

# **COMPRESSION RATIO AND CATALYST AGING EFFECTS ON AQUEOUS ETHANOL IGNITION (YEAR 2)**

**Final Report**

**KLK756A**

**Part 1. Compression Ratio Effects on Aqueous Ethanol Ignition**

**N09-11**



**National Institute for Advanced Transportation Technology**

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**September 2009**

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Compression Ratio and Catalyst Aging Effects on Aqueous Ethanol Ignition (Year 2): Part 1. Compression Ratio Effects on Aqueous Ethanol Ignition		5. Report Date September 2009	
		6. Performing Organization Code KLK756A	
7. Author(s) Anderson, Edwin; Cyr, Jason; Cordon, Daniel; Steciak, Dr. Judi; Beyerlein, Dr. Steve; Budwig, Dr. Ralph		8. Performing Organization Report No. N09-11	
9. Performing Organization Name and Address  National Institute for Advanced Transportation Technology University of Idaho PO Box 440901; 115 Engineering Physics Building Moscow, ID 838440901		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. <i>DTRT07-G-0056</i>	
12. Sponsoring Agency Name and Address  US Department of Transportation Research and Special Programs Administration 400 7 <sup>th</sup> Street SW Washington, DC 20509-0001		13. Type of Report and Period Covered  Final Report: August 2008 – September 2009	
		14. Sponsoring Agency Code <i>USDOT/RSPA/DIR-1</i>	
15. Supplementary Notes:			
16. Abstract  The lean burning of water ethanol blends has the potential to reduce NO <sub>x</sub> , CO, and HC emissions while reducing the ethanol fermentation production cost of distillation and dehydration. The torch style ignition produced by the catalytic igniter allows for the operation and cold start of a typical SI engine on ethanol/water fuels up to a 50/50 blend. This work reported here targets multiple operating conditions of a CFR engine and monitors in-cylinder pressure and emission characteristics. Premixing ethanol/water blends showed a reduction in NO <sub>x</sub> over separately injecting water and ethanol for blends up to 70/30 ethanol/water. Altering catalytic igniter voltage showed no control over CA50. This investigation will help researchers better understand the performance and emission characteristics of timing control in addition to different injection techniques for ethanol/water blends for catalytic ignition implementations focused on improving thermal efficiency and emission reduction.			
17. Key Words  Pollutant control, fuel systems, engine testing, renewable fuels		18. Distribution Statement  Unrestricted; Document is available to the public through the National Technical Information Service; Springfield, VT.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 14	22. Price ...

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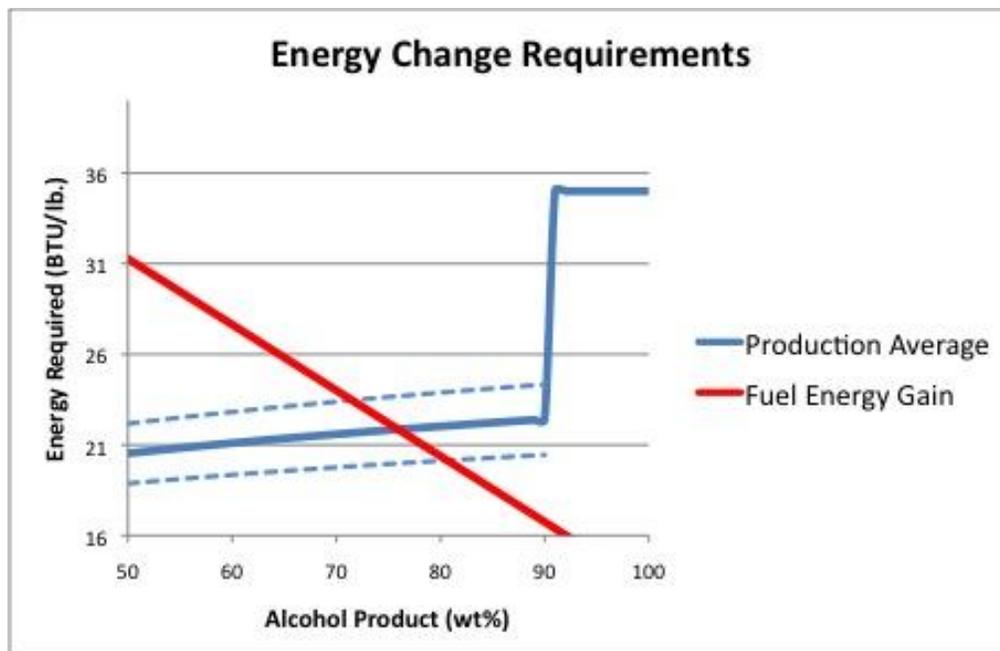
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**BACKGROUND**

**1.1 Ethanol Production**

It has been reported that the distillation consumes 50-80 percent of the energy required in a typical fermentation ethanol process. [Ladisch, 1979] Furthermore, distillation cannot remove the last ~6% of water from ethanol. Complete dehydration is achieved with molecular sieves. This process is aimed to remove the water that can be burned in a correctly modified internal combustion engine. If aqueous ethanol can be utilized, a reduction in production costs can be exposed.

Previous research from this author shows an optimal operating blend of water/ethanol fuel, 76% by volume ethanol, from a net energy production standpoint. [Anderson, 2009] Production energy to increase the ethanol concentration in a water/ethanol blend was compared to energy gained through mechanical work of an engine, Figure 1.



**Figure 1: Net energy requirements for ethanol production.**

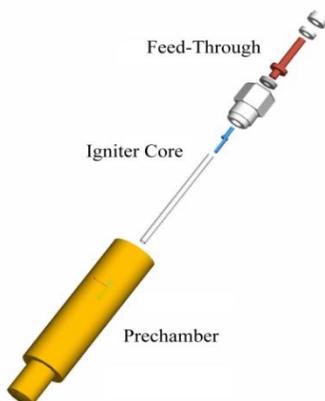
## 1.2 Catalytic Ignition

Initially designed for lean burning engines in 1990 by Automotive Resources, Inc (ARI), the catalytic igniter seen in Figure 2 was implemented to solve the problems surrounding cold start and ignition requirements of aqueous fuels. Its effectiveness has been proven in a research transit van at the University of Idaho. The transit van has the ability to cold start and operates on concentrations up to 50% water. [Olberding, 2005]



**Figure 2: Catalytic igniter.**

The catalytic igniter is a self-contained ignition system that can be retrofitted to the spark plug hole of an SI engine or the direct fuel injection port of a CI engine. The igniter consists of a brass pre-chamber that houses a platinum catalyst. An exploded view of the igniter can be seen in Figure 3.



**Figure 3: Catalytic igniter exploded view.**

Upon the compression stroke of the engine cycle fresh air fuel mixture enters the pre-chamber created by the catalytic igniter. Because of the reduced activation energy associated with

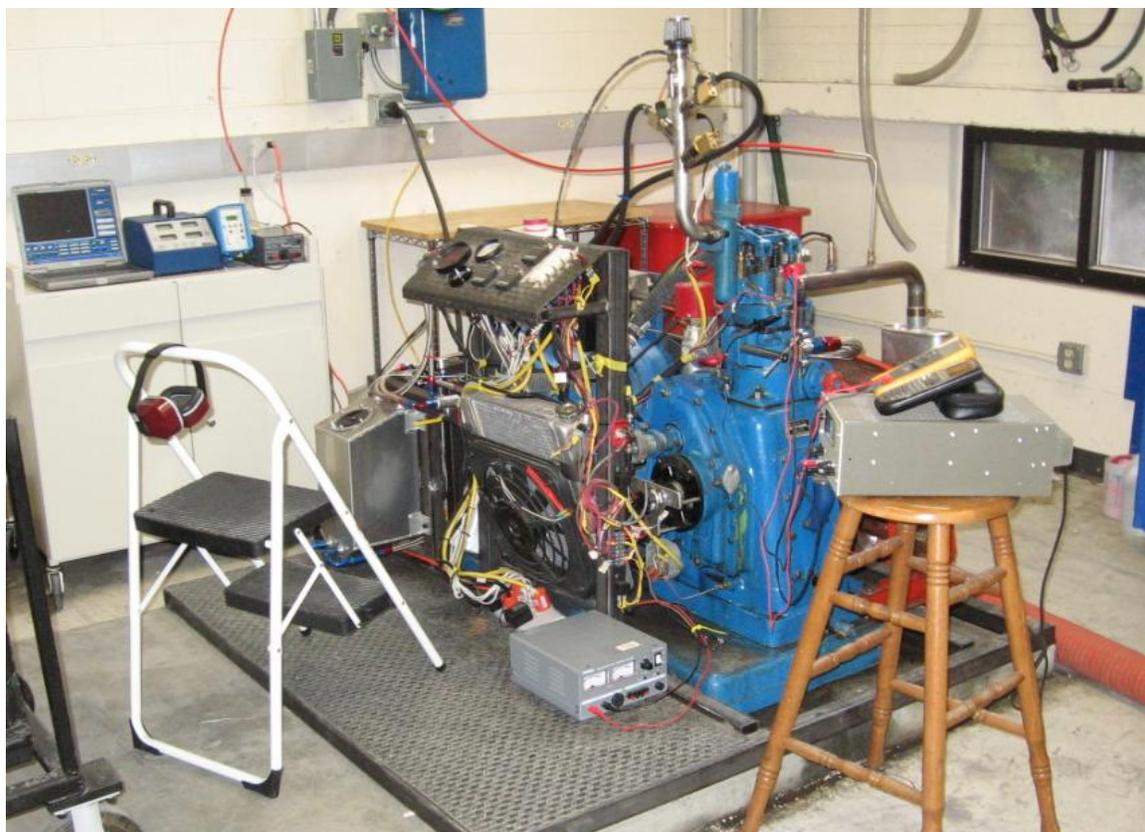
catalytic surface reaction, ignition occurs at temperatures far below the normal gas-phase ignition temperature. [Cho, 1986] A flame then propagates outside the pre-chamber causing torch style ignition of the main chamber. This torch style ignition, seen in Figure 4, has the capabilities of igniting mixtures with high ignition energy requirements.



**Figure 4: Catalytic torch ignition pattern.**

### **1.3 CFR Engine**

A significantly modified CFR, Co-operative Fuels Research engine was used as a platform for aqueous fuel combustion research in this work. Modifications to fueling, cooling, exhaust, and data acquisition systems were completed to support catalytic ignition of aqueous blends. A catalytic igniter was fabricated by ARI for this engine. A picture of the University of Idaho's CFR engine can be seen in Figure 5.



**Figure 5: University of Idaho CFR engine.**

Modifications to the fuel system included a stainless steel multi fuel injection intake, dynamic injector pulse width controller, multi fuel storage tank, and replaceable orifice plugs to control intake air. An Omega controller was added to govern the air intake temperature.

A complete stainless steel exhaust was fabricated; this system was equipped with dual stainless mufflers, an AFR sensor, and an emission-sampling bung. Due to the high level of water content in these fuels a water collector was added to the emissions sample line.

A closed loop cooling system was added with a radiator, fan, and water heater that was regulated by an Omega temperature controller. This 12-amp heater could slowly bring the engine up to temperature prior to ignition.

Extensive data acquisition capabilities were added to this engine. A high speed MeDAQ combustion analyzer coupled with an in-cylinder pressure sensor supplied performance data. An EMS 5 gas analyzer was installed to measure CO, NO<sub>x</sub>, and HC. The control panel of the engine

was equipped with an RPM, AFR, water-oil-air temperature, and oil pressure gauges. Manual override switches were also installed for most electronics.

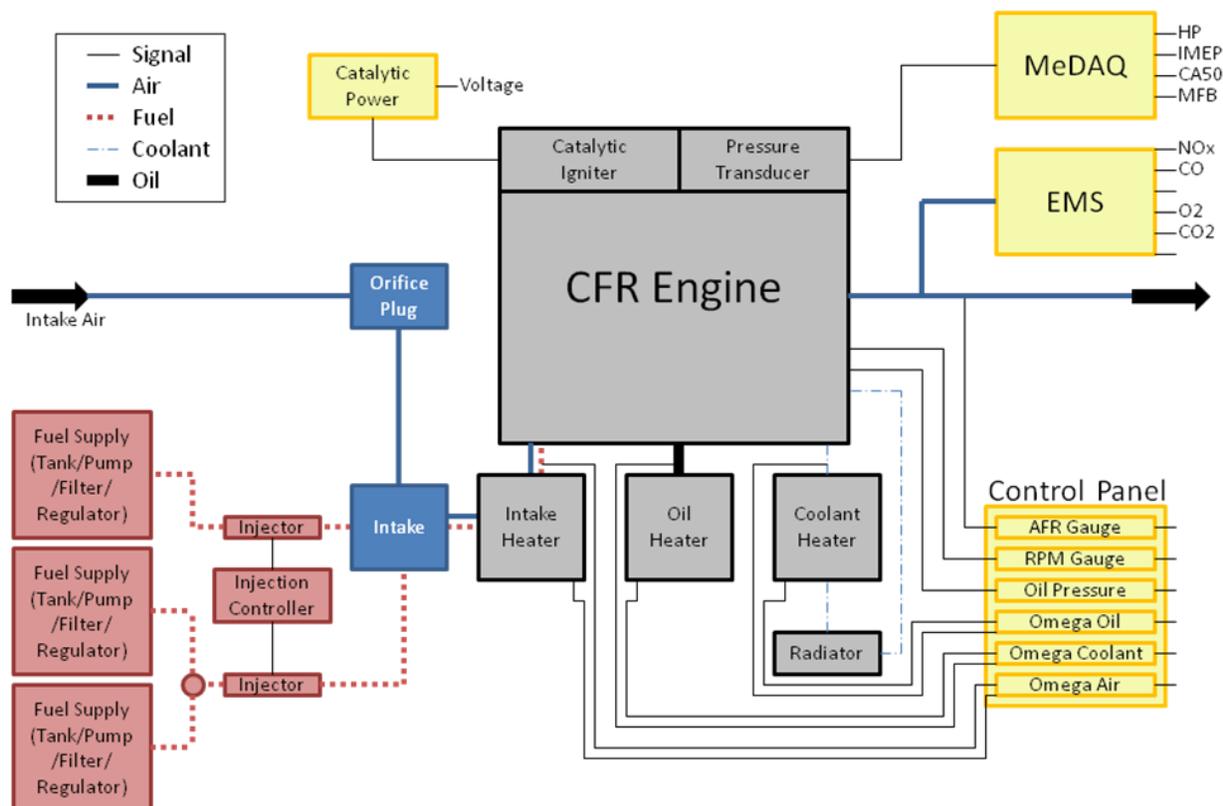


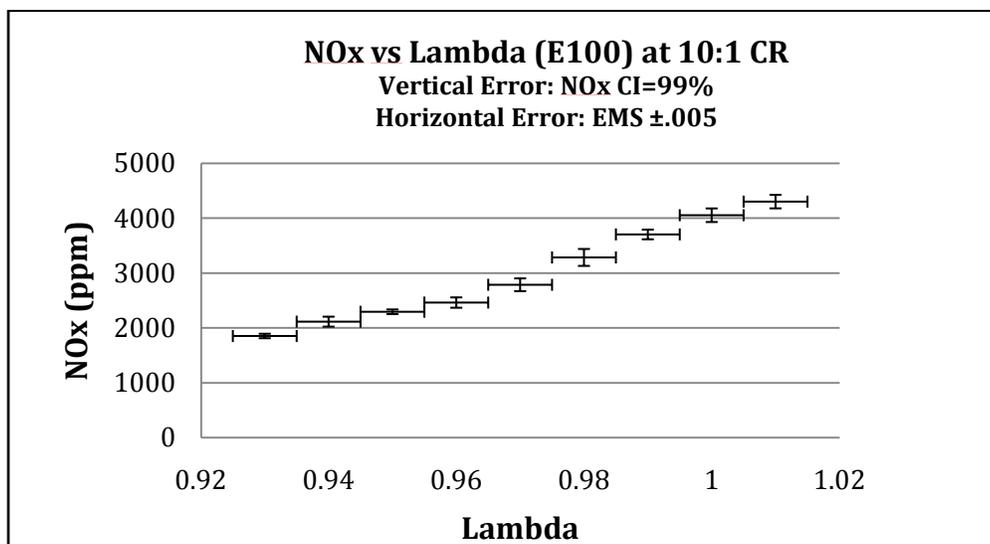
Figure 6: CFR instrumentation diagram.

## RESULTS

### 2.1 Effect of Injection Techniques on Emissions

During the first set of tests, the following variables were held constant: compression 10:1; coolant temperature 55°C; oil temperature 70°C; intake air temperature 25°C; RPM 900; igniter voltage 16VDC. With these parameters held constant, lambda, AFR/AFR<sub>stoic</sub>, was varied between 0.92 and 1.02 and CO, NO<sub>x</sub>, and HC were measured to create a set of control data. This data will later be used as a baseline to compare against the aqueous fuel blends. NO<sub>x</sub> and CO data are shown in Figures 7 and 8.

The second set of experiments was using three types of ethanol/water blended fuels: 80/20, 90/10 then 70/30. These blends were premixed. The target lambda was 0.97, but the lengthy tests showed a small variance. CO, NO<sub>x</sub>, HC, and lambda were recorded over a ten minute period. The average NO<sub>x</sub> and CO were compared to the baseline data with either a percent reduction or percent increase. These same fuel blends and procedure were then run again, but the water and ethanol were separately injected. Precision flow meters were used to monitor the flow rates of the ethanol and water to ensure the same blends of fuel were being used. The differences for these tests can be seen in Figure 9, Figure 10, and Figure 11. Table 1 reports on variability in emissions data.



**Figure 7: NO<sub>x</sub> vs lambda.**

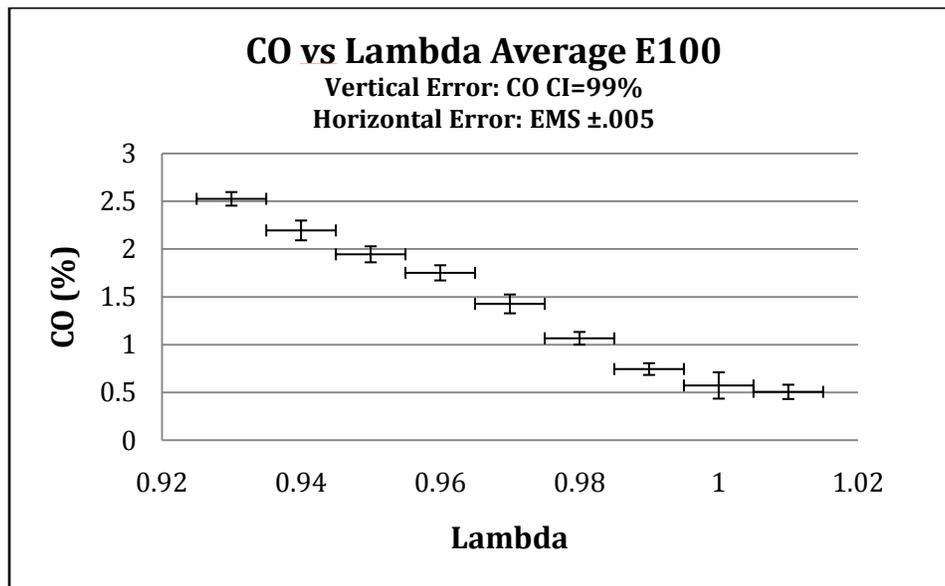


Figure 8: CO vs lambda.

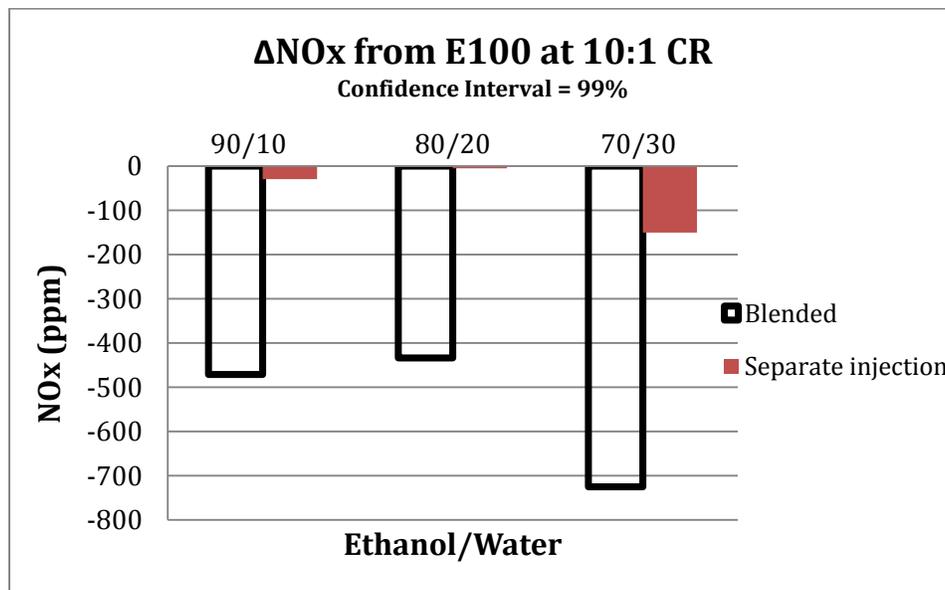


Figure 9: NO<sub>x</sub> vs ethanol/water fuel.

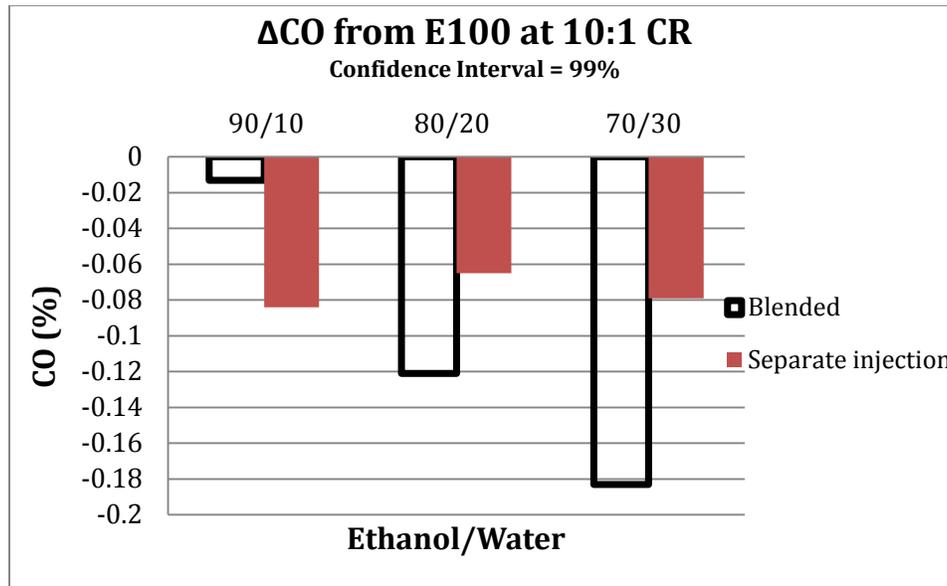


Figure 10: CO vs ethanol/water fuel.

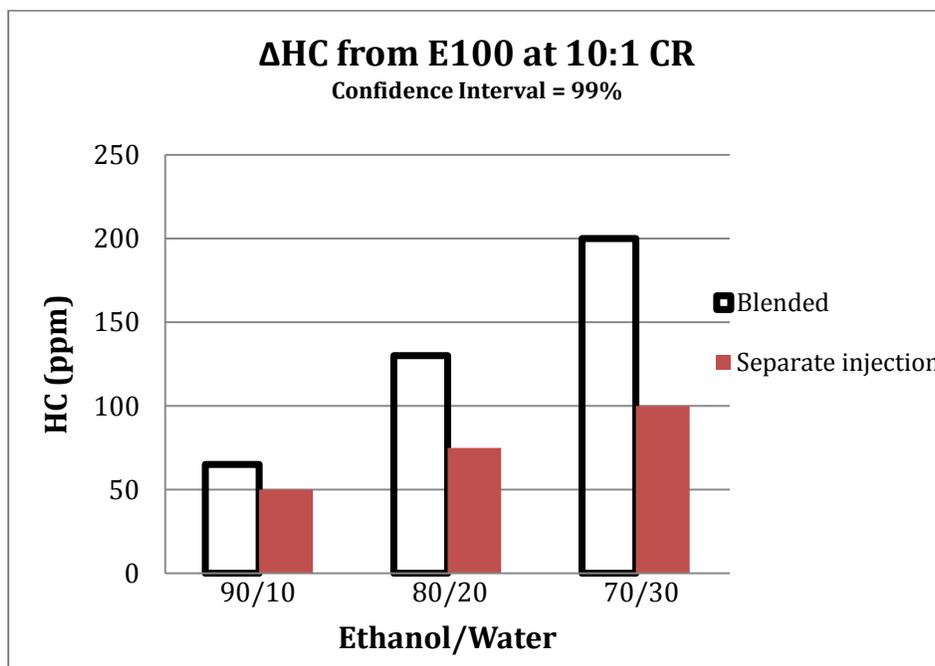


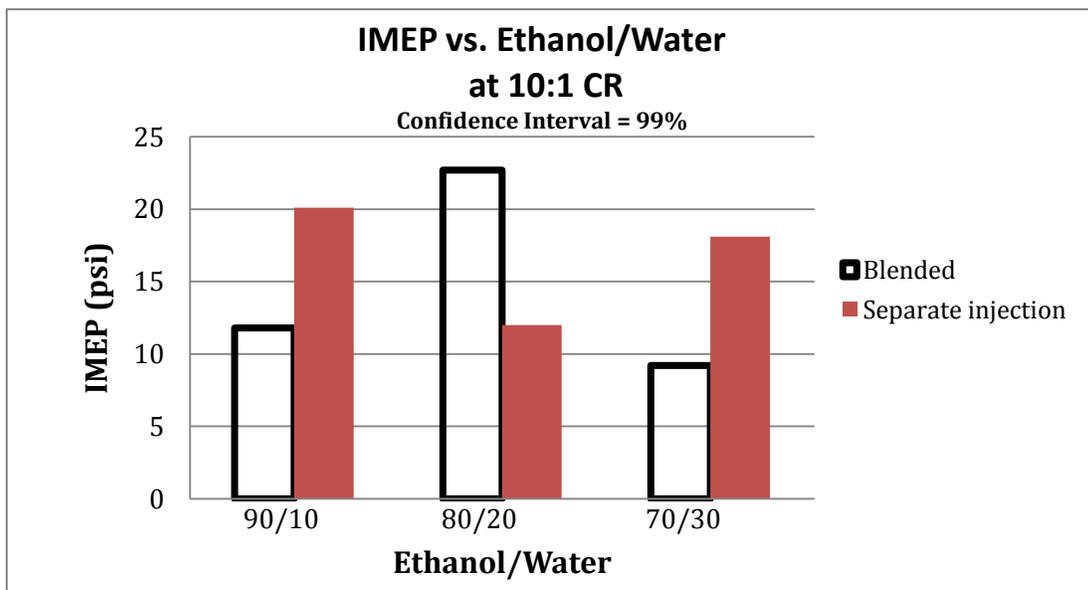
Figure 11: HC vs ethanol/water fuel.

**Table 1: Variability in Emissions Data**

Fuel	Ave-NOx (ppm)	Stdv-NOx (ppm)	Ave-CO (%)	Stdv-CO (%)	HC Delta (ppm)
Control	0	143	-0.001	0.071	0
B-90/10	-471	239	-0.013	0.255	65
B-80/20	-434	198	-0.121	0.152	130
B-70/30	-725	172	-0.183	0.171	200
S-90/10	-29	122	-0.084	0.122	50
S-80/20	0	111	-0.065	0.114	75
S-70/30	-155	141	-0.100	0.174	100

## 2.2 Effect of Injection Techniques on Performance

A high-speed combustion analyzer was used to record indicated mean effective pressure, IMEP, and the crank angle at which 50% of the fuel is burned, CA50. Table 2 reports on variability in performance data.



**Figure 12: IMEP vs ethanol/water fuel.**

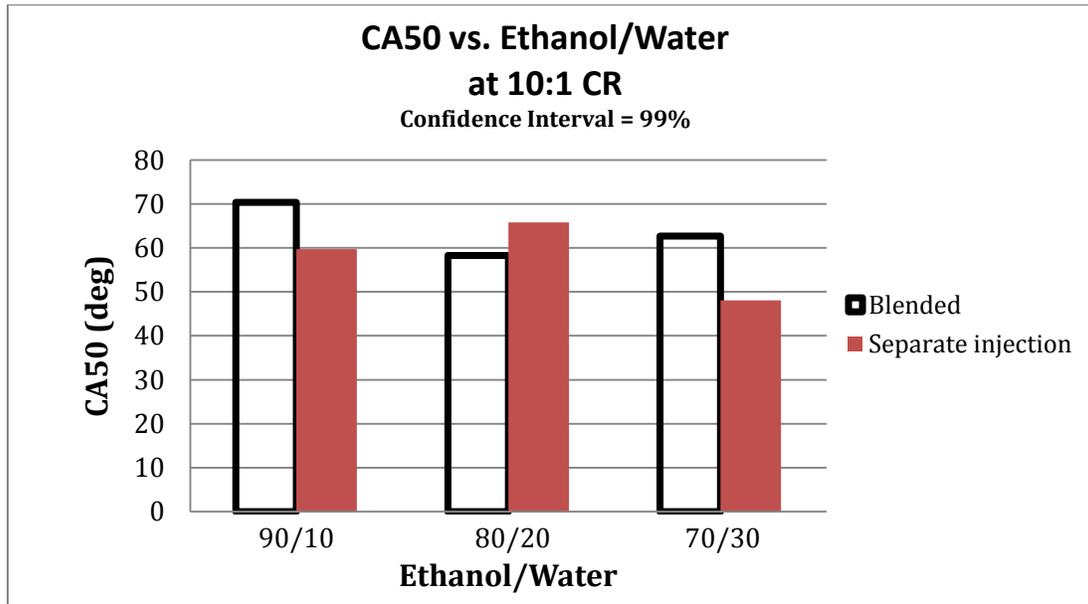


Figure 13: CA50 vs ethanol/water fuel.

Table 2: Variability in Performance Data

Fuel	Ave-IMEP	Stdv-IMEP	Ave-CA50	Stdv-CA50
Control	38.2	8.8	65.1	0.9
B-90/10	11.8	6.8	70.4	6.9
B-80/20	22.7	6.9	58.3	1.2
B-70/30	9.2	6.0	62.7	2.9
S-90/10	20.1	6.8	59.7	6.1
S-80/20	12.0	9.9	65.8	4.0
S-70/30	18.1	6.2	48.1	3.8

### **2.3 Catalytic Igniter Supply Voltage**

In this test the catalytic igniter was supplied various input voltages while CA50, NO<sub>x</sub>, CO, and HC's were recorded. The following variables were held constant, compression 8:1, coolant temperature 120 F, oil temperature 110 F, intake air temperature 75 F, RPM 900, lambda ~1, and fuel 100% ethanol. The results showed no significant affect on CA50, NO<sub>x</sub>, CO, and HC at 8:1 compression.

## **DISCUSSION**

Of the four compression ratios tested, 5:1, 6:1, 7:1, and 10:1, the greatest cycle to cycle repeatability was sustained at 10:1. As such, these were the results presented in this paper. Altering the catalytic igniter voltage was found to have no noticeable effect on CA50 above 8:1. Therefore, it is assumed that this is not an important variable in controlling ignition timing.

Past research has shown significant reduction in NO<sub>x</sub> emissions using aqueous ethanol blends. It was hypothesized that the primary effect of the water was to reduce flame temperatures, thereby obstructing the thermal formation of NO<sub>x</sub>. However, using separate injection of ethanol/water the nearly constant CO reported in Figure 7, coupled with the negligible NO<sub>x</sub> reductions in Figure 6 suggests that the addition of water alone is not responsible for the decrease in NO<sub>x</sub> emissions. Pre-mixed water/ethanol blends with the same water fraction have a much greater effect on NO<sub>x</sub> and CO emissions. More immediate contact between water molecules and ethanol under pre-mixed conditions appears to have a strong influence on combustion chemistry.

The catalytic igniter used in this work was designed for higher compression at speeds more typical of automotive engines. As such, the pre-chamber geometry could be better optimized for earlier main chamber torch ignition, insuring more complete ignition of HC's at the far side of the cylinder. The CFR engine used in this work operates at 900 RPM and has a 3.0" diameter bore. Evidence of some incomplete combustion can be seen in the IMEP and CA 50 data, even at 10:1.

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## CONCLUSIONS

In this research, the University of Idaho obtained a CFR engine and made modifications to support homogeneous charge catalytic ignition. The CFR engine can support catalytic ignition for multiple fuels, including 87 octane gasoline, 100% ethanol, and ethanol/water blends up to 50/50. To study effects of altering ethanol/water blends on NO<sub>x</sub>, CO, and HC's, the CFR engine was instrumented with a 5 gas analyzer as well as an elevated emission sample tube with an in-line water collector. Significant reduction in NO<sub>x</sub> and CO emissions were observed with pre-mixed water/ethanol compared with 100% ethanol as well as separately injected water and ethanol. This may be attributable to more extensive fuel cracking in the pre-chamber prior to gas phase ignition as well as closer proximity of water and fuel molecules during main chamber combustion.

The current catalytic igniter was designed for higher compression and higher engine speed. At the relatively low compression ratios attainable with the CFR engine, late pre-chamber ignition leads to retarded main-chamber ignition, resulting in incomplete burning of the fuel. Even at 10:1 compression, there is evidence of this situation in the IMEP and CA50 data. Design of a next generation igniter for future CFR testing is underway to remedy this deficiency in the current engine hardware.

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