of gasoline was consumed in 38 minutes during this test. Exhaust port and ambient temperatures were also recorded for the duration of the test and can be seen in the temperature graph presented. Exhaust port temperature plateaued around 290 C.

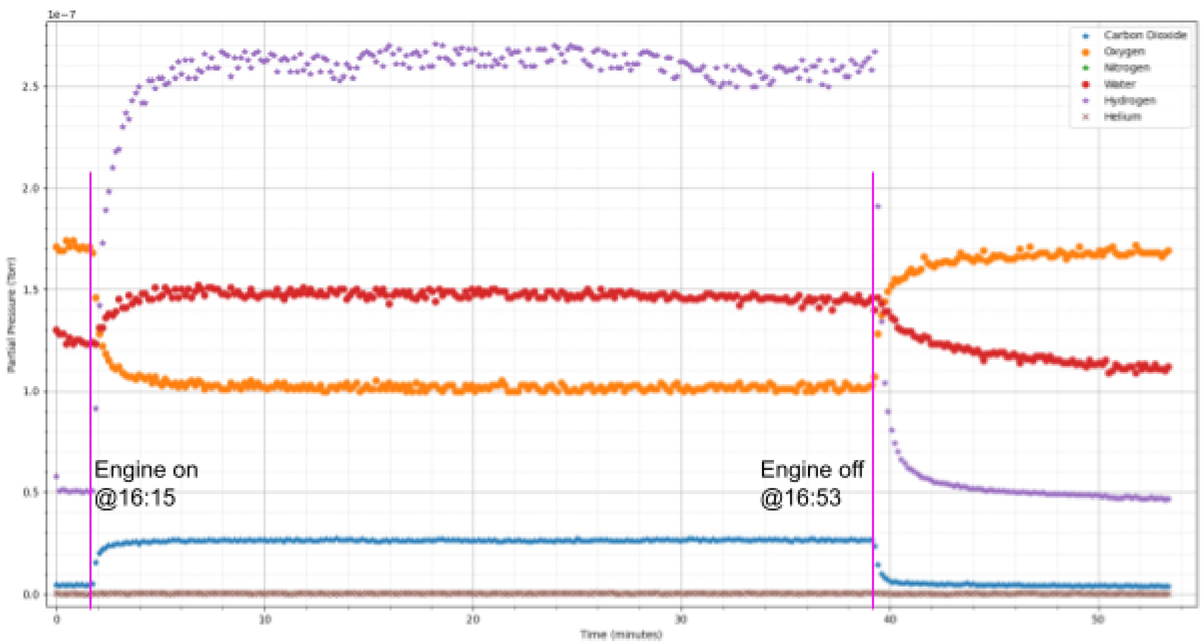


*Figure **XX***. Zoomed in mass spectrometer gas analysis of Unloaded#3 generator test.

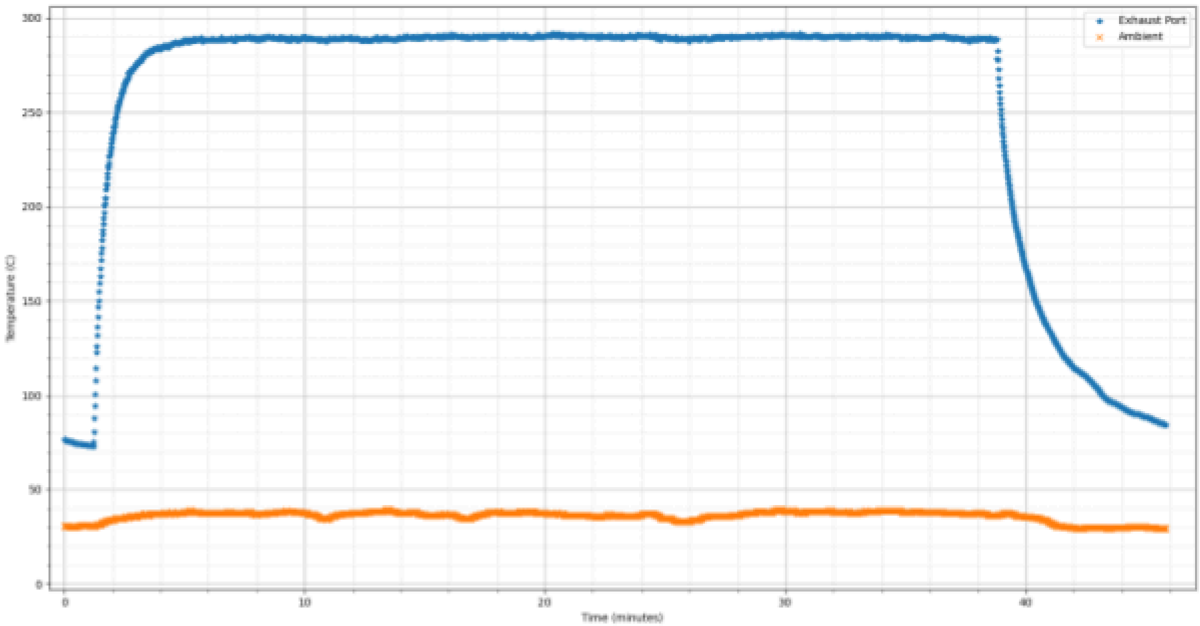


Figure ***XX***. Exhaust port and ambient temperatures during Unloaded#3 generator test. Pink vertical lines are used to roughly indicate relevant times during the experiment.

Gasoline weight data was continuously recorded at a rate of about 1 sample/second. The linear negative slope region of the graph was used for linear regression to obtain a fuel consumption rate. A fuel consumption rate of 0.244 grams gasoline/second (0.878 kg gasoline/hr) was obtained with an R^2 value greater than 0.999.

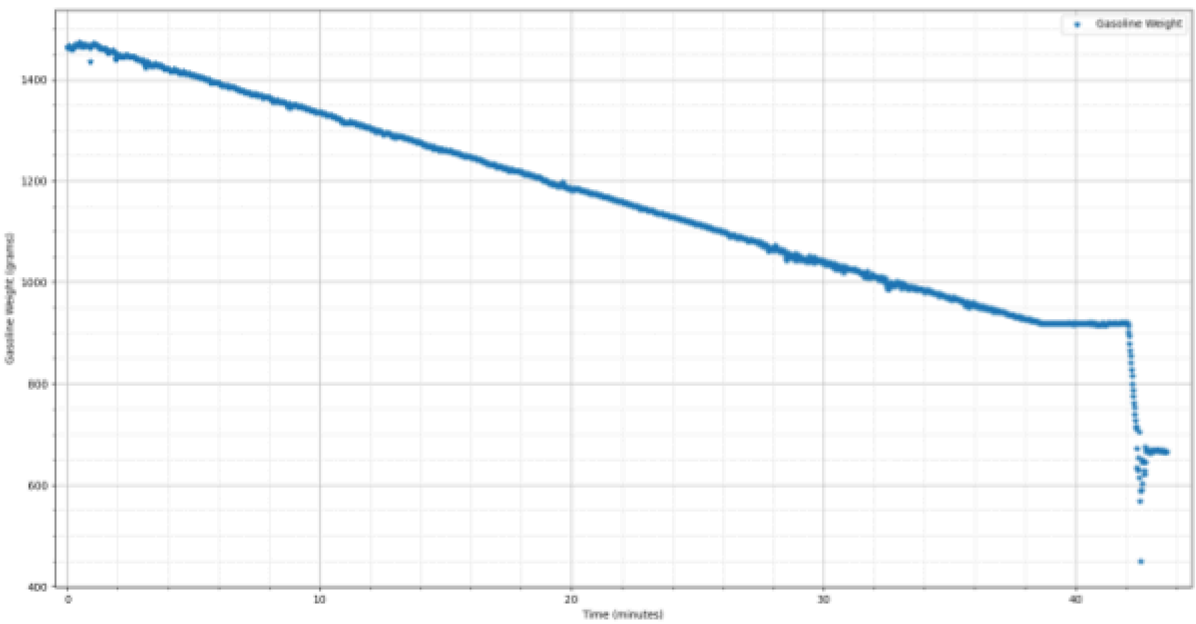
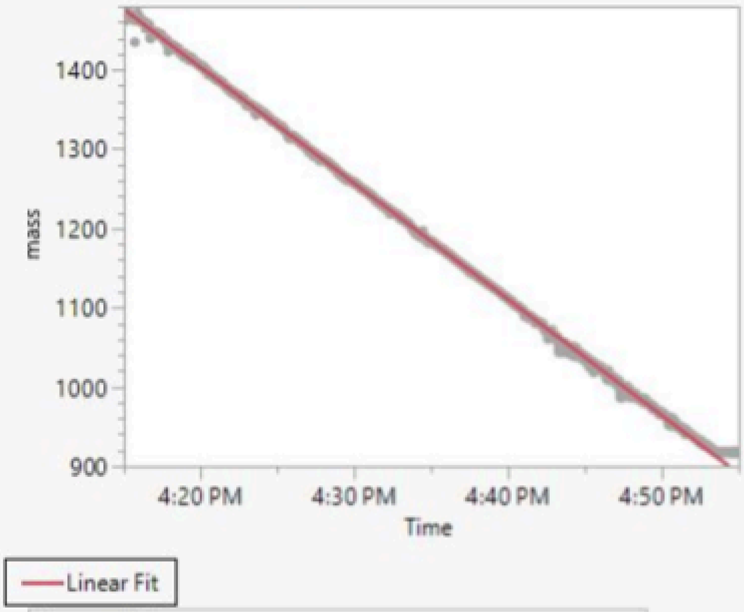


Figure ***XX***. Weight of graduated cylinder containing gasoline during Unloaded#3 generator test. The linear decline middle portion was regressed to obtain fuel consumption rate. A rate of 0.244 grams/second (0.878 kg/hr) was obtained. Pink vertical lines are used to roughly indicate relevant times during the experiment.

Bivariate Fit of mass By Time Name=Unloaded #3



Linear Fit

mass = 15743.65 - 0.2438852*Time

Summary of Fit

RSquare	0.999699
RSquare Adj	0.999699
Root Mean Square Error	2.721762
Mean of Response	1185.147
Observations (or Sum Wgts)	1985

*Figure **XX***. Linear regression of Unloaded#3 test. A slope of -0.244 grams fuel/second is obtained with a coefficient of determination (R^2) value of 0.999699.

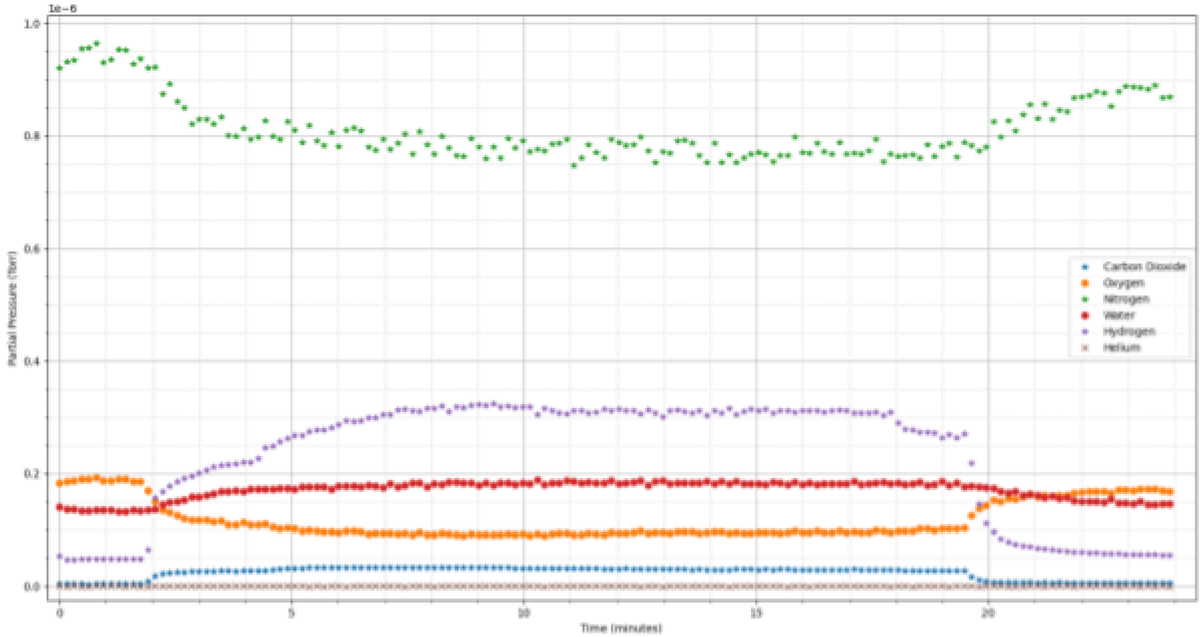


Figure ***XX.*** Mass spectrometer gas analysis of Loaded#1 generator test. The load was inconsistent during this test due to one of the hotplates continually shutting off and on. Two hot plates were used for the load, one consuming about 1,396 Watts, the second which was shutting off and on, consuming about 1,428 Watts when on.

The first no retrofit loaded generator test titled Loaded#1 began at 14:45, and the engine was shut down at 15:03. Around this time, the weather conditions were as follows:79 F, 28 F dew point, 15 % RH, 24.57 in pressure. Roughly 428 grams of gasoline was consumed in 18 minutes during this test. Two hot plates with pots of water were used to load the generator. The recorded wattage use of the hotplates were 1,396 Watts for hotplate #1 and 1,428 Watts for hotplate #2. During the test, hotplate #2 began continually shutting itself on and off, resulting in an inconsistent load during this test. Only hotplate #1 was used for the

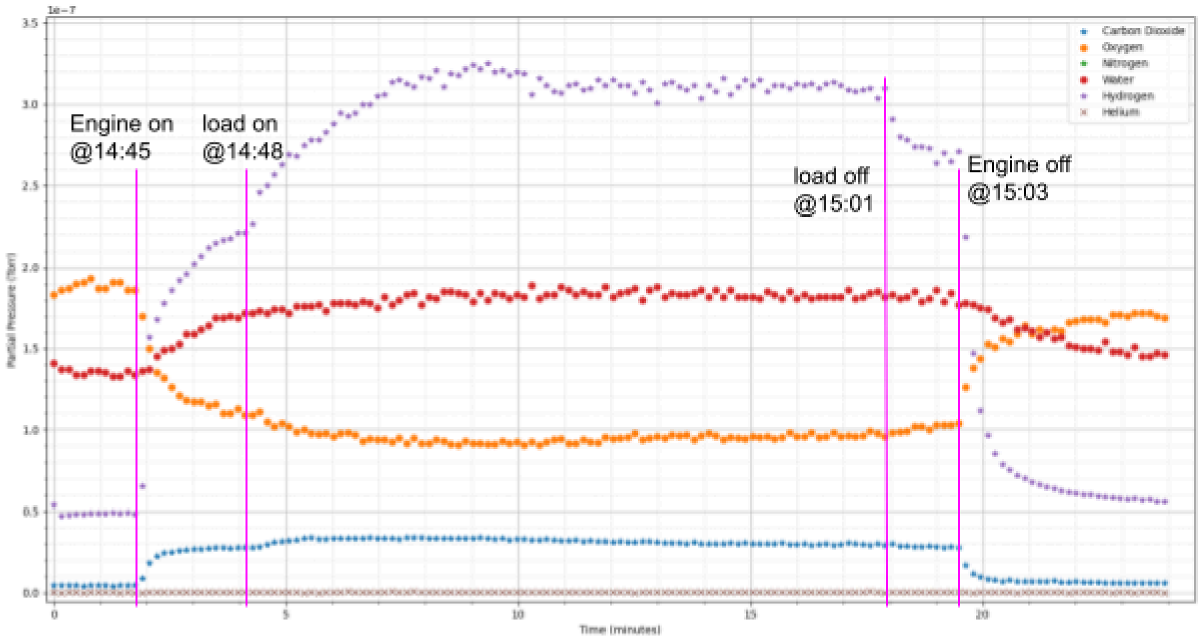


Figure ***XX.*** Zoomed in mass spectrometer gas analysis of Loaded#1 generator test. Notice the hydrogen response when load is enabled/disabled.

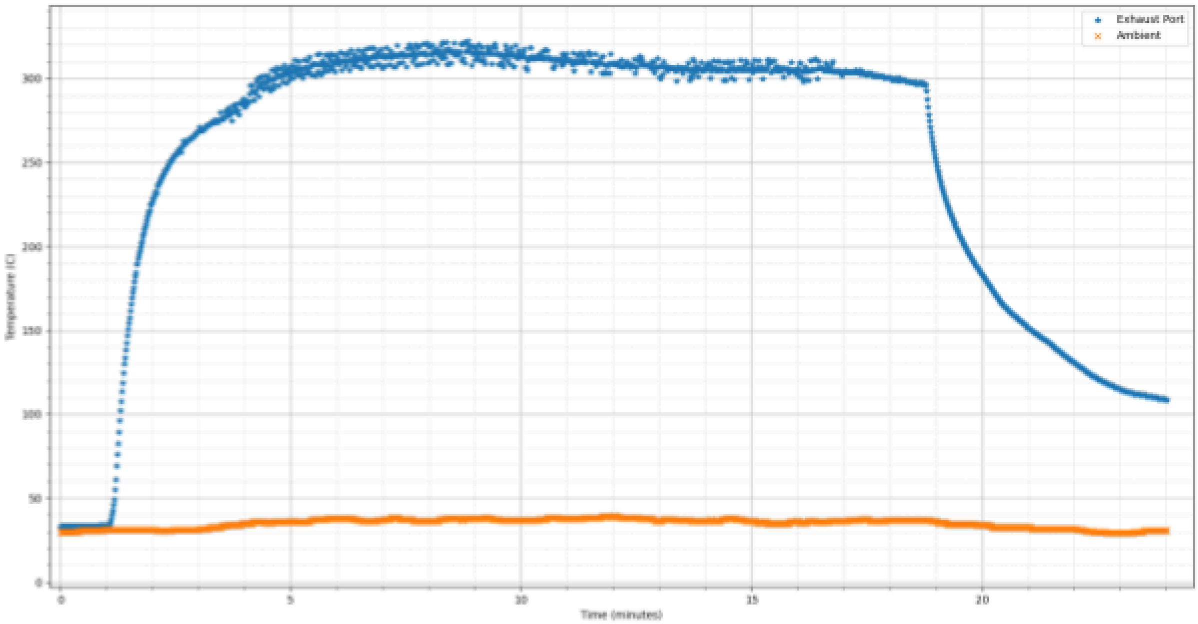


*Figure **XX***. Exhaust port and ambient temperatures during Loaded#1 generator test. Signal noise induced by the generator can be seen on the exhaust port temperatures starting ~3.5 minute mark, and ending ~17 minute mark. Pink vertical lines are used to roughly indicate relevant times during the experiment.

proceeding Loaded#2 test. Exhaust port and ambient temperatures were also recorded for the duration of the test and can be seen in the temperature graph presented. When enabled and under load, the generator causes a small amount of electrical noise resulting in noisier exhaust port temperature data. Exhaust port temperature reached a maximum of about 315 C and plateaued around 305 C.

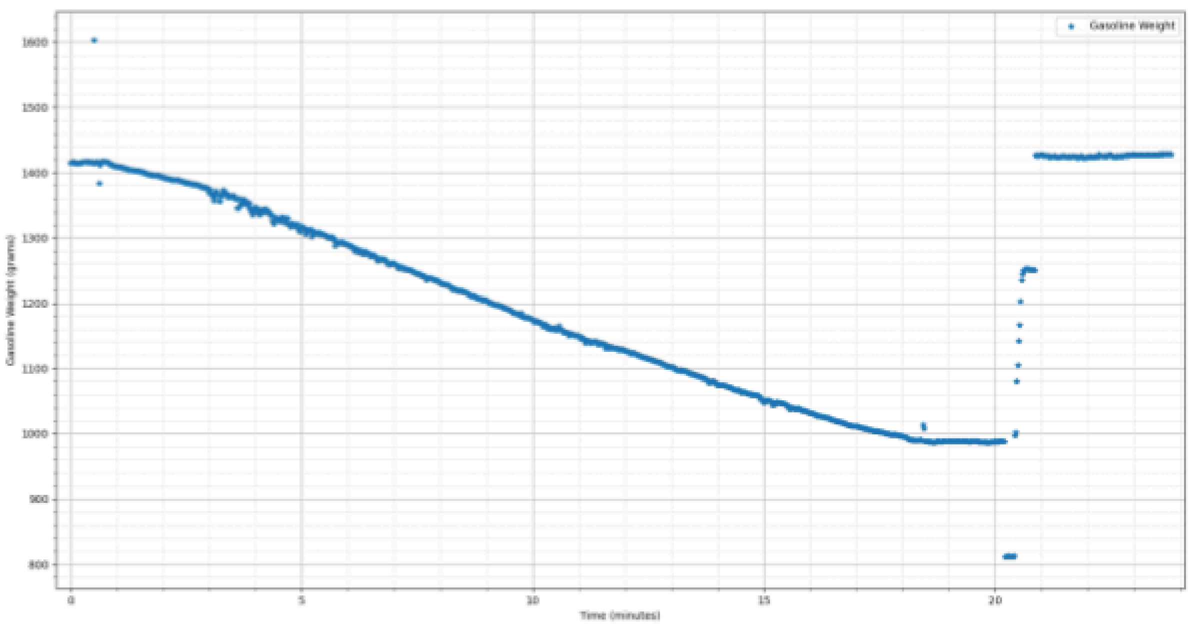
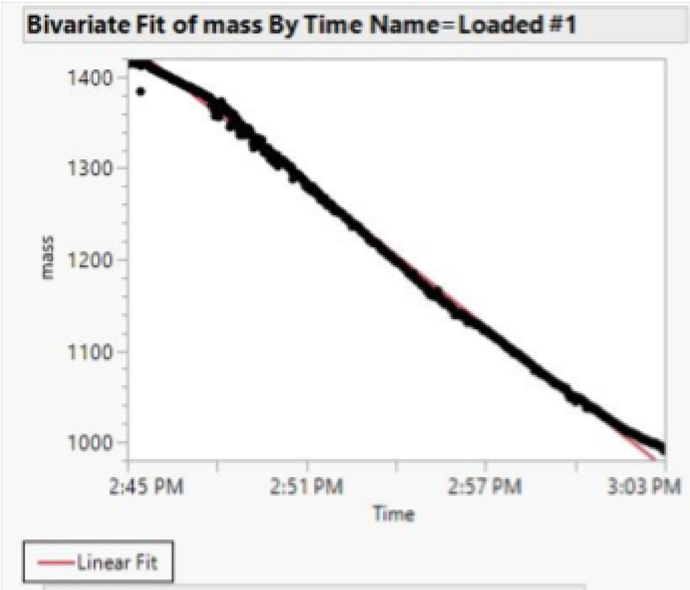


*Figure **XX***. Weight of graduated cylinder containing gasoline during Loaded#1 generator test. The linear decline middle portion was regressed to obtain fuel consumption rate. A rate of 0.432 grams/second (1.555 kg/hr) was obtained. Pink vertical lines are used to roughly indicate relevant times during the experiment.

Gasoline weight data was continuously recorded at a rate of about 1 sample/second. The linear negative slope region of the graph was used for linear regression to obtain a fuel consumption rate. A fuel consumption rate of 0.432 grams gasoline/second (1.555 kg gasoline/hr) was obtained with an R^2 value greater than 0.99.



Linear Fit

mass = 24360.611 - 0.4316873*Time

Summary of Fit

RSquare	0.997057
RSquare Adj	0.997054
Root Mean Square Error	6.670764
Mean of Response	1187.698
Observations (or Sum Wgts)	877

Figure ***XX***. Linear regression of Loaded#1 test. A slope of -0.432 grams fuel/second is obtained with a coefficient of determination (R^2) value of 0.997057.

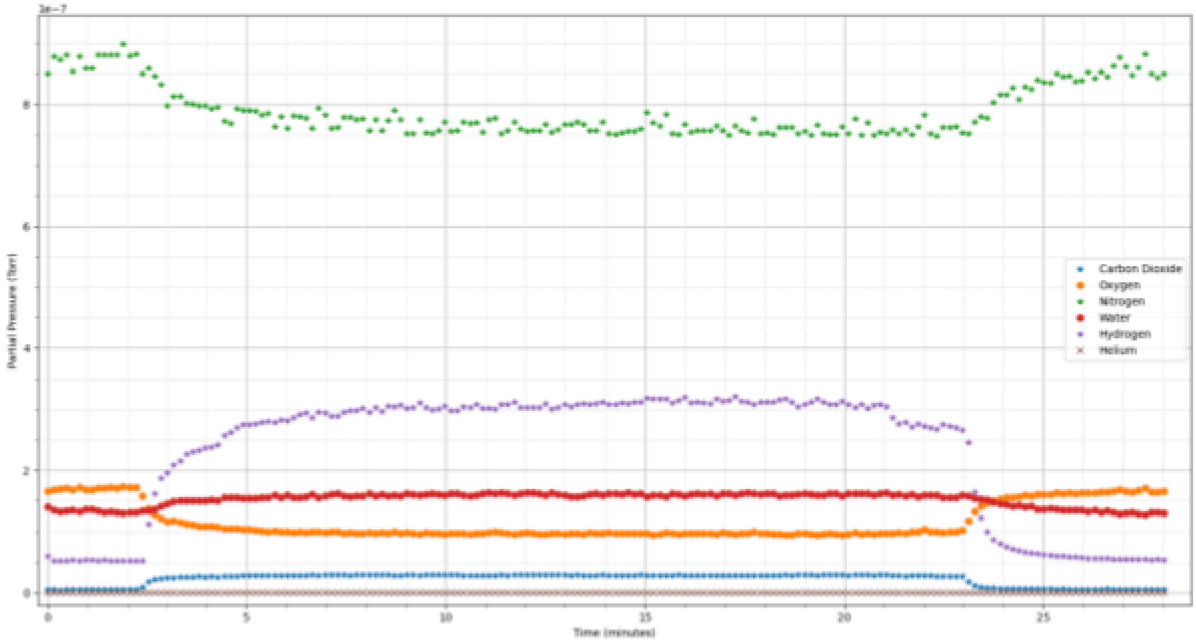


Figure ***XX.*** Mass spectrometer gas analysis of Loaded#2 generator test. One hot plate was used for the load, consuming about 1,327 Watts.

The second no retrofit loaded generator test titled Loaded#2 began at 15:45, and the engine was shut down at 16:06. Around this time, the weather conditions were as follows:80 F, 24 F dew point, 13 % RH, 24.55 in pressure. Roughly 429 grams of gasoline was consumed in 21 minutes during this test. One hot plate with pots of water was used to load the generator. The hotplate drew about 1,330 Watts of power during the test.

Exhaust port and ambient temperatures were also recorded for the duration of the test and can be seen in the temperature graph presented. When enabled and under load, the

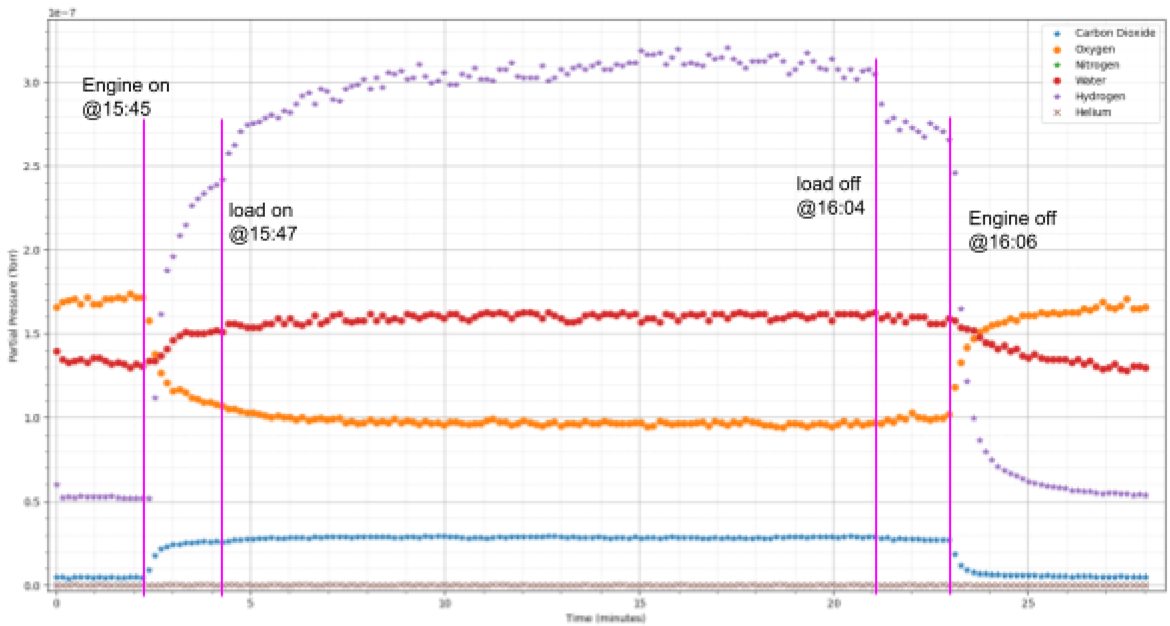


Figure ***XX.*** Zoomed in mass spectrometer gas analysis of Loaded#2 generator test.

generator causes a small amount of electrical noise resulting in noisier exhaust port temperature data. Exhaust port temperature plateaued around 300 C.

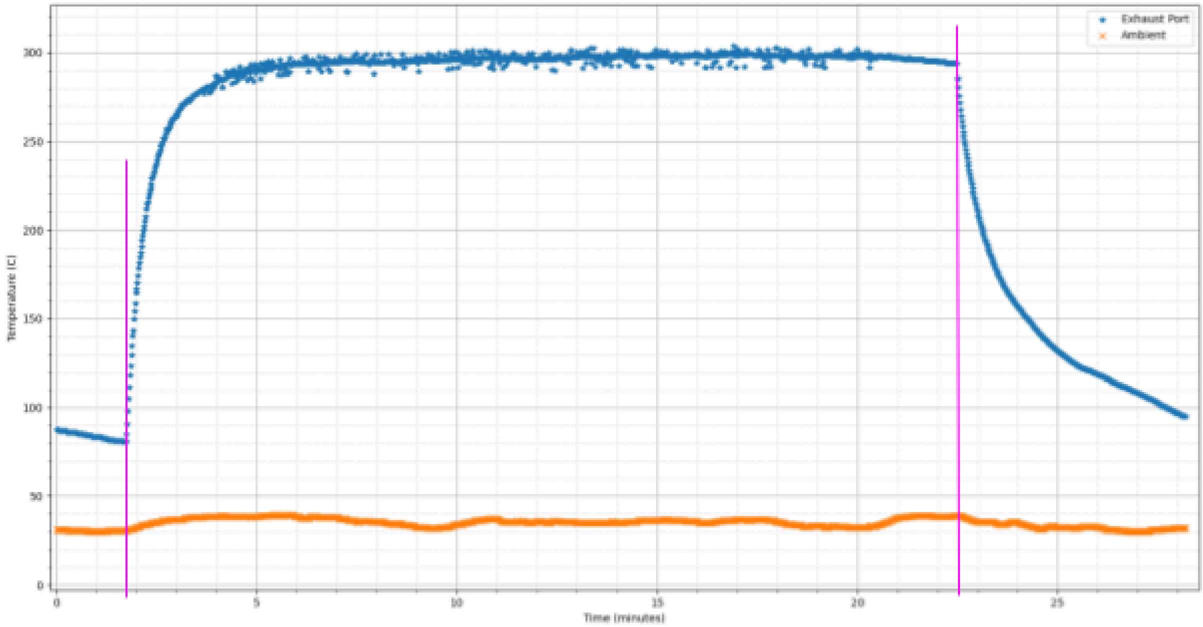


Figure ***XX***. Exhaust port and ambient temperatures during Loaded#2 generator test. Signal noise induced by the generator can be seen on the exhaust port temperatures starting ~4.5 minute mark, and ending ~20.5 minute mark. Pink vertical lines are used to roughly indicate relevant times during the experiment.

Gasoline weight data was continuously recorded at a rate of about 1 sample/second. The linear negative slope region of the graph was used for linear regression to obtain a fuel consumption rate. A fuel consumption rate of 0.361 grams gasoline/second (1.300 kg gasoline/hr) was obtained with an R^2 value greater than 0.999.

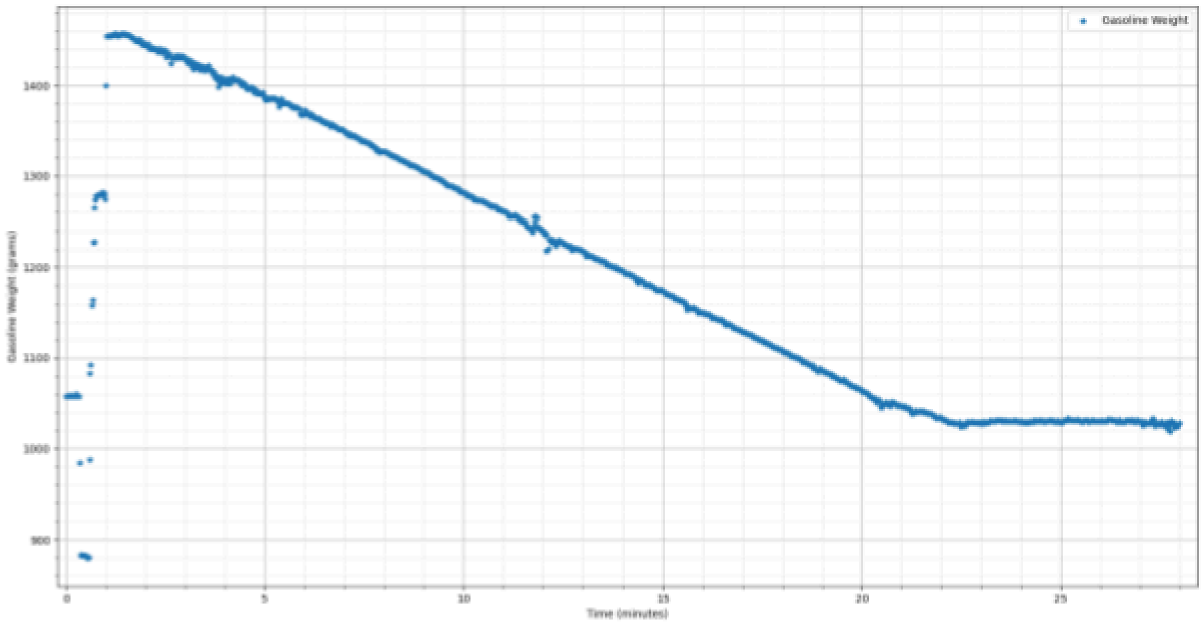


Figure ***XX***. Weight of graduated cylinder containing gasoline during Loaded#2 generator test. The linear decline middle portion was regressed to obtain fuel consumption rate. A rate of 0.361 grams/second (1.300 kg/hr) was obtained. Pink vertical lines are used to roughly indicate relevant times during the experiment.

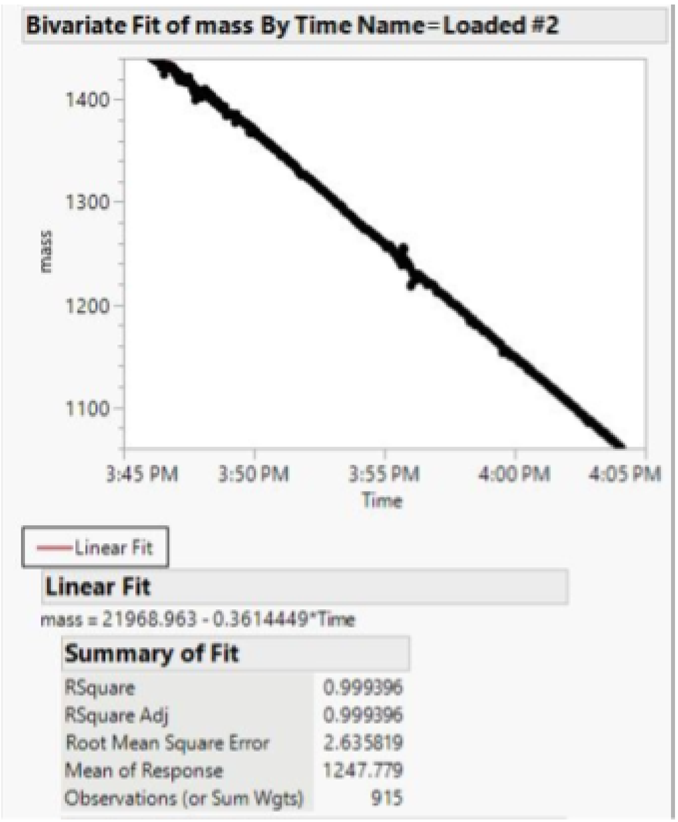


*Figure **XX**.* Linear regression of Loaded#2 test. A slope of -0.361 grams fuel/second is obtained with a coefficient of determination (R^2) value of 0.999396.

Overall, this set of tests was successful. Continuous gasoline weight recording worked very well, the data is linear and easy to fit/regress. A shed is being constructed at the test site which will allow for not needing to break the entire set up down at the end of every test day. The mass spec will also be under continuous vacuum now in the shed, and will have a much cleaner background after staying under high vacuum for a few weeks straight. Two hot plates without self regulation capability for 50-60% load tests will be implemented during the next baseline tests.

After one more day (likely weekend of 11/4/23) of baseline testing, we should be ready to move on to the control tube tests. Once the compressed Argon is acquired, may do a couple extra baseline tests just to have a comparison with constant Argon background injection. Either way, very close to being done with baselining the engine/generator.

Ideas for implementation

**Weather vane for local environment data

Ordered and delivered

**Another hot plate that does not regulate ON/OFF

Ordered and delivered

**Need to work on implementing Argon background injection to be able to quantify mass spec gas data

Need a small ~3.5 cubic foot tank for Argon, along with regulator, preferrably 2-stage for ultra high purity gases, preferably ultra high purity Argon

Tank ordered and delivered, will fill up with Argon around weekend of 11/10/23

Already have a mass flow controller that would work perfectly for this

5.4 Results and Discussion

6.0 Theoretical Basis for Claimed Effects of Retrofit System

6.1 Pre-ionizer

6.2 Diffusor/Bubbler

Charge separation and toroidal plasma generation may be achieved in areas of hydrodynamic shear. (10)

**Energies involved with cavitation and bubble collapse, star in a jar

**Toroidal geometry formation from a collapsing sphere

6.3 vortex tube

**Plasmoid formation due to vortex flows/shear flows?

**What are the implications of charged species (plasmoid or otherwise) traveling inside a vortex at rotational speeds approaching 1,000,000 RPM? Currents and magnetic fields generated could be quite high

**If fields are entirely contained inside the plasmoids themselves, then there is still the question of potentials

**How is gas reforming taking place? If no transmutation on the atomic level, then is there a more conventional cracking/reforming process happening? If cracking/reforming, the inside of the vortex tube should be accumulating some kind of carbon solid, maybe coking type of action?

Topics/points to remember for later incorporation

Exhaust gas pressure/volume released versus intake air

Molar ratios of CO_2/N_2/O_2/CO etc for exhaust versus intake air dilution calculations

CFD model of vortex tube

Bubble formation/collapse in presence of shockwave propagating through the bubble media

Magnetic interactions of the charged particles flowing inside the inner and outer vortices

Presence of fields versus potentials (claims of fractal toroidal charge clusters having a sort of event horizon where EM fields disappear outside the horizon, but the potentials are still present), consequences for forces, no field, no force on charged particles

Ideal gas law versus cubic equation of state for exhaust gas properties estimation, is it even worth the extra accuracy to use something other than ideal gas law in this case?

Fusion calculator potential combinations, is this a relatively "simple" gas cracking/reforming action or is there actual elemental transmutation going on? "Coking" of carbon inside the vortex tube would be indicative of at least some cracking/reforming as CO_2 and CO give up oxygen and leave behind carbon as coke. If transmutation is being done, need to run fusion calcs will all available constituents to see where the carbon can go, potentially hydrogen1 hydrogen1 carbon6 to oxygen….who knows, still would need neutrons for oxygen 16….yada yada this is a rough rabbit hole

Proposed mechanism of action of plasmoids through their magnetic field to attract paramagnetic elements/species, and expel diamagnetic elements/species

References

1. **Bendall, Malcolm.** The 'Thunderstorm Generator' - Atomic Energy From Water Plasmoid Protium Power. *strikefoundation.earth.* [Online] https://www.strikefoundation.earth/open-source-research.

2. *Gasoline engine exhaust gas recirculation - A review.* **Haiqiao, Wei, Tianyu, Zhu and Gequn, Shu.** 2012, Applied Energy, pp. 534-544.

3. **Shoulders, Ken.** An EVO Scope for Electrolysis Projectile Measurement. May 11, 2009.

4. **TeslaTech LLC.** TeslaTech Home. *TeslaTech.* [Online] August 8, 2023. https://teslatech.us/.

5. *Review of Ranque-Hilsch effects in vortex tubes.* **Eiamsa-ard, Smith and Promvonge, Pongjet.** 2008, Renewable & Sustainable Energy Reviews, pp. 1822-1842.

6. *CFD simulation on optimum material to fabricate the counter flow of Ranque-Hilsch vortex tube.* **K, Kiran Kumar Rao, A, Ramesh and Hampali, Chennabasappa.** 2022, Scientific Reports.

7. *Experimental study of ionized matter projected across a magnetic field.* **Bostick, Winston H.** 1956, University of California Radiation Laboratory, Livermore Sire.

8. *Further Insight into the Nature of Ball-Lightning-Like Atmospheric.* **Friday, David M., et al.** 2013, The Journal of Physical Chemistry, pp. 9931-9940.

9. **Gray, Harry B.** *Electrons and Chemical Bonding.* New York : W. A. Benjamin, INC., 1965.

10. *Toroidal plasmoid generation via extreme.* **Ghariba, Morteza, et al.** 2017, PNAS.

11. **Bendall, Malcolm.** Open Source Research. *Strike Foundation Guarantee Limited.* [Online] August 15, 2023. strikefoundation.earth.

12. *Recent progress in the thermodynamics of ferrotoroidic materials.* **Planes, Antoni, Castan, Teresa and Saxena, Avadh.** 2015, Multiferroic Materials.

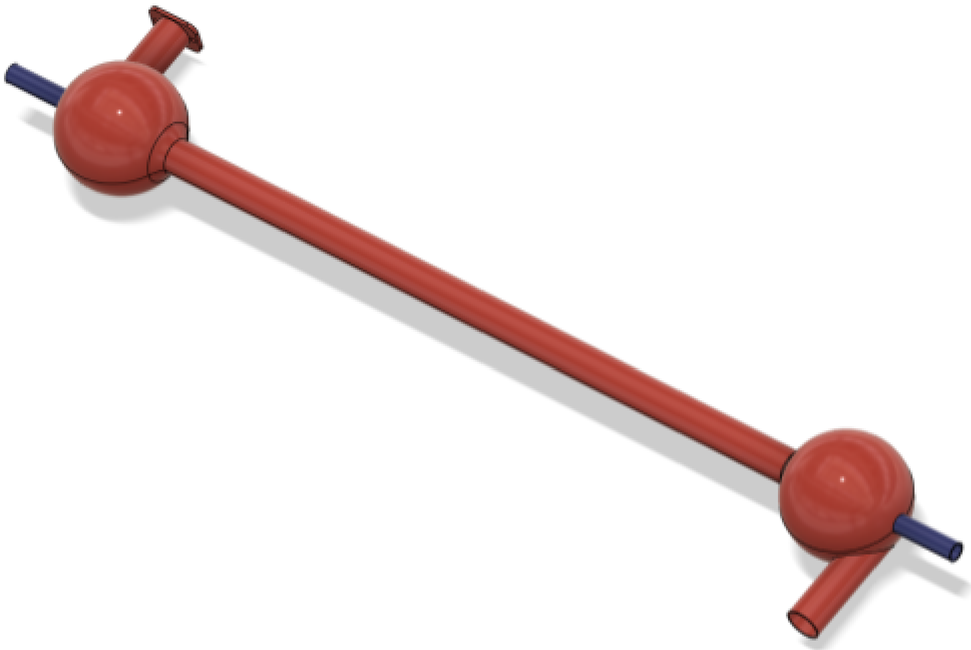
13. *Hofmeister series: The quantum mechanical viewpoint.* **Henry, Marc.** 2016, Current Opinion in Colloid & Interface Science, pp. 119-125.

14. **Halpern, Joshua.** *Howard University General Chemistry An Atoms First Approach.* s.l. : LibreTexts, 2023.

15. **Manthey, David.** Grand Orbital Table. *Orbital Central.* [Online] 2001. [Cited: September 15, 2023.] https://www.orbitals.com/orb/orbtable.htm.

****Images to incorporate in document**

Double sphere vortex tube



Double sphere vortex tube. Ideal design including smooth transitions from spheres to center tubes.

Model of typical portable generator VGR system.