Autonomous Hydrogen and Oxygen Generator
for
Internal Combustion Engine

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Abstract

Fuel mixtures of gasoline and oxyhydrogen (HHO) gas have been used to reduce emissions and improve the performance of internal combustion engines (ICEs). The purpose of this study is to develop a feedback controller that maintains maximum thermal efficiency for an ICE, based on an experimentally determined optimal mixture of HHO and gasoline. To do so, a multidisciplinary team of mechanical and electrical engineering students and faculty members at Old Dominion University have begun constructing an experimental apparatus in which HHO can be generated and injected into a Briggs & Stratton 950 engine. Tests aim to quantify the effects on engine thermal efficiency, specific power output, specific fuel consumption, and emission characteristics. Optimal HHO parameters will then be determined based on collected data and a feedback control system will be employed to maintain optimal HHO inclusion based on engine speed.

Table of Contents

List of Figures

List of Tables

Introduction

The harmful environmental impact and limited amount of fossil fuels has encouraged research focused on improving the performance of ICEs. Developing methods to reduce fuel consumption and harmful pollutants. The combustive properties of hydrogen provide support to its potential as a clean alternative fuel source [1]. However, issues arise from safely refueling and storing hydrogen without dramatic changes to current automobile designs and fueling stations. On demand generation of hydrogen in the form of HHO, through the electrolysis of water, has emerged as a solution [2].

When studied directly, the inclusion of HHO into four-stroke engines has shown measurable increases in thermal efficiency, as well as decreases in harmful pollutants: CO and NOx. Yilmaz et.al. conducted a thorough review of these proposed claims by incorporating the output from a fuel-cell into the intake manifold on a diesel engine [3]. He showed that when 7% (by mass) of the diesel was replaced with HHO, braking thermal efficiency increased by 9% and that specific fuel consumption decreased by as much as 17%. In terms of pollutant emissions, Musmar et.al. compared concentrations of CO, NO, NOx, and hydrocarbons in the exhaust stream of a small (197cc) gasoline engine with and without the inclusion of HHO gas [4]. CO, NO, and hydrocarbon emissions showed a 20%, 50%, and 40% reduction when combustion was boosted by HHO. These studies suggest that oxyhydrogen improves the performance of ICEs, however, little research has been done into the optimal quantity of HHO to maximize these benefits. This project aims to fill in that gap; a multidisciplinary team of mechanical and electrical engineers intends to determine the optimal rate HHO inclusion and develop a feedback control mechanism to maintain optimal conditions on a 200cc engine.

Methods

Completed Methods

Thus far, completed work has consisted of predicting HHO flow rates, and preparing the engine and testing environment. Initially, design goals were aimed at analyzing engine performance from running on 0% to 100% HHO included, which required flow rate estimates in order to select an appropriately sized fuel cell. Flow rate modeling was based on the first law of thermodynamics and the ideal gas law, and a detailed sample calculation is available in Appendix C.

To calculate efficiency, the flow rate of fuel into the engine and the power output must be known. Power output can be measured by a dynamometer, and volumetric flow of oxyhydrogen can be sensed by a digital rotameter, however, measuring the volumetric flow of gasoline, which is on the order of milliliters per minute, requires specialized and expensive equipment. Therefore, an alternative method for was devised that makes use of a 50 mL volumetric burette, normally used for titrations in analytical chemistry labs. By routing the gasoline flow into the engine through a burette, the volumetric flowrate can be determined by measuring the volume differential in a measured amount of time. For accurate results, the burette was calibrated accordingly.

Burette calibration is a straightforward procedure, and involves dispensing aliquots of deionized water from the burette and weighing them using an analytical balance. First, the burette is filled with deionized water, and the temperature of the water is recorded. Next, a small beaker is cleaned, dried, and pre-weighed on an Acculab Atilon 0.1mg balance, which was calibrated prior to use. Finally, the burette was allowed to drain into the beaker starting first from the 50.0 mL mark, and the mass of water delivered was determined by weighing the filled beaker. By looking up the density of water at the recorded temperature, this mass can be converted to volume, which then gives the correction for the 50mL mark of the burette. This procedure was done at 10mL intervals, with 5 data points in total. From the attached graph below, it is evident why calibration is necessary, especially when gasoline flow rates are very small and accuracy is imperative.

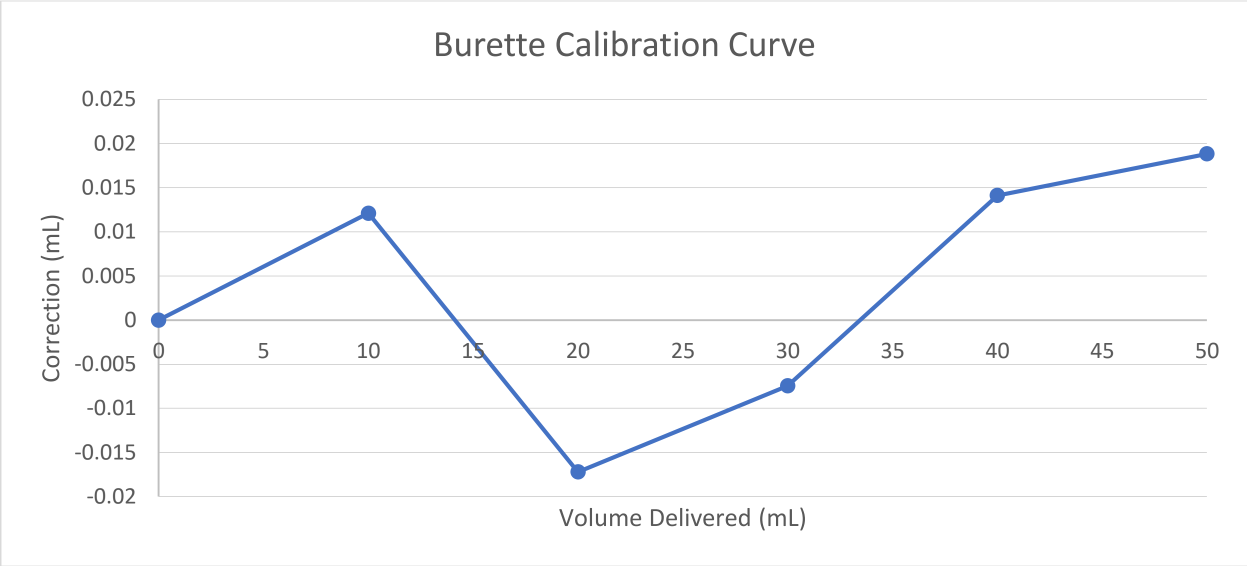


Figure 1: Burette Calibration Curve

Other completed methods include preparing the engine mount for use with ODU's dynamometer. This mount is a ½ inch thick aluminum plate which can be bolted to the dynamometer and to which the engine can be bolted to. This allows the engine to be oriented properly with the water brake. To make the mount, the necessary threaded holes were drilled by ODU's machine shop.

Additionally, the HHO injection system and test cart have been designed, and parts have been ordered. Until the necessary parts arrive however, these items cannot be built.

Proposed Methods

The testing environment needs to finish being prepared for testing to begin. First and foremost, attempts to repair the ODU dynamometer will continue. The possibility of purchasing the dynamometer license and receiving training will be pursued. In the possible scenario that ODU's dynamometer cannot fulfill the needs of the project, backup plans have been made to use a dynamometer at Tidewater Community College (TCC). If it is needed, assistance from a faculty member will be utilized to become familiar with that dynamometer.

The modifications to the engine, as well as the test cart, will be finalized once all ordered parts arrive. Modifications that need to be installed include the gasoline flow rate apparatus and HHO injection port. While the burette used in the gasoline flow rate apparatus has been acquired and calibrated, it still needs to be integrated into the engine fuel input. The overall schematic is shown below, and all that remains to be done is the installation of awaited parts. The HHO injection apparatus also needs to be installed. This involves drilling a threaded hole into the carburetor beyond the throttle and installing a carburetor jet to which the output of the fuel cell will be linked. Finally, the last item to prepare before live tests is the emissions probe, which will be tested and calibrated if necessary.

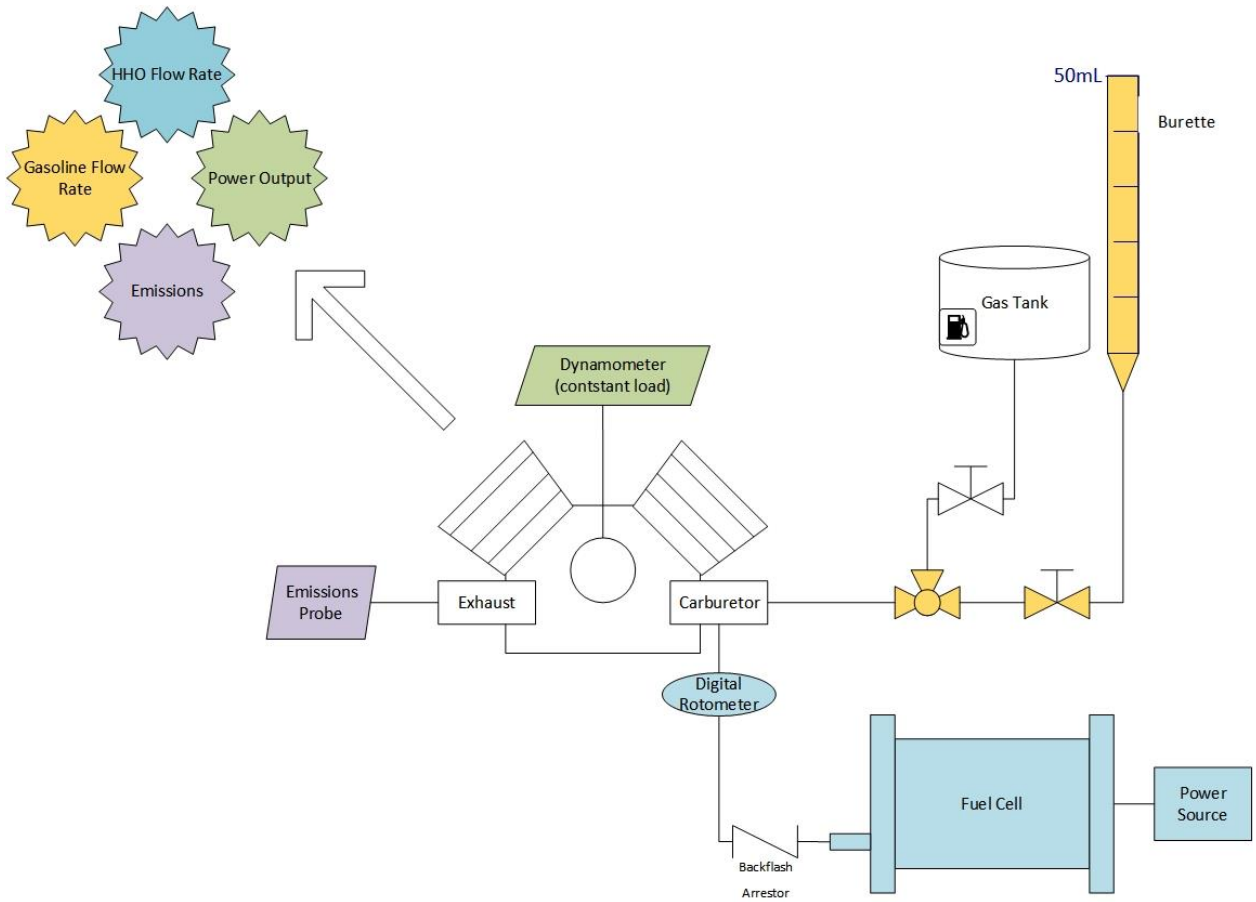


Figure 2: Tabulated HHO Flowrate Predictions

Once all the required modifications are made, a baseline test of pure gasoline will be conducted according to the gasoline baseline procedure outlined in detail in Appendix D. This test will give performance characteristics of the engine, such as specific fuel consumption, fuel specific power output, emission pollutant concentration, and thermal efficiency, each as a function of RPM. This data will serve as reference points for comparing the effect of oxyhydrogen on engine performance. At this point, problems with the engine modifications, testing procedure, or testing set-up may have presented themselves, in which case troubleshooting and modification will be necessary.

After a baseline test with gasoline only, the testing with oxyhydrogen will be done according to the detailed procedure in the appendix. These tests will show the effect of oxyhydrogen inclusion, measured as the percentage of fuel by mass, on performance characteristics at several fixed RPMs. Compiling these datum runs will yield surface plots with RPM and oxyhydrogen percentage as independent variables, and performance characteristics as the dependent variable.

From the data collected, an optimal operating curve will be determined based on the absolute maxima of performance characteristics. These operating conditions will be the basis of the control system that will then be implemented on the fuel cell, regulating output in response to the RPM of the engine. This control system will be designed, programmed, and implemented into the fuel cell before being tested and revised. Testing the control system's performance will involve running the engine and accessing response time to RPM changes, the stability of fuel cell output, and its ability to achieve the specified optimal conditions.

Preliminary Results

Table 1: Tabulated HHO Flowrate Predictions

HHO % (by mass)	*Gasoline % (by mass)*	*Gasoline Mass Flowrate (kg/s)*	*HHO Volumetric Flowrate (L/min)*
0	100	0.0004977	0
10	90	0.0004808	4.10
20	80	0.0004612	8.85
30	70	0.0004382	14.42
40	60	0.0004109	21.03
50	50	0.0003779	29.01
60	40	0.0003373	38.84
70	30	0.0002861	51.24
80	20	0.0002194	67.37
90	10	0.0001291	89.22
100	0	0.0000000	120.49

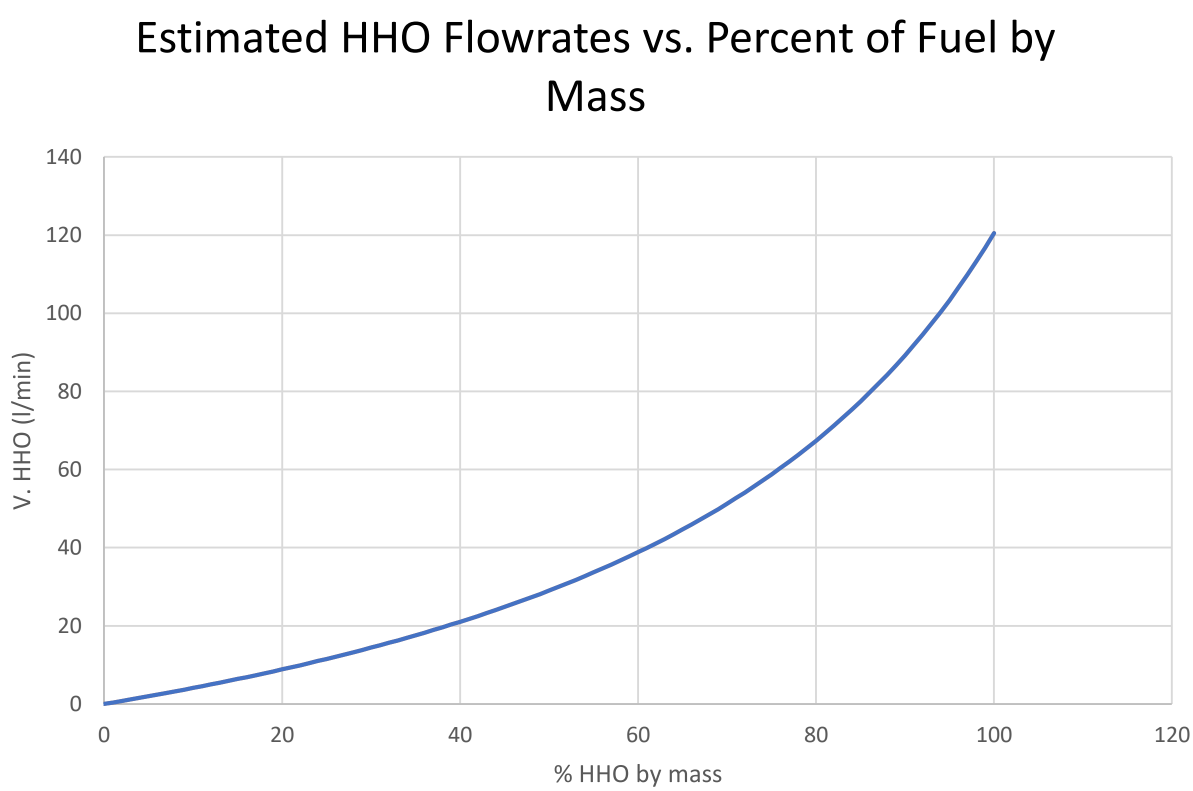


Figure 3: Tabulated HHO Flowrate Predictions

Discussion

The result of this project is the construction of a system including an ICE, a fuel cell, and a control system that automatically produces oxyhydrogen gas for an ideal fuel mixture. The engine and fuel cell have been acquired and modified and in the future, tests will be performed to establish the ideal fuel mixtures. Testing the efficiency of different fuel mixtures across a variety of engine loads results in the documentation of thermal efficiencies. Then, analyzing the results, it will be possible to determine ideal mixture for every condition. Finally, this analysis will be implemented into the control system and the project will be completed.

The results will be slightly skewed by the testing materials. The dynamometer to be used in testing has questionable reliability. Furthermore, none of the team has much training or familiarity with the device, and user error is a concern.

Additional limitations of the project can be attributed to its narrow scope corresponding to the size of the budget. The selection of an ICE intended for use in a lawnmower was based on that the cost of a larger engine and fuel cell would exceed the available capital. Also, maximizing the fuel efficiency of lawnmowers is not a concern to the public and markets. While this limits the usefulness of our project, our results can still be used as a proof of concept for all ICEs.

Future projects and research can use the results of our study and build off of them. With an expanded budget, this project could be repeated with a larger ICE, such as a car or truck engine. The result of such a project would have high relevance because of the increasing marketability of fuel-efficient automobiles.

Works Cited

[1] S. Wang, C. Ji, J. Zhang, and B. Zhang, “Improving the performance of a gasoline engine with the addition of hydrogen-oxygen mixtures,” *Int. J. Hydrogen Energy*, vol. 36, no. 17, pp. 11164–11173, Aug. 2011.

[2] A. A. Al-Rousan, “Reduction of fuel consumption in gasoline engines by introducing HHO gas into intake manifold,” *Int. J. Hydrogen Energy*, vol. 35, no. 23, pp. 12930–12935, Dec. 2010.

[3] A. C. Yilmaz, E. Uludamar, and K. Aydin, “Effect of hydroxy (HHO) gas addition on performance and exhaust emissions in compression ignition engines,” *Int. J. Hydrogen Energy*, vol. 35, no. 20, pp. 11366–11372, Oct. 2010.

[4] S. A. Musmar and A. A. Al-Rousan, “Effect of HHO gas on combustion emissions in gasoline engines,” *Fuel*, vol. 90, no. 10, pp. 3066–3070, Oct. 2011.

Appendix A: Budget

Labor

Table A-1: Labor Breakdown

	Task Name	Duration	Actual Duration	Projected Hours	Actual Hours	Projected Cost	Actual Cost
1	Engine Modification	111	74.25	888	594	$22,200.00	$14,850.00
	Select Engine Parameters	10	10	80	80	$2,000.00	$2,000.00
	Purchase Engine	6	6	48	48	$1,200.00	$1,200.00
1.2	Preignition	33	7.97	264	63.76	$6,600.00	$1,594.00
1.2.1	Optimize cylinder timing	11	0	88	0	$2,200.00	$0.00
1.2.2	Optimize cylinder cooling	11	0	88	0	$2,200.00	$0.00
1.2.3	Modify spark plugs	7	7	56	56	$1,400.00	$1,400.00
1.3	HHO Safety	16	16	128	128	$3,200.00	$3,200.00
1.3.1	Design HHO safety system	0	0	0	0	$36,800.00	$24,810.00
1.3.2	Install temperature sensors	1	1	8	8		
1.3.2	Install HHO safety system	9	9	72	72	$1,800.00	$1,800.00
1.4	HHO Fuel Injection	15	9.17	120	73.36	$3,000.00	$1,834.00
1.4.1	Design HHO fuel injection system	4	4	32	32	$800.00	$800.00
1.4.2	Install HHO fuel injection	8	7	64	56	$1,600.00	$1,400.00
1.4.3	Test wit fuel cell output	6	0	48	0	$1,200.00	$0.00

1.5	Monitoring	98	71.87	784	574.96	$19,600.00	$14,374.00
1.5.1	Design engine mount	22	22	176	176	$4,400.00	$4,400.00
1..5.2	Install engine mount	7	7	56	56	$1,400.00	$1,400.00
1.5.3	Install a tachometer	6	6	48	48	$1,200.00	$1,200.00
1.5.4	Install or modify throttle governor	9	5	72	40	$1,800.00	$1,000.00
1.5.5	Get testing device	14	14	112	112	$2,800.00	$2,800.00
1.5.6	Implement feedback control	16	0	128	0	$3,200.00	$0.00
2	Thermodynamic Analysis	94	49.31	752	394.48	$18,800.00	$9,862.00
2.1	Modeling	94	87.52	752	700.16	$18,800.00	$17,504.00
2.1.1	Data Processing	2	0	16	0	$400.00	$0.00
2.1.2	Predict HHO parameters	27	27	216	216	$5,400.00	$5,400.00
2.2	Testing	61	9.53	488	76.24	$12,200.00	$1,906.00
Total		205	123.56	1640	988.5	$41,000.00	$24,712.00

Materials

Table A-2: Materials Breakdown

Part	*Price*	*Unit*	*QTY*	*Cost ($)*
Briggs & Stratton 950 series Horizontal OHV Engine	$209.99	ea.	1	$209.99
Gasoline Jerry Can	$33.59	ea.	1	$10.00
10W-30 Oil	$5.29	ea.	1	
Tachometer	$21.99	ea.	1	$21.99
Tubing 100ft	$14.69	per foot	1	
Flashback arrestor	$17.95	ea.	1	$17.95
Flashback arrestor	$24.95	ea.	1	$24.95
1/4 in T Valve	$9.65	ea.	2	$19.30
Gasoline	$2.25	per gallon	10	$22.50
Fuel Line (6ft)	$9.95	ea.	1	$9.95
Hose clamp (10 piece)	$5.65	ea.	1	$5.65
Fuel shut off valve (3 piece)	$4.99	ea.	1	$4.99
Arduino	$38.50	total	-	$38.50
Temp Sensor	$9.95	total	-	$9.95
Control Wire	$19.95	total	-	$19.95
Hydraulic Pressure Sensor	$13.38	total	-	$13.38
Solid State Relay	$76.47	total	-	$76.47
KOH	$6.95	total	-	$6.95
Hydroxy Flowmeter	$34.75	total	-	$34.75
3/16" Key Stock	$3.00	ea.	1	$3.00
Total		Total		$550.22

Equipment and Software License Fees

Machinery and software used in this project are provided by the ODU Motorsports Lab, therefore the accompanying fees are not included in this budget.

Facilities

Testing will be performed outside of the ODU Motorsports Lab. As stated above, the use of the university property was not counted in the analysis of the budget. Currently, the dynamometer in the ODU Motorsports Lab is malfunctioning.

Subcontractors/Consultants

This budget subsection is not applicable to this project. Consultants are only ODU faculty members at this point of the project.

Travel

Travel is not an applicable expense for this project. All phases of the study are to be performed at ODU.

Contingency

There is a $1000 contingency built into the budget to cover possible future expenses. Most of the contingency budget is for the purchase of an additional fuel cell if more oxyhydrogen needs to be produced. Future expenses can also include extra gasoline, additional parts for engine modification, or replacement parts for any parts broken during testing.

Funding

A $2500 grant for material costs was provided by the Army Night Vision and Electronic Sensors Directorate.

Analysis

a) Total Budgeted Cost - The total budgeted cost for this project is $43,500. This includes labor and material costs.

b) Cumulative budgeted cost (CBC) – Plotted on Figure A-1.

c) Cumulative actual cost (CAC) – Plotted on Figure A-1.

d) Cumulative earned value (CEV) – Plotted on Figure A-1.

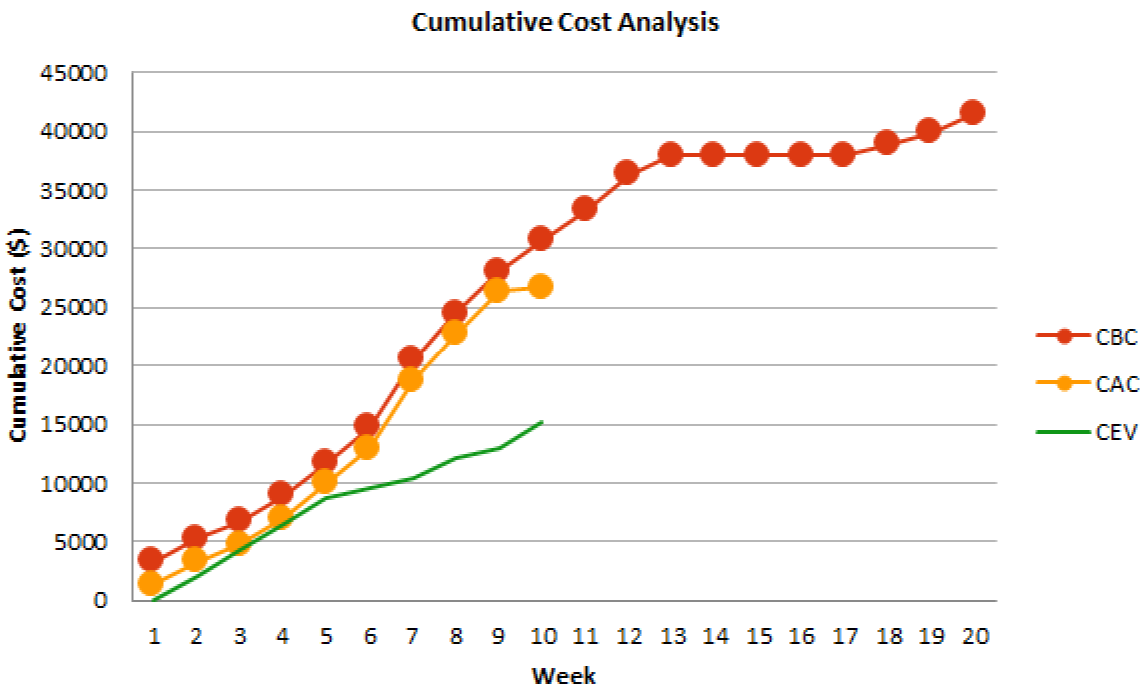


Figure A-1: Cumulative Cost Analysis Weekly Breakdown

e) Cash Variance (CV)

$$CV = CBC - CAC$$

For Week 10, CV = $3929.78. This value includes labor and material costs. By subtracting the material cost cash variance ($1929.78), the labor cost variance is $2000.

f) Cost Performance Index (CPI)

The calculation for the cost performance index calculation and the values up until week 10 are given by equation:

$$CPI = \frac{Earned\ Value}{Actual\ Cost} = \frac{15225}{26750.22} = 0.569$$

g) Forecasted Cost at Completion (FCAC)

Value given by equation:

$$FCAC = Actual\ Cost + \frac{(Budget\ cost\ at\ completion) - (Budget\ cost\ of\ work\ performed)}{CPI}$$

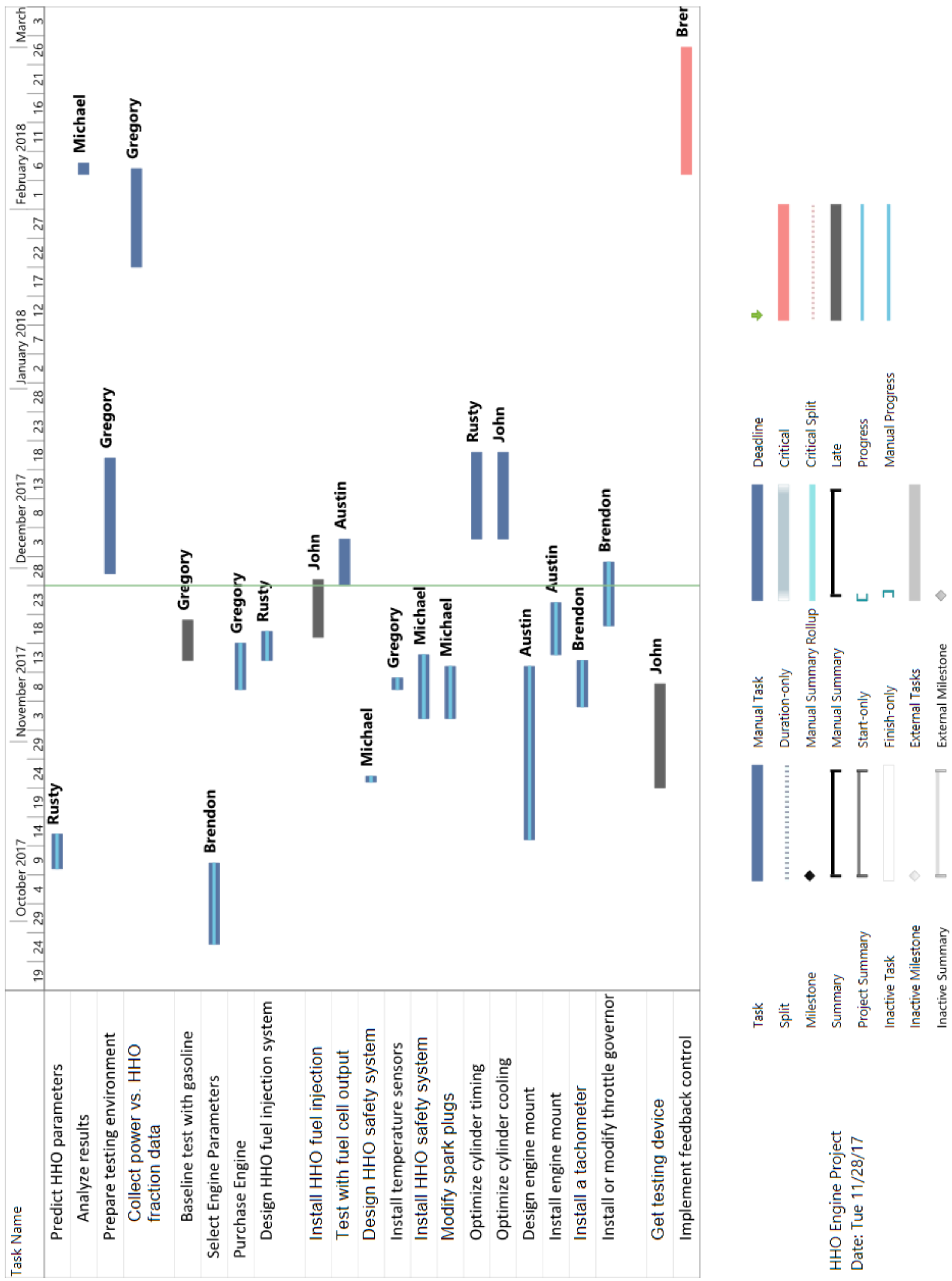
$$= 26{,}750.22 + \frac{43{,}500 - 15{,}225}{0.569} = \$55{,}025.22$$

Questions

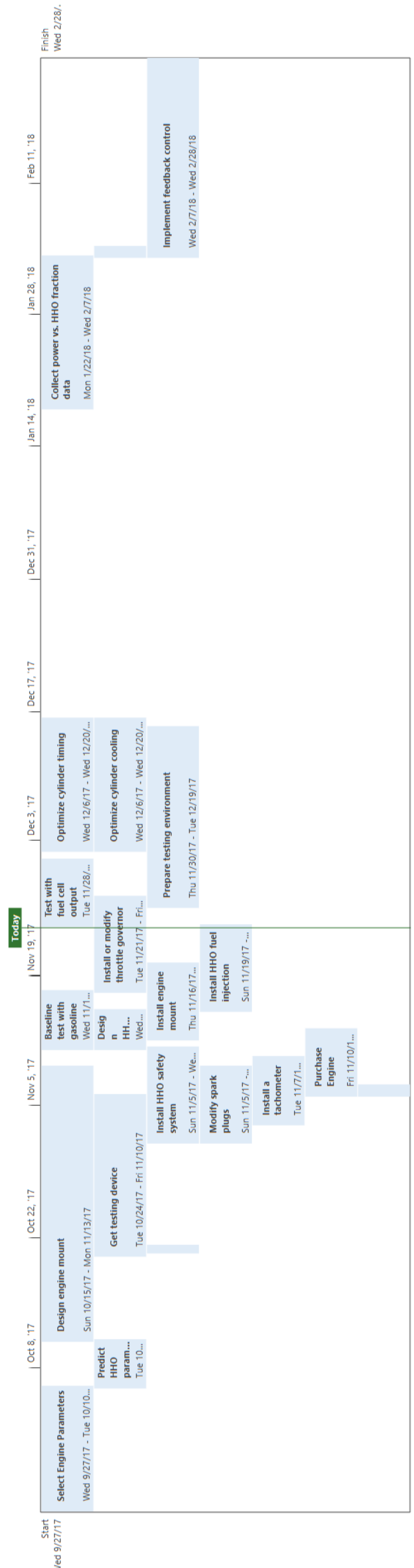
Based on the analysis of the budget, the project was on track for the first 5 weeks. Most of the time spent on the project so far has been developing a plan to execute the objectives in our project. The dynamometer in the ODU Motorsports Laboratory is malfunctioning. This has put the project behind schedule because engine baseline testing cannot be performed. Baseline testing occurs on the project's critical path, repairing the dynamometer or locating another one to use for analysis is crucial to completing the project on time and under budget. To get back on track with the project schedule, the issue with the dynamometer needs to be dealt with immediately. Troubleshooting of the device has started, and an alternate dynamometer was located at Tidewater Community College (TCC). To stay on budget for MAE 435, the necessary engine modifications, assembling testing apparatus, and preparing the testing environment must be completed as soon as possible so testing can be performed immediately when the dynamometer is repaired. Additional labor hours on critical tasks such as preparing the testing environment, and modifying the engine needed to meet the proposed timeline. Currently, the project's labor cost variance is almost $2000. Therefore, approximately 80 extra labor hours can be to meet project deadlines without exceeding budgeted labor expenses.

Appendix B: Project Structure

Gantt Chart

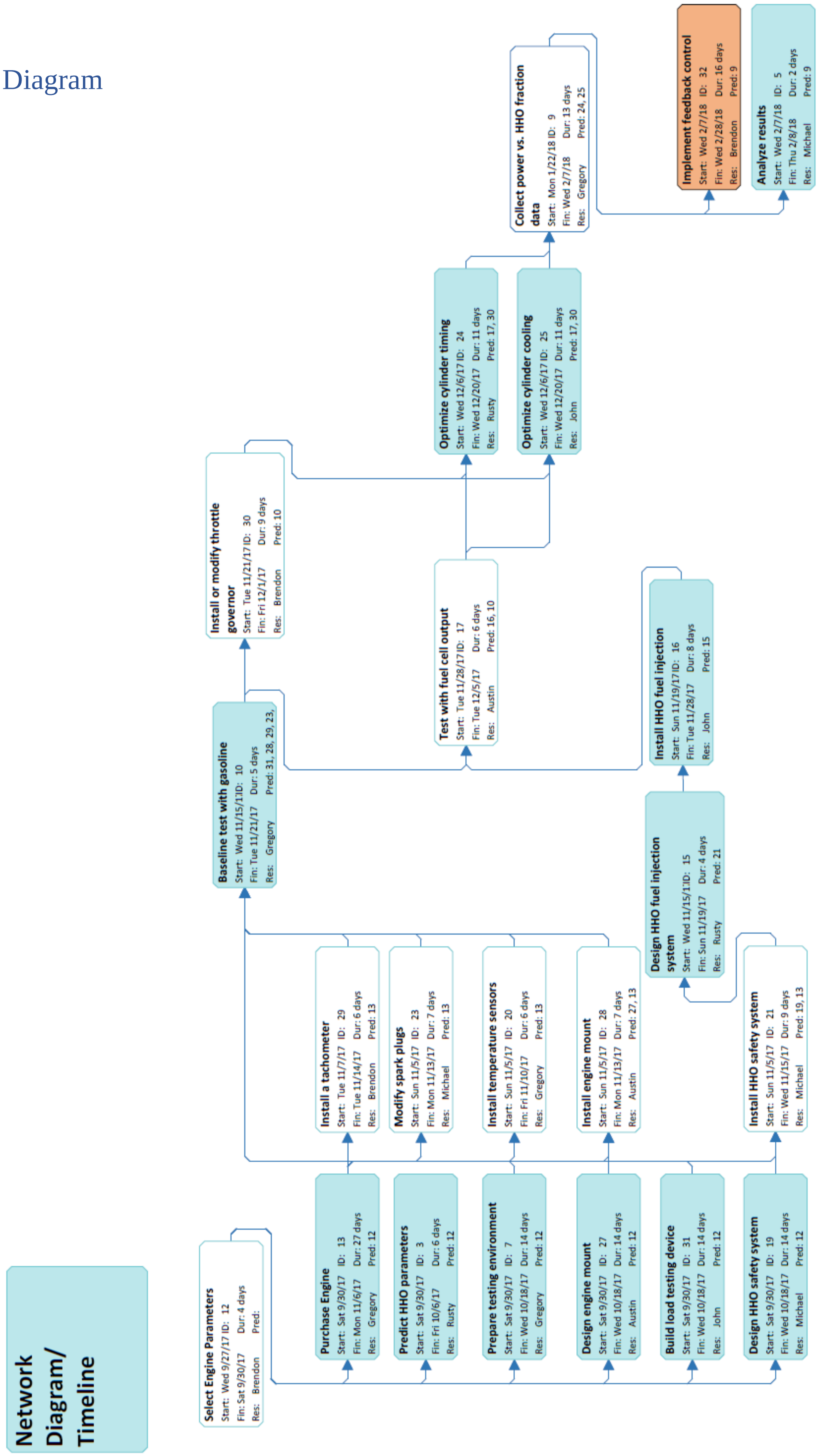


Timeline

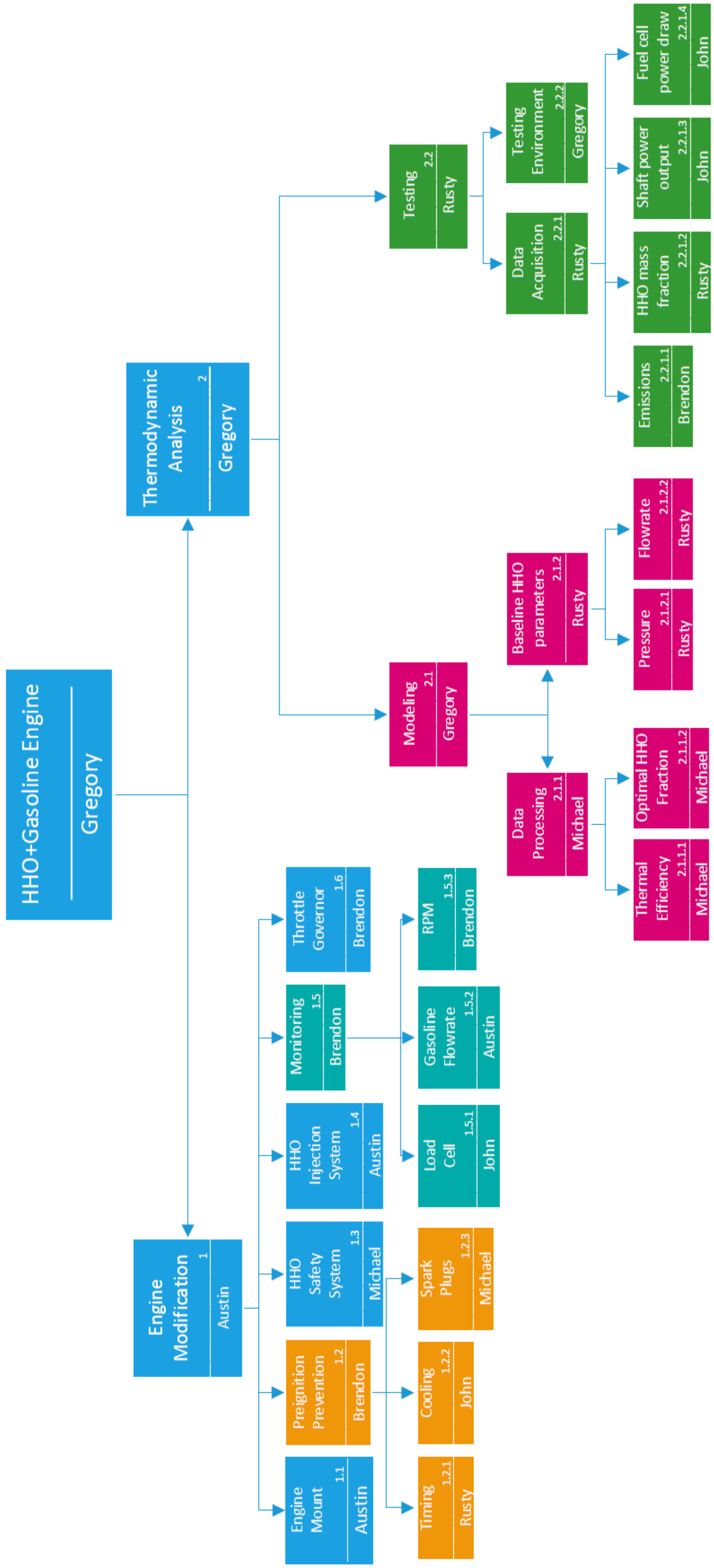


Start
Wed 9/27/17
Finish
Wed 2/28/.
Oct 8, '17
Oct 22, '17
Nov 5, '17
Nov 19, '17
Dec 3, '17
Dec 17, '17
Dec 31, '17
Jan 14, '18
Jan 28, '18
Feb 11, '18
Today
Select Engine Parameters
Wed 9/27/17 - Tue 10/10...
Predict HHO param...
Tue 10...
Design engine mount
Sun 10/15/17 - Mon 11/13/17
Get testing device
Tue 10/24/17 - Fri 11/10/17
Install HHO safety system
Sun 11/5/17 - We...
Modify spark plugs
Sun 11/5/17 -...
Install a tachometer
Tue 11/7/1...
Purchase Engine
Fri 11/10/1...
Baseline test with gasoline
Wed 11/1...
Desig n HH...
Wed...
Install engine mount
Thu 11/16/17...
Install HHO fuel injection
Sun 11/19/17 -...
Install or modify throttle governor
Tue 11/21/17 - Fri...
Test with fuel cell output
Tue 11/28/...
Prepare testing environment
Thu 11/30/17 - Tue 12/19/17
Optimize cylinder timing
Wed 12/6/17 - Wed 12/20/...
Optimize cylinder cooling
Wed 12/6/17 - Wed 12/20/...
Collect power vs. HHO fraction data
Mon 1/22/18 - Wed 2/7/18
Implement feedback control
Wed 2/7/18 - Wed 2/28/18

Network Diagram



Work Breakdown Structure



Responsibility Assignment Matrix

WBS Item	Work Item	Brendon	Gregory	Rusty	Michael	John	Austin
	HHO+Gasoline Engine	S	P	S	S	S	S
1	Engine Modification	S			S		P
1.1	Engine Mount	S	S		S		P
1.2	Preignition Prevention	P		S	S		
1.2.1	Cylinder Timing	P			S		
1.2.2	Cylinder Cooling	S			P		
1.2.3	Spark Plugs	S			P		
1.3	HHO Safety System			S	P	S	
1.4	HHO Injection System					S	P
1.5	Monitoring	P				S	
1.5.1	Load Cell	S				P	
1.5.2	Gasoline Flowrate		S				P
1.5.3	RPM	P					S
1.6	Throttle Governor	P					S
2	Thermodynamic Analysis	S	P				
2.1	Modeling		P				S
2.1.1	Data Processing			S	P		
2.1.1.1	Thermal Efficiency				P		S
2.1.1.2	Optimal HHO Fraction		S		P		
2.1.2	Baseline HHO Parameters			P		S	
2.1.2.1	Pressure			P		S	
2.1.2.2	Flowrate			P		S	
2.2	Testing	S	S	P	S	S	S
2.2.1	Data Acquisition		S	P			
2.2.1.1	Emissions	P	S				
2.2.1.2	HHO Mass Fraction			P	S		
2.2.1.3	Shaft Power Output	S				P	
2.2.1.4	Fuel Cell Power Draw		S			P	
2.2.2	Testing Environment		P				S

Appendix C: Calculations

Sample HHO Flowrate Calculation

Table C-1: HHO Predictions Stated Assumptions

Assumptions and Parameters Used:	
Max Engine Power Output	5.7 hp
	4.25 kW
Gasoline (87 octane) Lower Heating Value	42.7 MJ/kg
H_2 Lower Heating Value	121 MJ/kg
Engine Thermal Efficiency (Estimate)	0.2
Fuel Cell Output Pressure	161.325 kPa
Fuel Cell Output Temperature	298.15 K

$$Mass\ fraction\ of\ H_2\ in\ HHO: x_{H2} = \frac{2 * M_H}{2 * M_H + M_O} = 0.1119$$

$$Mass\ HHO = \frac{Mass\ H_2}{x_{H2}}$$

$$\frac{1\ kg\ H_2}{0.1119} = 8.936\ kg\ HHO$$

$$1\ kg\ H_2 \Rightarrow 121\ MJ$$

$$8.936\ kg\ HHO\ \Rightarrow 121\ MJ$$

$$HHO\ Lower\ Heating\ Value = \frac{121\ MJ}{8.936\ kg} = 13.541\frac{MJ}{kg}$$

$$\dot{W}_{in} = \frac{\dot{W}_{out}}{\eta} = \frac{4.25}{.2} = 21.25\ kW$$

$$\dot{W}_{in} = \left(LHV_{gasoline} * \dot{m}_{gasoline}\right) + \left(LHV_{HHO} * \dot{m}_{HHO}\right)$$

$$X = \frac{\dot{m}_{HHO}}{\dot{m}_{HHO} + \dot{m}_{gasoline}}$$

$$\dot{m}_{HHO} = \dot{m}_{gasoline} * \frac{X}{1 - X}$$

$$\dot{W}_{in} = \left(LHV_{gasoline} * \dot{m}_{gasoline}\right) + \left(LHV_{HHO} * \dot{m}_{gasoline} * \frac{X}{1 - X}\right)$$

$$\dot{W}_{in} = \dot{m}_{gasoline}\left(LHV_{gasoline} + LHV_{HHO} * \frac{X}{1 - X}\right)$$

$$\dot{m}_{gasoline} = \frac{\dot{W}_{in}}{LHV_{gasoline} + LHV_{HHO} * \frac{X}{1-X}}$$

$Ideal\ gas\ behavior\ is\ assumed\ at\ 25C$:

$$\dot{V}_{H_2}\left(\frac{L}{m}\right) = \frac{\dot{n}_{H_2} * T * R}{P} * 60$$

$$\dot{n}_{H_2} = \frac{\dot{m}_{HHO} * x_{H2} * 1000}{M_H * 2}$$

$$\dot{V}_{O_2}\left(\frac{L}{m}\right) = \frac{\dot{n}_{O_2} * T * R}{P} * 60$$

$$\dot{n}_{O_2} = \frac{\dot{m}_{HHO} * x_{O2} * 1000}{M_O * 2}$$

$$\dot{V}_{HHO} = \dot{V}_{O_2} + \dot{V}_{H_2}$$

$Where$:

x_{H2} $is\ the\ mass\ fraction\ of\ H_2\ in\ HHO$

$M\ is\ the\ molar\ mass$

$\dot{W}_{in}$ $is\ the\ chemical\ power\ input$

$\dot{W}_{out}$ $is\ the\ maximum\ power\ output$

$\eta\ is\ the\ thermal\ efficiency\ of\ the\ cycle$

$X\ is\ the\ mass\ fraction\ of\ HHO\ in\ the\ fuel$

$\dot{m}\ is\ the\ mass\ flowrate$

$\dot{V}\ is\ the\ volumetric\ flowrate$

$\dot{n}\ is\ the\ molar\ flowrate$

$T\ is\ the\ temperature$

$R\ is\ the\ ideal\ gas\ constant$

$P\ is\ the\ pressure$

Appendix D: Detailed Testing Procedures

Gasoline Baseline Procedure

1. Turn on and allow the dynamometer to warm up.
2. Mount the engine to the dynamometer and position the test cart.
3. Tare the appropriate readouts while the engine is not running.
4. Hook up the emissions probe to the exhaust of the engine. Record reference outputs while the engine is not running
5. With the fuel line set to draw from the tank, start the engine and allow it to warm up at idle speeds.
6. Choose an appropriate load on the dynamometer. Keep this load constant throughout testing.
7. With the throttle in a fixed position and RPM constant, measure the power output of the engine.
8. Record emission concentrations
9. Measure the gasoline flowrate at this RPM by switching the fuel flow to the 50mL burette. Once the gasoline level in the burette falls at a constant rate, measure the amount of time it takes for the level to drop by 10mL.
10. Switch the fuel line to draw from the tank.
11. Change the throttle position and allow the RPM to stabilize.
12. Repeat steps 7-11 for several different RPMs to get a representative depiction of the performance of the engine as a function of RPM.

HHO Testing Procedure:

1. Turn on and allow the dynamometer to warm up.
2. Mount the engine to the dynamometer and position the test cart.
3. Tare the appropriate readouts while the engine is not running.
4. Hook up the emissions probe to the exhaust of the engine. Record reference outputs while the engine is not running
5. With the fuel line set to draw from the tank, start the engine and allow it to warm up at idle speeds.
6. Choose an appropriate load on the dynamometer. Keep this load constant throughout testing.
7. Open the oxyhydrogen shut-off valve and turn on the fuel cell to its minimum output flowrate.
8. Record the volumetric flowrate of oxyhydrogen.
9. With the throttle in a fixed position and RPM constant, measure the power output of the engine.
10. Record emission concentrations
11. Measure the gasoline flowrate at this RPM by switching the fuel flow to the 50mL burette. Once the gasoline level in the burette falls at a constant rate, measure the amount of time it takes for the level to drop by 10mL.
12. Switch the fuel line to draw from the tank.
13. Increase the output of the fuel cell.
14. Allow the RPM to stabilize back to the original value.

15. Repeat steps 8-14 for several different levels of fuel cell output to get a representative depiction of the performance of the engine as a function of oxyhydrogen flowrate at a fixed RPM.
16. Repeat for a new RPM by adjusting the governor spring to get a representative depiction of the performance of the engine as a function of oxyhydrogen flowrate at several fixed RPMs.