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Coal Water Slurry Combustion in a Simulated Diesel Engine Cylinder

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COAL WATER SLURRY COMBUSTION IN A SIMULATED

DIESEL ENGINE CYLINDER

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This thesis, submitted by Allan Robert Holmes in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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ABSTRACT

Uncertainty about the reliability of the imported oil supply to the United States has led to research into alternative sources for domestic energy needs. Because of the relative abundance of coal reserves in the United States, much of this research has focused on developing methods of using coal for fuel where oil products have traditionally been used. This thesis reports results of a study to determine the suitability of using coal water slurry fuels in diesel engine operation.

The primary focus of this study was to determine if the ignition and combustion characteristics of a coal water slurry are comparable to those of diesel fuel and are suitable for use in a diesel engine. This testing was done using a Parr combustion bomb modified to allow injection of a test fuel and recording of the bomb pressure. Prior to injecting the test fuel, the combustion bomb was brought to the high temperature and high pressure conditions typical of a diesel engine cylinder by combustion of a hydrogen, oxygen, and nitrogen gas mixture.

Two types of coal water slurry fuels were tested and a standard number two diesel fuel was used for baseline testing.

One of the slurry fuels was produced from a low rank lignite coal, while the other was produced from a higher rank bituminous coal. Besides the slurry type, the primary test variables in this study were bomb pressure and temperature at the time of fuel injection. The pressures and temperatures ranged from 400 to 800 psia and 900 to 1300°K, respectively.

The time required for ignition and combustion of the test fuel were measured. It was found that increasing the bomb injection temperature decreased the time required to ignite and burn the test fuel. This effect was more pronounced when using the less volatile bituminous coal slurry. The lignite slurry ignited and burned at about the same rate as did the baseline diesel fuel, while the bituminous coal slurry took slightly longer to ignite and burn. Changing the bomb injection pressure did not have a significant effect.

CHAPTER I. INTRODUCTION

Methods of converting coal into forms in which it can be used as a substitute for oil products include liquefaction, gasification, and the production of coal-water slurries. Coal-water slurry technology has been developed to allow for the utilization of coal in a liquid form. This study is geared toward determining the feasibility of using such slurries in powering diesel engines. In diesel engine operation, the fuel injected into the engine cylinder must autoignite and burn out rapidly. The ignition delay, defined as the elapsed time from fuel injection to ignition, was particularly important.

The primary objective of this study was to identify the combustion characteristics of coal-water slurries in the high temperature and high pressure environment of a diesel engine cylinder. This information was compared with results obtained using diesel fuel as a baseline. These tests will be used as a first step in determining the feasibility of using coal-water slurries diesel engines.

Two types of coal-water slurry were tested and the results were compared with those obtained using No. 2 diesel fuel as a baseline. The slurry of bituminous coal was prepared by Otisca Laboratories, while the Velva (ND) lignite slurry was prepared at the University of North Dakota Energy and Environmental Research Center (UNDEERC). The lignite slurry has a relatively low heating value, high ash content, and low sulfur content. A modified combustion bomb was used to simulate conditions of a diesel engine cylinder. The modifications consisted of inserting a diesel fuel injector and installing a pressure transducer, to record the combustion event. Because fuel injection and ignition take place within a few milliseconds, a computer data acquisition system (including software) was developed to acquire and store data at a rapid rate. Combustion of a $H_2/O_2/N_2$ gas charge was used to obtain the desired high temperature and high pressure test conditions. The pressure and temperature conditions tested in this study ranged from 400 to 800 psia and 900 to 1300°K, respectively.

Information gathered in this study consisted primarily of ignition delays, which were based on bomb and fuel line pressure data taken at a high sampling rate. In addition, calorimeter data were used to determine the extent of fuel burnout for a run. Information about the physical aspects of using coal-water slurries in equipment designed for diesel fuel was also obtained. The results of this study can be used to better understand the limitations of using coal water slurry fuels for these types of applications and compare the use of a bituminous slurry fuel with that of a lignite slurry.

This testing is a first step in determining if a fuel's combustion characteristics make it a suitable candidate for use in a diesel engine and the operating parameter limitations that might be encountered. The next step would be to test suitable slurry fuels in a diesel engine facility where it can be examined on a short term continuous basis.

CHAPTER II. BACKGROUND

The diesel engine is an internal combustion engine that relies on the autoignition of the fuel in a high temperature, high pressure environment, in contrast to the spark fired internal combustion engine (commonly used in automobiles) which uses a spark plug to ignite the fuel. The diesel engine is used worldwide. Industrialized countries utilize the diesel engine as its main workhorse, and it can be found in varying work applications from small generator units, marine crafts, and lawn equipment to large semi-trucks, construction equipment, locomotives, and generator plants(1).

Rudolf Diesel originally designed his internal combustion engine to operate burning powdered coal. He found that engine failure occurred after short periods of operation with coal and ultimately determined that oil products made a better fuel for his engine. Some of the problems Diesel encountered in his attempts to burn coal in his internal combustion engine may also apply to any current attempts to burn coal-water slurry in a diesel engine. These problems include erosion of parts due to the granular nature of the coal particles and the much higher ash content found in coal as compared to standard diesel fuel. The engine parts that see the most erosion are the fuel pump, the fuel injector plunger and barrel, and the piston and cylinder wall. Recent advancements in the development of ceramic materials which resist erosion, corrosion, and heat transfer may make the use of coal fuels in the diesel engine more practical. These ceramic materials applied to diesel engines will reduce wear of the engine components and create a more nearly adiabatic engine. It is also important that the combustion characteristics of any coal-based fuel resemble those of diesel fuel.

Most of the recent efforts to determine the viability of burning a coal-water slurry in a diesel engine have mainly centered on testing coal water slurries made from higher ranked coals. Siebers and Dyer(2) studied the autoignition and combustion of coal-water slurry in a combustion bomb designed to simulate diesel engine conditions. Their combustion bomb was designed to provide chamber pressure and temperature, as well as visual access to the combustion chamber throughout the combustion event. A low-ash bituminous coal was used in a 50 percent solids coal-water slurry. Results of these tests were used to determine ignition delay, ignition site, combustion development, combustion duration, and combustion completeness. It was found that a combustion bomb temperature of over 800°K was needed to get adequate ignition and burnout. They observed ignition delays with the slurry fuel approximately five times as long as with diesel fuel.

Leonard and Fiske(3) injected a single shot of a coal-water slurry into a combustion bomb apparatus that simulated the environment of a diesel engine cylinder. They were able to obtain improved ignition delays between 2.4 and 10.2 milliseconds with higher fuel injection pressures. They found the ignition delay to depend on fuel line pressure, gas density and bomb temperature.

The advantages of higher rank coals, such as bituminous coals, over lower ranked lignite coals are lower ash content, higher heating value, and lower inherent water content, which results in higher coal loadings when made into a slurry form. Advantages of using lignites over higher ranked coals are: (1) they ignite easier, (2) they burn faster because of relatively higher volatile matter, (3) they are generally lower in sulfur content, (4) they are non-agglomerating so slurry particles do not stick together as readily upon atomization, and (5) they are less expensive than bituminous coals.

CHAPTER III. EXPERIMENTAL PROCEDURE

This chapter includes a discussion of the materials and equipment used in this study. The test preparation and test procedure are also discussed.

Materials

Nitrogen, oxygen, and hydrogen contained in pressurized cylinders were used to prepare the gas charge that was used to bring the combustion bomb to diesel engine conditions. Two types of coal water slurry were tested along with standard No. 2 diesel fuel. The ultimate analysis of the No. 2 diesel fuel and the proximate and ultimate analyses of the two slurry fuels are shown in Table 1. One of the coal-water slurry fuels was produced at Otisca Laboratories using a bituminous coal. The other slurry was prepared at the University of North Dakota's Energy and Environmental Research Center (UNDEERC) using the hot water drying process. This slurry was prepared from Velva (ND) lignite coal. The particle size distributions of the two slurries are presented in Table 2. The mass median diameter of the Otisca slurry was 2.73 microns compared to a mass median diameter of 5.88 microns for the Velva Lignite slurry.

Table 1. Test Fuel Analyses.

	No. 2 Diesel Fuel As Rec'd (%)	Velva Slurry Moisture Free (%)	Otisca Slurry Moisture Free (%)
Proximate Analysis			
Volatile Matter		41.94	35.61
Fixed Carbon (ind)		56.12	63.58
Ash		1.94	0.81

	No. 2 Diesel Fuel As Rec'd (%)	Velva Slurry As Rec'd (%)	Otisca Slurry As Rec'd (%)
Ultimate Analysis			
Hydrogen	13.19	8.27	8.17
Carbon	85.04	32.5	41.95
Nitrogen	0.01	0.52	0.73
Sulfur	0.22	0.17	0.44
Oxygen (ind)	1.54	57.65	46.72
Ash	0	0.88	1.96
Total	100	99.99	99.97
Moisture		54.6	47.6
Heating Value (Btu/lb)			
Calc. Calorific Value (As Rec'd)	19894	5639	7550
As rec'd hydrogen not including that from moisture		2.2	2.87
As rec'd oxygen not including that from moisture		9.1	4.39

Table 2. Slurry Fuel Particle Size Distribution.

Velva Lignite Slurry Particle Size Distribution

Diameter (um)	Mass Percent
>50.8	0
40.3 - 50.8	1.5
32.0 - 40.3	4.5
25.4 - 32.0	6
20.2 - 25.4	7.5
16.0 - 20.2	6
12.7 - 16.0	5
10.1 - 12.7	6.5
8.0 - 10.1	11
6.35 - 8.0	14
5.04 - 6.35	15
4.00 - 5.04	14
3.17 - 4.00	12
0 - 3.17	0

Otisca Slurry Particle Size Distribution

Diameter (um)	Mass Percent
>10.5	0
9.5 - 10.5	3.7
8.5 - 9.5	2.4
7.5 - 8.5	2.5
6.5 - 7.5	2.7
5.5 - 6.5	6.2
4.5 - 5.5	10.0
3.5 - 4.5	11.5
2.5 - 3.5	14.5
1.5 - 2.5	17.1
0.5 - 1.5	24.4
0 - 0.5	5.1

Equipment

A modified Parr combustion bomb was used to simulate a diesel engine cylinder. Testing with the combustion bomb was done using a Parr calorimeter. The combustion bomb and calorimeter set up is shown in Figure 1. Modifications to the combustion bomb included installing a typical diesel engine pintle type fuel injector in the top of the bomb. The bomb also was modified to allow for introduction of a $H_2/O_2/N_2$ gas charge and isolation of the bomb after the charge was introduced. A pressure transmitter, used to determine the ignition was also added to the bomb. The signal from the

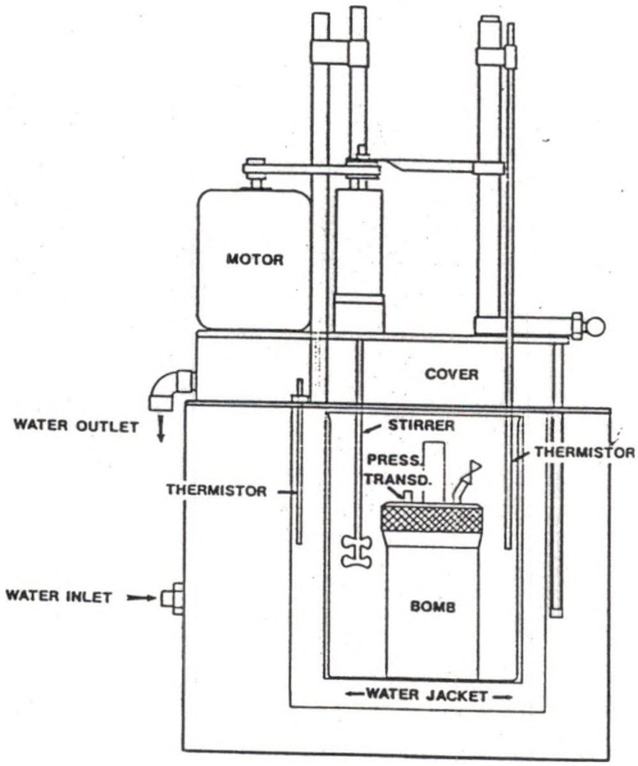

Figure 1. Combustion Bomb and Calorimeter.

pressure transmitter was fed to the data acquisition system. Note that all of these modifications involved changes to the cap of the bomb. No significant changes were made to the Parr calorimeter.

Test Procedure

The fuel injection system is pictured in Figure 2. A typical diesel engine fuel pump and pintle type fuel injector were used. To avoid the need to frequently clean the fuel pump, the slurry fuels were not run through this pump. Instead, the fuel line was first filled with the test slurry using a peristaltic pump, and the fuel line was then connected to the fuel pump and the fuel injector. Diesel fuel was used at the intake to the fuel pump to force the slurry through the fuel injector. A solenoid connected to a lever was used to exert the necessary pressure on the fuel pump to initiate a fuel spray, acting as the cam would in a normal diesel engine. After forcing a couple of shots of slurry through the injector, the bomb head/fuel injector assembly was placed on the bomb and the system was prepared for the test run.

A gas charge of $H_2/O_2/N_2$ was ignited to bring the test bomb to the desired temperature and pressure. An evacuated premix vessel was used to prepare the gas charge. The H_2, O_2, and N_2 gases were introduced into the vessel. The vessel pressure was recorded after the addition of each gas, so that the molar ratio of the $H_2/O_2/N_2$ mixture could be controlled.

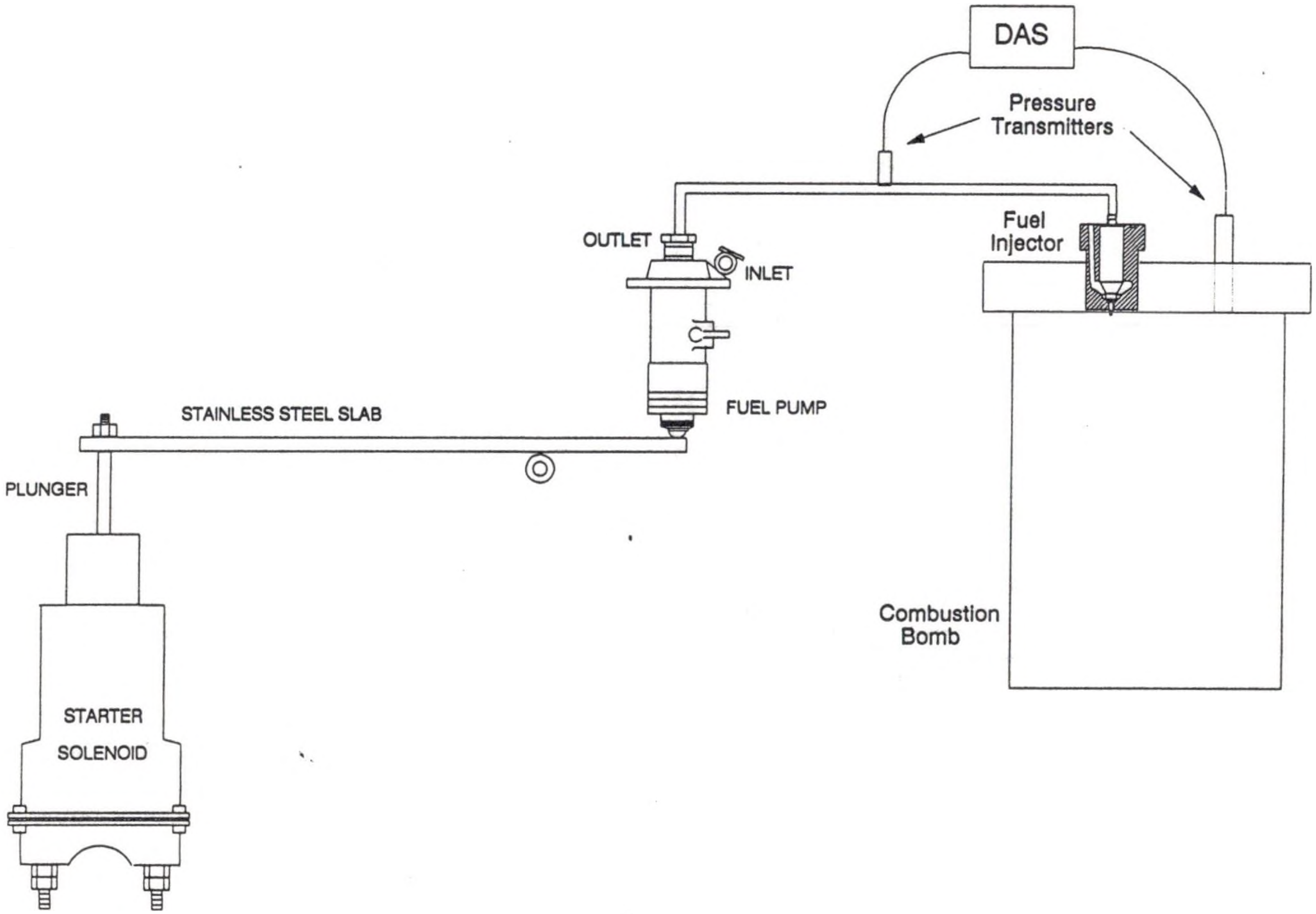

Figure 2. Fuel Injection System.

A portion of this gas was then transferred to the combustion bomb, which was first evacuated.

The pressure in the combustion bomb, after it was filled with the gas mixture, was used to determine the moles of hydrogen added to the bomb and the expected temperature increase upon combustion of the gas charge. The desired pressure and temperature conditions in the bomb were attained by controlling the amount of gas, particularly hydrogen, added to the bomb. The $H_2/O_2/N_2$ molar ratio was generally kept about the same in an attempt to obtain the approximate gas concentrations a diesel engine cylinder would see during operation.

After preparation of the fuel injection system was complete and the bomb had been charged with the $H_2/O_2/N_2$ gas mixture, the combustion bomb was immersed in the calorimeter water bath and the bath temperature was recorded. The sequence of burning the gas charge and injecting the test fuel was initiated using the computer data acquisition system. The computer system first caused the combustion bomb fuse wire to burn, igniting the gas charge and resulting in a rapid rise in the pressure and temperature inside the bomb. A short time after the gas charge was ignited, the computer activated the solenoid system that drove the fuel pump, which produced one shot of fuel spray in the combustion bomb. Because of the high pressure and high temperature in the combustion bomb, the fuel spray autoignites, just as does a fuel spray in a diesel engine cylinder. The lapse of time between ignition of the gas charge and injection of the fuel spray was controlled by altering the parameters of a FOR NEXT loop in the data acquisition Basic program. Changing this interval affected the pressure and temperature at the time of fuel injection.

During this sequence of events, the pressure in the bomb and the fuel line pressure were continuously monitored and copied to a computer print file at intervals of 0.10 or 0.12 milliseconds. These print files were imported into a Lotus 123™ spreadsheet for data analysis. After a full set of pressure data was recorded and stored in a print file, the data acquisition program displayed the calorimeter water bath temperature reading on the computer monitor. The final water bath temperature was recorded and used along with the initial water bath temperature to determine the heat released by the reactions taking place in the bomb. The bomb temperature was calculated using the measured gas pressure, the moles of gas in the bomb and the ideal gas law.

CHAPTER IV. RESULTS AND DISCUSSION

Fuel Injector Standardization

A series of tests were performed to determine the average mass of a single shot of fuel from the fuel injector with the three types of fuel used in this study. Standardization of the fuel injector was required because there was no means to directly measure the mass of fuel injected during a test run. The standardization runs involved injecting three shots of fuel into a pre-weighed watchglass and cloth. The weight of a single shot of fuel was then calculated using the increase in weight of the watch glass and cloth after receiving the shots of fuel. The mass of fuel injected was used to determine the expected heat release from combustion.

A summary of the results of the fuel injector standardization tests are presented in Table 3. The average mass of a shot of diesel fuel was 0.0913 grams with a standard deviation of 0.0052 grams. The average masses of the Otisca and Velva Lignite slurry fuels were 0.0988 and 0.0986 grams, with standard deviations of 0.0174 and 0.0354, respectively. Also included in Table 3 is the expected heat release with one shot of fuel for each test fuel. Because of the higher heating value of diesel fuel as compared with those of the two slurry fuels, the expected heat release with the two slurry fuels is significantly lower than that of the diesel fuel.

Table 3. Fuel Injector Standardization.

Fuel Type	Mass of 1 Fuel Shot (g)	Mass of 1 Fuel Shot (lb)	Energy Release (Btu)	Energy Release (cal)
Diesel Fuel	0.0913	0.000201	4.01	1010
Otisca Slurry	0.0988	0.000218	1.65	415
Velva Slurry	0.0986	0.000217	1.23	309

Experimental Design

The coal water slurry testing in this study was based on using a 2^3 factorial design (plus center points) with bomb pressure, bomb temperature, and slurry percent solids as the three test variables. The same design was used for the diesel fuel but, because it made no sense to include percent solids as a variable, a 2^2 factorial (plus center points) was used. Table 4 shows the experimental designs and the nominal test conditions. The results of the experiments are discussed below.

Ignition Delay

The ignition delay is defined as the time lapse between the fuel injection and when the bomb pressure first begins to rise (indicating fuel ignition). This is called the pressure recovery ignition delay. The time of fuel injection was taken as the time when after fuel injection was initiated, the fuel

Table 4. Test Matrices for Diesel Fuel and Coal-Water Slurries.

Design Test Matrix for Diesel Fuel Testing

Design Run #	Temp	Pressure
1	−	−
2	+	−
3	−	+
4	+	+
5	0	0

Temperaure (°K)			Pressure (psia)		
−	0	+	−	0	+
900	1100	1300	400	600	800

Design Test Matrix for Slurry Fuel Testing

Design Run #	Temp	Pressure	% Solids
1	−	−	−
2	+	−	−
3	−	+	−
4	+	+	−
5	−	−	+
6	+	−	+
7	−	+	+
8	+	+	+
9	0	0	0

Temperaure (°K)			Pressure (psia)			% Solids		
−	0	+	−	0	+	−	0	+
900	1100	1300	400	600	800	45	50	55

line pressure reached a maximum, indicating opening of the pintle fuel injector.

The time when fuel ignition began was found by determining the point where the steady slight pressure decrease in the bomb gave way to the increase in bomb pressure resulting from ignition of the fuel spray. To do this, a block of data clearly covering the fuel injection and ignition event was chosen. The ignition point was found statistically. Specifically, the block of data was systematically broken into two subsets of data, with an equation being fit to each subset. The first subset of data represented the steady slow decrease in bomb pressure seen after ignition of the gas charge had been completed, but prior to ignition of the slurry or diesel fuel spray. This subset of data was fit using the linear equation:

$$\text{Bomb Pressure} = a_1 + b_1(\text{time}). \quad \text{(eqn. 1)}$$

The second subset of data represented the pressure increase resulting from ignition and combustion of the fuel. This subset of data was fit to the equation:

$$(P-P_o) = b_2(t-t_o) + c_2(t-t_o)^2. \quad \text{(eqn. 2)}$$

In this equation t equals time, t_o is the time at the boundary between the two subsets, P equals the bomb pressure, and P_o equals the calculated bomb pressure at time, t_o, using the equation from the first subset data regression. The sum of squares from each of the two regression analyses were added to get a total sum of squares. The value of t_o for which the total sum of squares was the lowest was taken as the time of fuel ignition. An example of the results of one of the runs is shown in Table 5. A more detailed explanation of this analysis is given in Appendix B.

The injection, ignition and combustion of the fuel should take less than 12 milliseconds to be considered suitable for use in a medium speed diesel engine. A method of determining the duration of the combustion event was devised. The combustion duration was determined using the quadratic equation (eqn. 2) from the regression analysis of the second subset of data. This quadratic equation characterizes the ignition and burnout of the test fuel spray. The maximum in this curve is the time of complete combustion. The maximum is determined by setting the derivative of this equation equal to zero:

$$b_2+2c_2(t-to) = 0. \quad \text{(eqn. 3)}$$

Rearranging this equation gives the following equation for time, t_c, at the point of complete combustion:

$$t_c = -b_2/(2c_2) + to. \quad \text{(eqn. 4)}$$

In most cases, the quadratic was found to be a good fit for the data, and using the derivative provided a reasonable method of determining the duration of the combustion event.

Diesel Fuel Results

Testing of the diesel fuel followed a 2^2 factorial design with bomb temperature and pressure the two test variables.

Table 5. Diesel Fuel Test CB2DF53 Data Reduction Results.

First Data Set Minimum time = 80.04 milliseconds
Second Data Set Maximum time = 150 milliseconds

Injection Time = 135.84 millisec
Injection Press = 596 psia
Injection Temp = 1321 K

Ignition Time = 137.1 millisec

Ignition Delay = 1.26 millisec
Comb. Duration = 9.23 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
136.14	64885	22799	87684	1319	595	803	-1.528	37.9	-1.251	151.28
136.26	64960	20638	85598	1319	595	803	-1.529	40.0	-1.486	149.71
136.38	64961	18836	83797	1318	595	803	-1.530	42.1	-1.730	148.54
136.5	65429	16771	82200	1318	595	803	-1.525	44.2	-1.981	147.65
136.62	65451	15271	80723	1318	594	803	-1.524	46.4	-2.255	146.91
136.74	65642	13884	79527	1318	594	802	-1.521	48.7	-2.541	146.32
136.86	66211	12336	78547	1318	594	802	-1.515	51.0	-2.841	145.83
136.98	66352	11472	77824	1318	594	801	-1.513	53.4	-3.165	145.42
137.1	66495	11205	77699	1317	594	802	-1.515	56.0	-3.515	145.07
137.22	66502	11924	78426	1316	594	802	-1.516	58.6	-3.875	144.78
137.34	66805	13080	79886	1316	594	801	-1.512	61.2	-4.242	144.55
137.46	67855	14049	81904	1317	594	801	-1.505	63.7	-4.621	144.36
137.58	68354	16242	84596	1317	594	800	-1.500	66.4	-5.025	144.19
137.7	69397	18623	88020	1317	594	800	-1.493	69.1	-5.444	144.05
137.82	69985	22361	92346	1317	594	799	-1.488	71.9	-5.885	143.93
137.94	70837	26855	97692	1317	594	798	-1.482	74.6	-6.342	143.83

Because equipment shakedown was primarily completed using diesel fuel, twelve runs with diesel fuel were completed rather than the five in the experimental design. One of the primary purposes of the diesel fuel testing was to use the results as a baseline comparison with the coal-water slurry tests.

A summary of the test conditions and results when using diesel fuel are shown in Table 6. In general, the ignition delay times when using diesel fuel were between 1 and 2 milliseconds and were relatively constant over the range of conditions tested. The duration of the combustion event was generally between 8 and 11 milliseconds.

Table 6. Diesel Fuel Test Conditions and Ignition Delay Results.

Trial	Fuel Injection Bomb Conditions Moles (gmol)	Temp (°K)	Pressure (psia)	Ignition Delay (millisec)	Combustion Duration (millisec)	Match With Design Run #
CB2DF53	0.129	1321	596	1.38	9.23	No Match
CB2DF61	0.149	1091	570	1.86	5.29	5
CB2DF62	0.089	1149	360	1.14	9.26	No Match
CB2DF63	0.156	1070	584	1.44	9.55	5
CB2DF65	0.128	927	416	1.26	9.97	1
CB2DF67	0.177	1284	793	1.38	10.17	4
CB2DF68	0.255	1030	918	1.98	9.23	No Match
CB2DF69	0.156	1139	620	1.44	8.40	5
CB3DF75	0.088	1209	374	1.02	8.23	2
CB3DF85	0.244	935	797	1.98	11.86	3
CB3DF86	0.156	1168	636	1.26	10.49	5
CB2DF114	0.088	1267	390	1.45	7.96	2

A statistical analysis(5) was performed to determine if any of the independent variables (or their interactions or curvature) significantly affected the ignition delay. The results are shown in Table 7. A more detailed discussion of this analysis is presented in Appendix B. Only bomb pressure significantly affected ignition delay at the 95% confidence level. Increasing the bomb pressure from 400 to 800 psia caused a slight average increase of 0.5 milliseconds in the ignition delay time. A similar analysis with the combustion duration as the dependent variable showed no significant effects. The final analysis is presented in Table 8. Plots showing the pressure trace and the ignition delay for each of the diesel fuel runs are shown in Figures 3 through 14.

Slurry Fuel Results

Some minor problems with plugging of the fuel injection system were experienced when using the Otisca slurry. However, all conditions included in the 2^3 factorial design matrix for the Otisca slurry were completed. Variables studied under this test matrix included the bomb pressure and temperature at the time of fuel injection and solids content of the slurry. A total of thirteen runs with the Otisca slurry were completed.

The Otisca slurry test conditions and results are shown in Table 9. The most pronounced results were those obtained at the lower bomb temperatures (900°K). Fuel ignition was not

Table 7. Diesel Fuel Ignition Delay Analysis.

Significance Test

Trial	Ignition Delay (msec) y	Normalized Pressure x2
CB2DF53	1.38	-0.02
CB2DF61	1.86	-0.15
CB2DF62	1.14	-1.2
CB2DF63	1.44	-0.08
CB2DF65	1.26	-0.92
CB2DF67	1.38	0.965
CB2DF68	1.98	1.59
CB2DF69	1.44	0.1
CB3DF75	1.02	-1.13
CB3DF85	1.98	0.985
CB3DF86	1.26	0.18
CB2DF114	1.45	-1.05

Regression Output:

Constant		1.481
Std Err of Y Est		0.232
R Squared		0.508
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	0.246	
Std Err of Coef.	0.077	
t value	3.211	

With 10 degrees of freedom, term is significant
at 95% confidence level if t value is greater than 2.228

Calculation of effects

$y = 1.48 + 0.25(x2)$

Going from low normalized pressure (x2=-1) to high normalized pressure (x2=+1)
Change in y = (0.25)(+1)-(.25)(-1) = 0.50 millisecond

Table 8. Diesel Fuel Combustion Duration Analysis.

Significance Test

Trial	Combustion Duration (millisec) y	Normalized Temperature x1	Normalized Pressure x2
CB2DF53	9.23	1.105	-0.02
CB2DF61	5.29	-0.045	-0.15
CB2DF62	9.26	0.245	-1.2
CB2DF63	9.55	-0.15	-0.08
CB2DF65	9.97	-0.865	-0.92
CB2DF67	10.17	0.92	0.965
CB2DF68	9.23	-0.35	1.59
CB2DF69	8.4	0.195	0.1
CB3DF75	8.23	0.545	-1.13
CB3DF85	11.86	-0.825	0.985
CB3DF86	10.49	0.34	0.18
CB2DF114	7.96	0.835	-1.05

y = Combustion Duration
Regression Output:

Constant		9.252
Std Err of Y Est		1.630
R Squared		0.169
No. of Observations		12
Degrees of Freedom		9
X Coefficient(s)	-0.492	0.576
Std Err of Coef.	0.781	0.551
t value	-0.630	1.047

With 9 degrees of freedom, term is significant
at 95% confidence level if t value is greater than 2.262

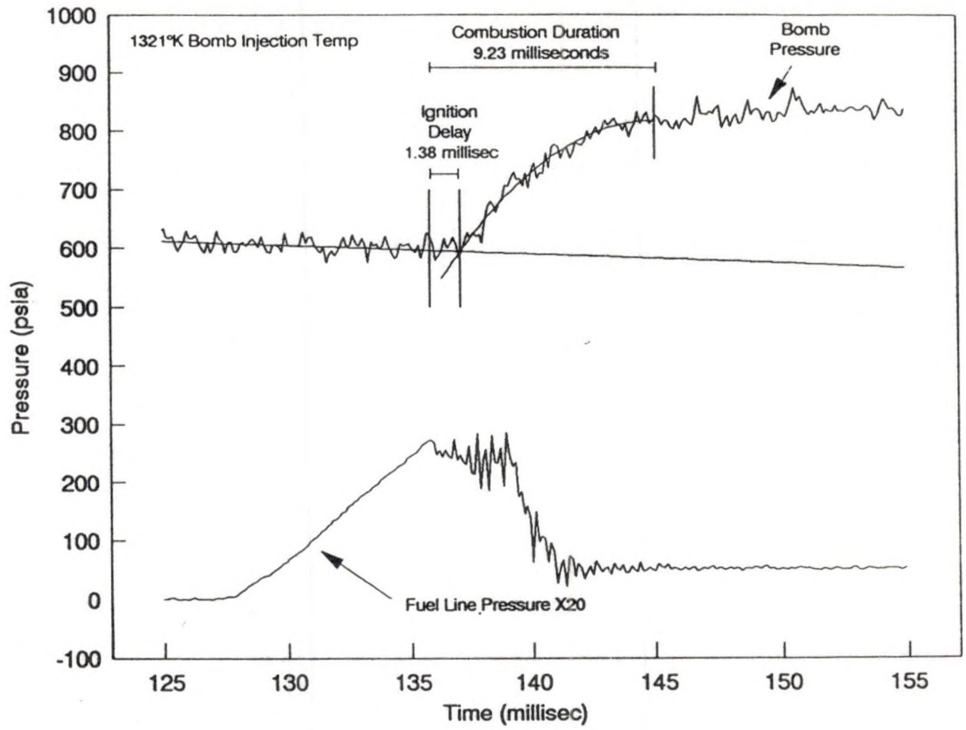

Figure 3. Diesel Fuel Test CB2DF53 Pressure Trace.

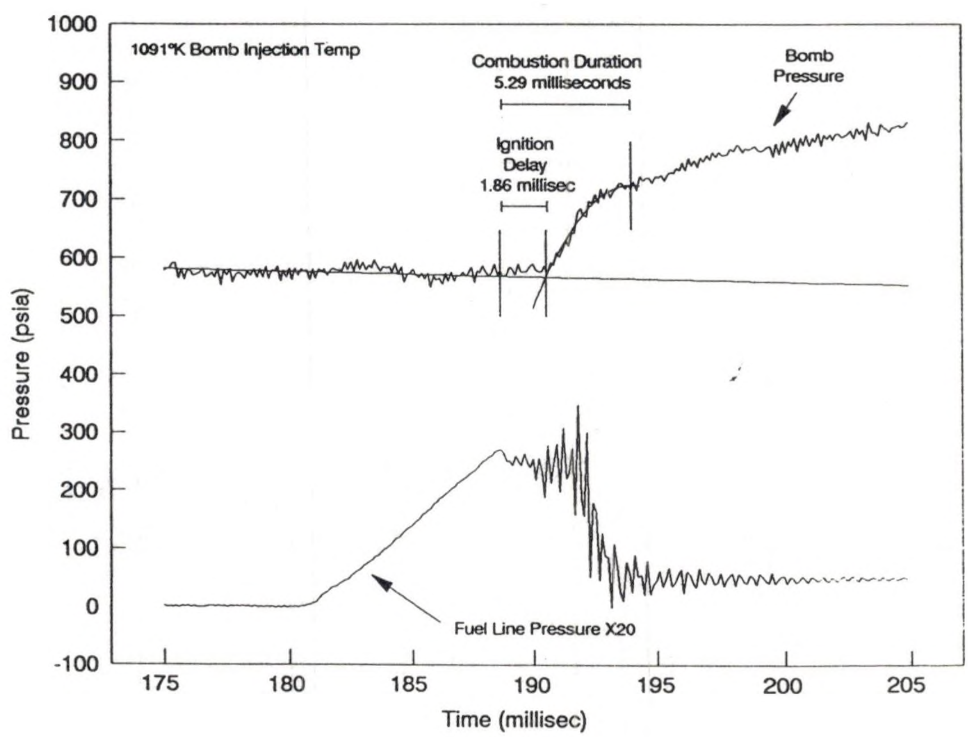

Figure 4. Diesel Fuel Test CB2DF61 Pressure Trace.

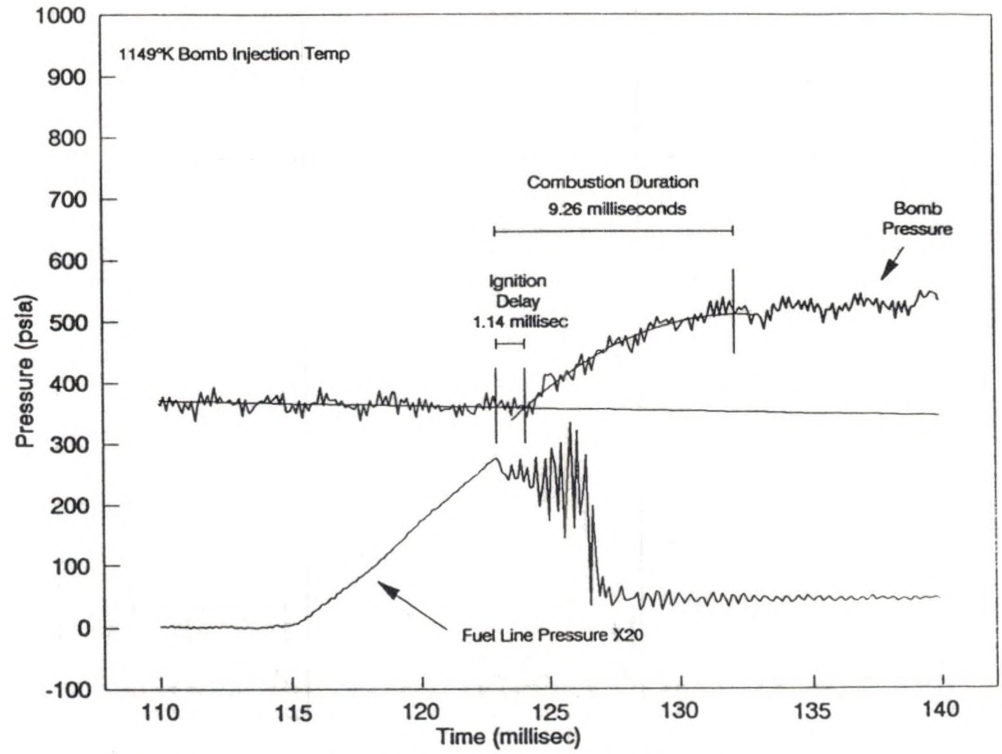

Figure 5. Diesel Fuel Test CB2DF62 Pressure Trace.

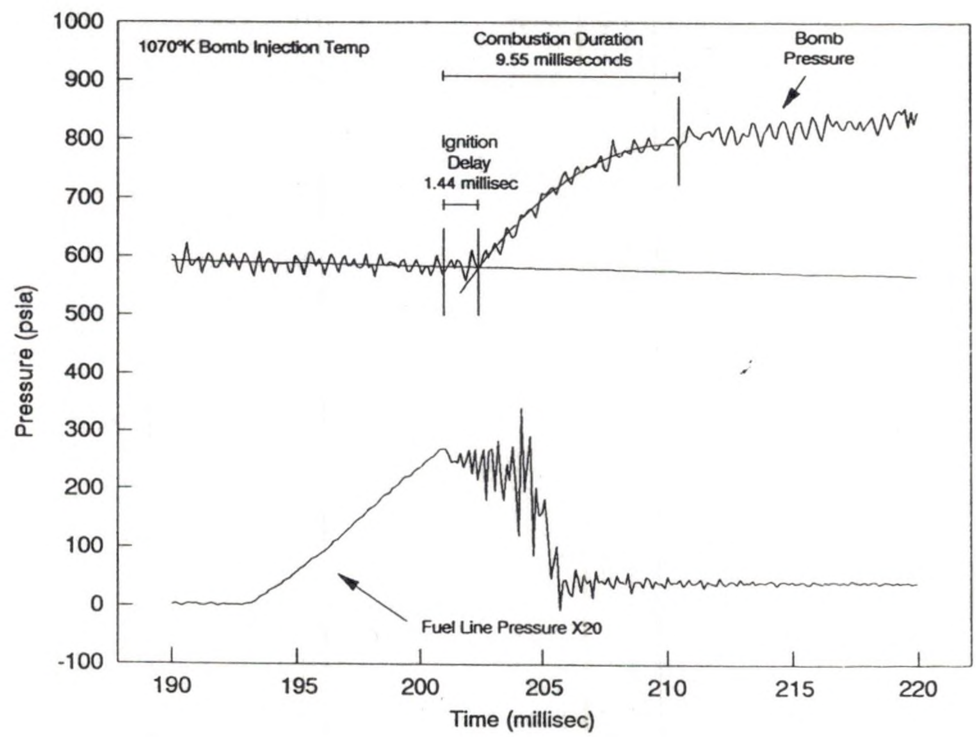

Figure 6. Diesel Fuel Test CB2DF63 Pressure Trace.

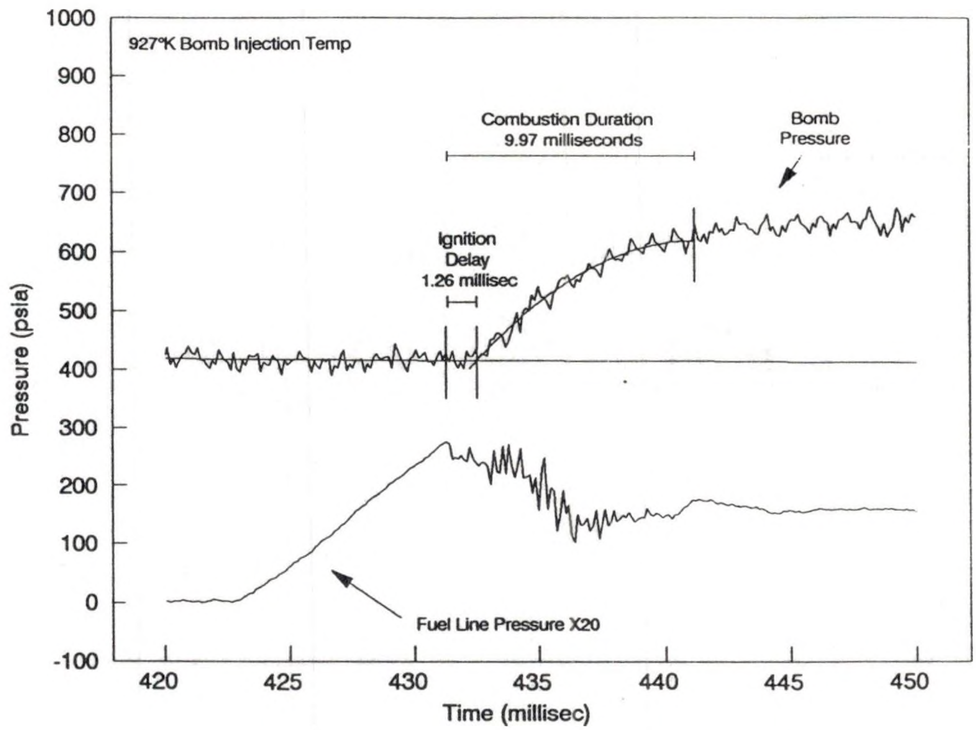

Figure 7. Diesel Fuel Test CB2DF65 Pressure Trace.

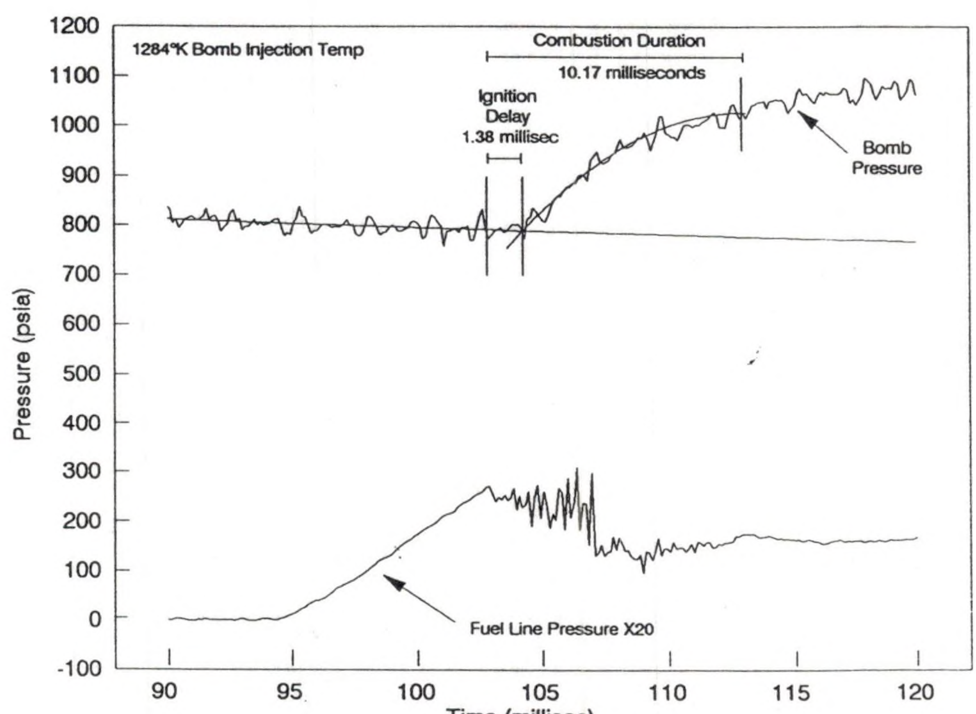

Figure 8. Diesel Fuel Test CB2DF67 Pressure Trace.

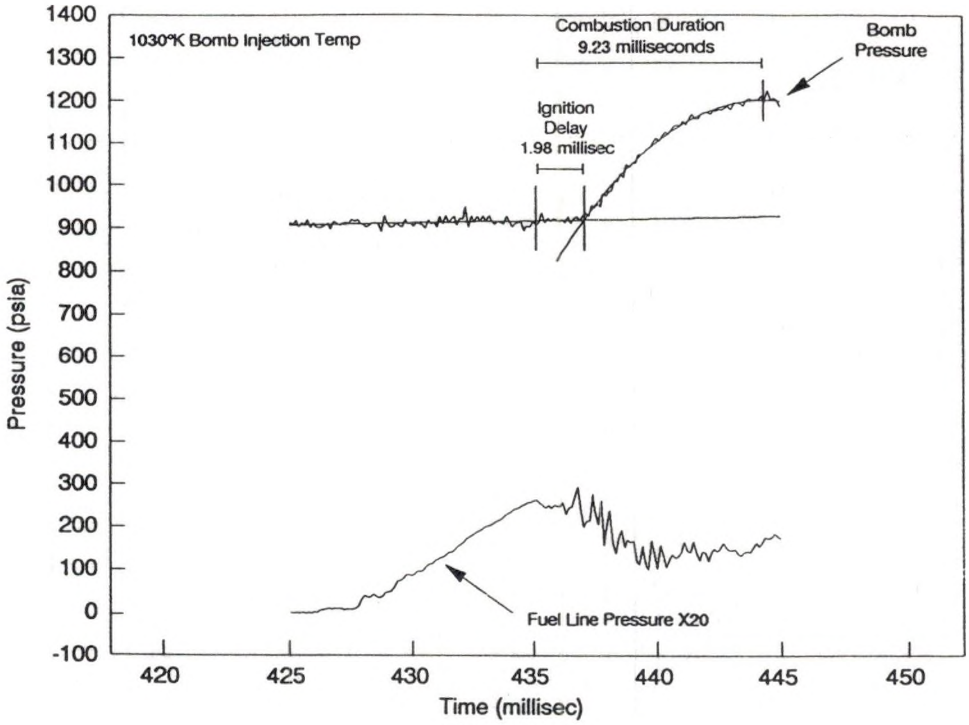

Figure 9. Diesel Fuel Test CB2DF68 Pressure Trace.

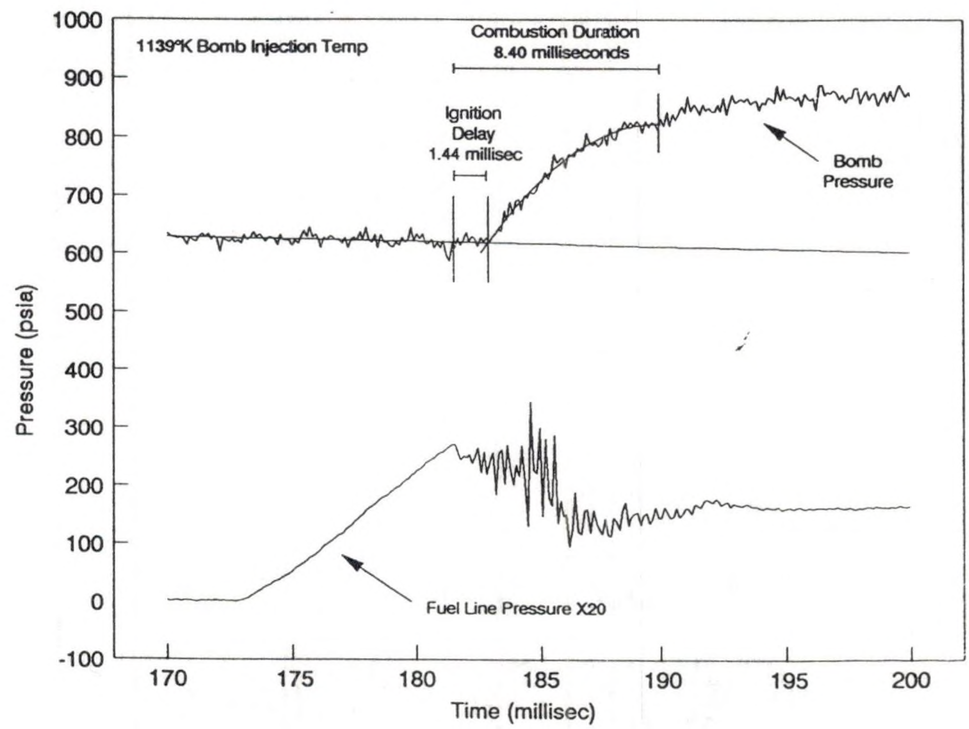

Figure 10. Diesel Fuel Test CB2DF69 Pressure Trace.

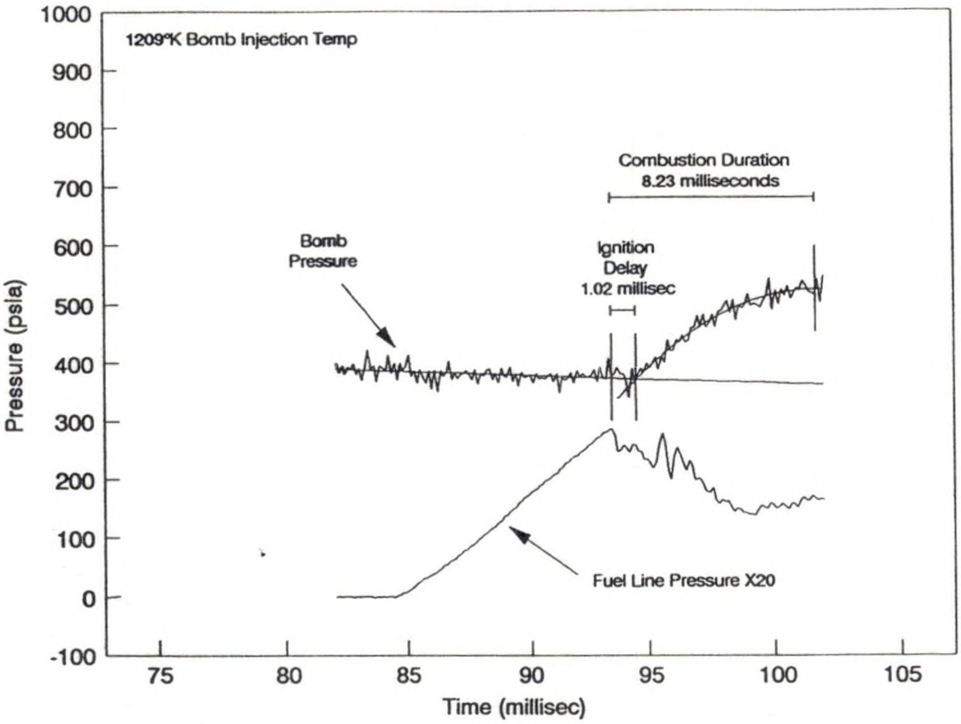

Figure 11. Diesel Fuel Test CB3DF75 Pressure Trace.

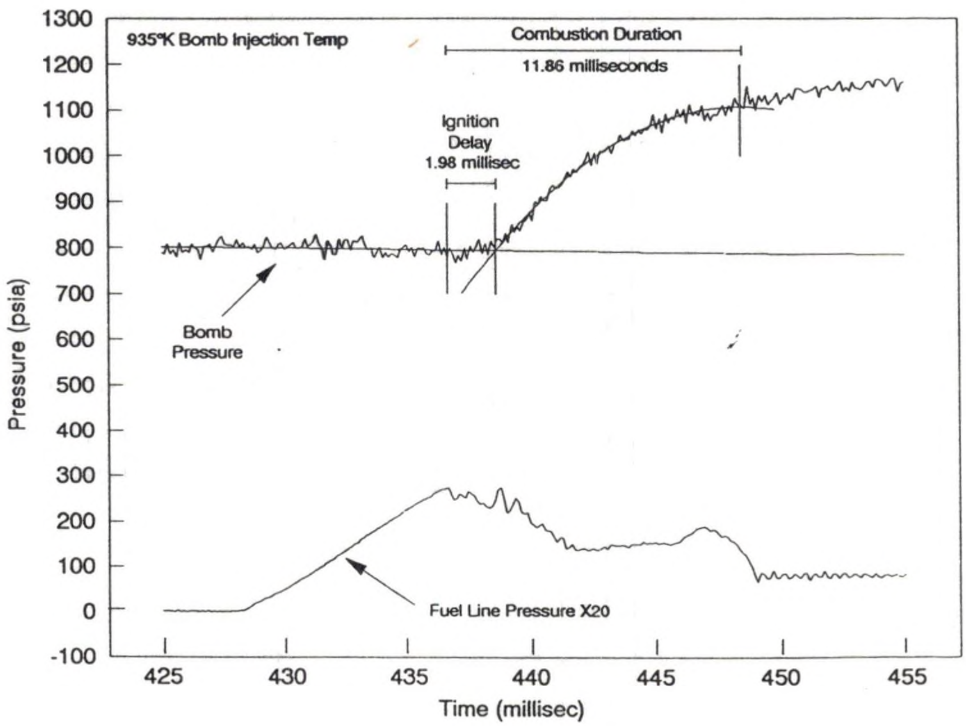

Figure 12. Diesel Fuel Test CB3DF85 Pressure Trace.

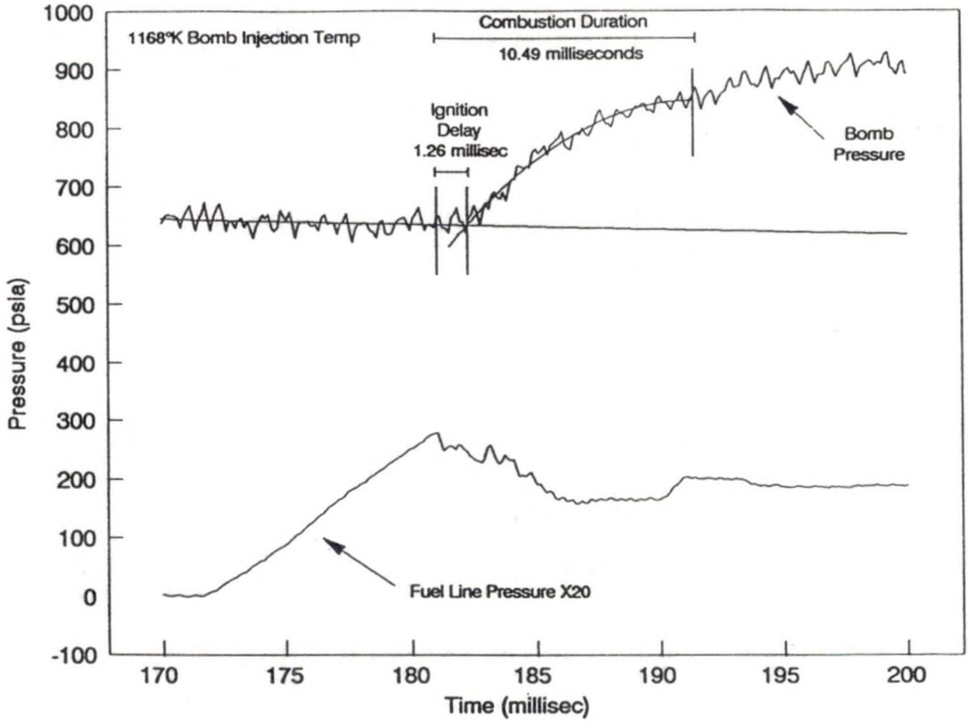

Figure 13. Diesel Fuel Test CB3DF86 Pressure Trace.

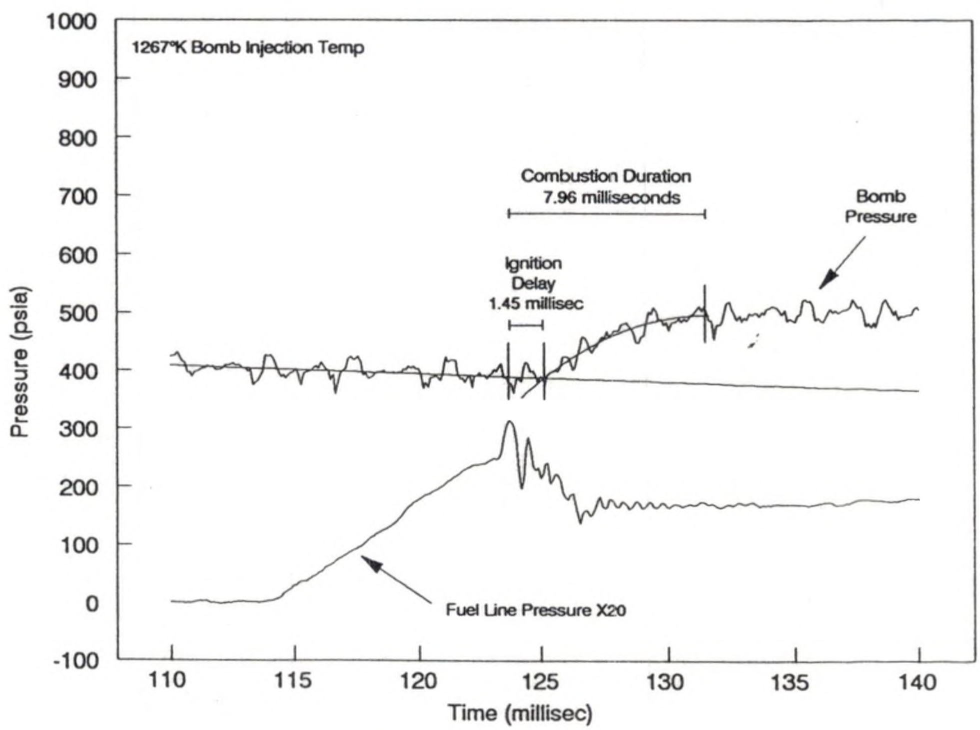

Figure 14. Diesel Fuel Test CB2DF114 Pressure Trace.

Table 9. Otisca Slurry Test Conditions and Ignition Delay Results.

Trial	Slurry % Solids (%)	Fuel Injection Bomb Conditions Moles (gmol)	Temp (°K)	Pressure (psia)	Ignition Delay (msec)	Combustion Duration (msec)	Design Run Match
CB2OT89	53.4	0.129	901	406	5.85	17.57	5
CB2OT90	53.4	0.177	1254	776	1.75	7.69	8
CB2OT91	53.4	0.089	1201	373	1.45	13.20	6
CB2OT93	53.4	0.254	868	772	6.90	14.75	7
CB2OT94	53.4	0.089	1336	415	1.95	14.48	6
CB2OT97	49.4	0.158	1137	631	2.75	12.03	9
CB2OT99	49.4	0.156	1106	603	1.55	7.43	9
CB2OT102	44.0	0.087	1270	386	1.15	7.16	2
CB2OT103	44.0	0.177	1252	775	1.50	7.91	4
CB2OT104	44.0	0.085	1205	358	1.75	10.52	2
CB2OT105	44.0	0.177	1243	769	3.35	12.13	4
CB2OT106	44.0	0.255	909	808	No Ignition		3
CB2OT107	44.0	0.126	924	407	No Ignition		1

even achieved when the 45 percent solids Otisca slurry was injected into the bomb at 900°K, and the ignition delay was noticeably greater when testing the 55 percent solids slurry at that temperature. The ignition delays at these conditions were unacceptable for diesel engine operation. Ignition delays at higher temperatures were all acceptable (less than 3 milliseconds with most below 2.5 milliseconds). The combustion duration generally ranged from 7 to 15 milliseconds. Pressure trace plots displaying the ignition delay are presented in Figures 15 through 27.

A 2^3 factorial design was also planned for the Velva lignite slurry testing. Bomb pressure and bomb temperature at the time of fuel injection along with the solids content of the slurry were the design variables for the test matrix. No

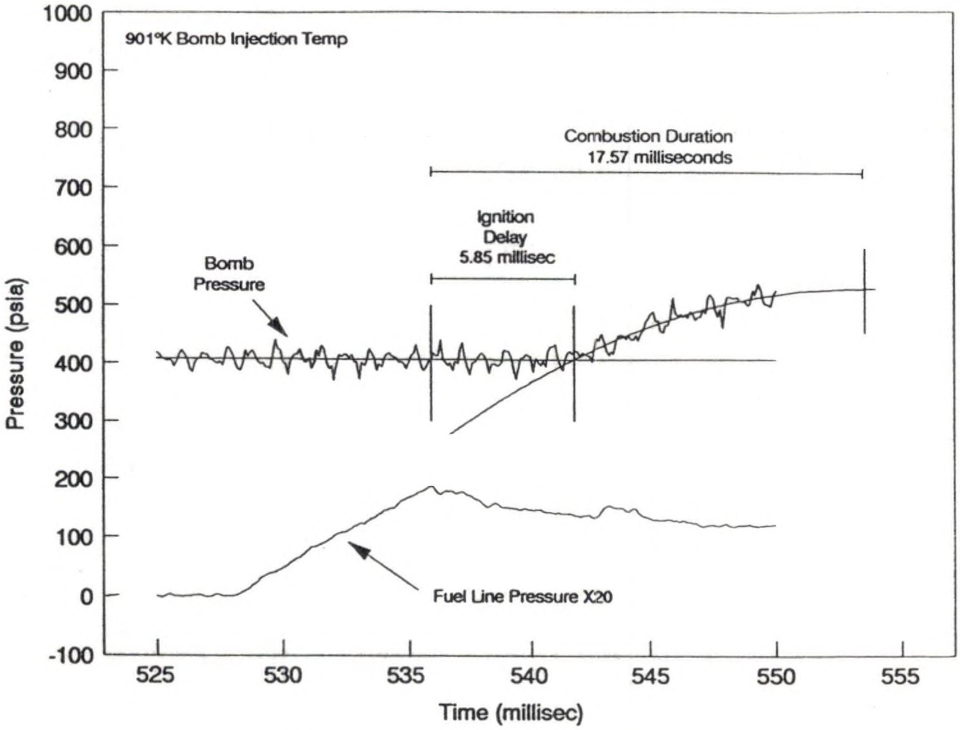

Figure 15. Otisca Slurry Test CB2OT89 Pressure Trace.

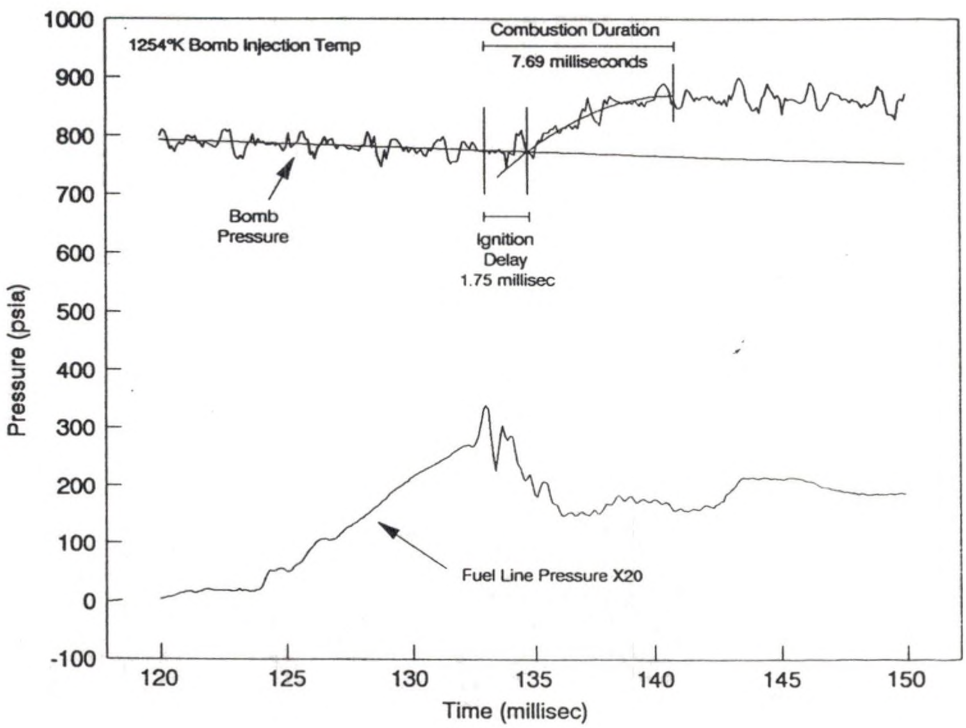

Figure 16. Otisca Slurry Test CB2OT90 Pressure Trace.

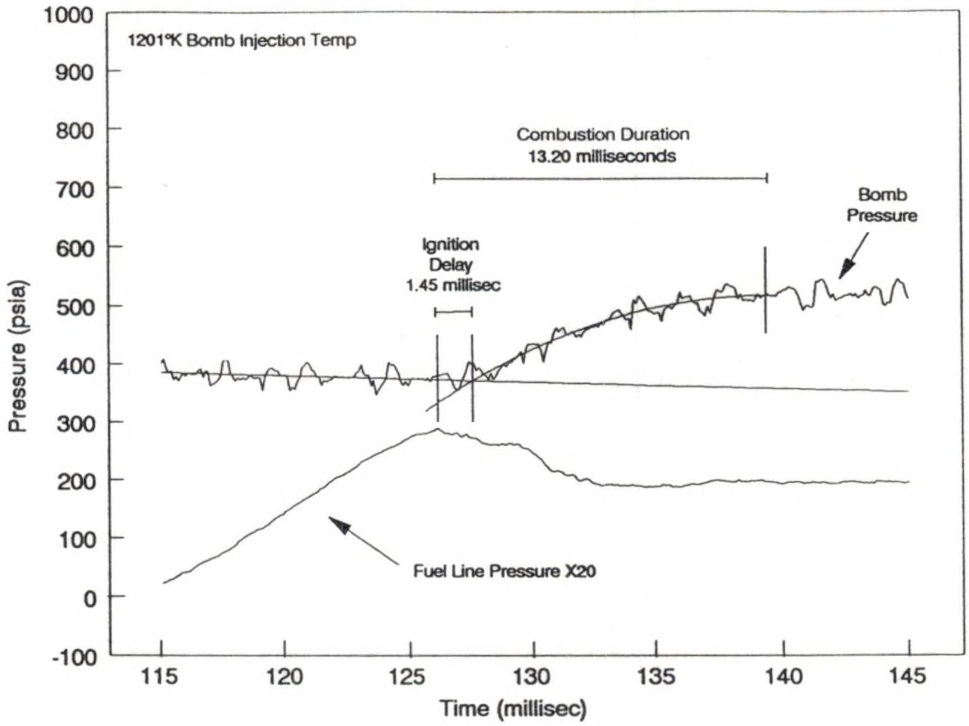

Figure 17. Otisca Slurry Test CB2OT91 Pressure Trace.

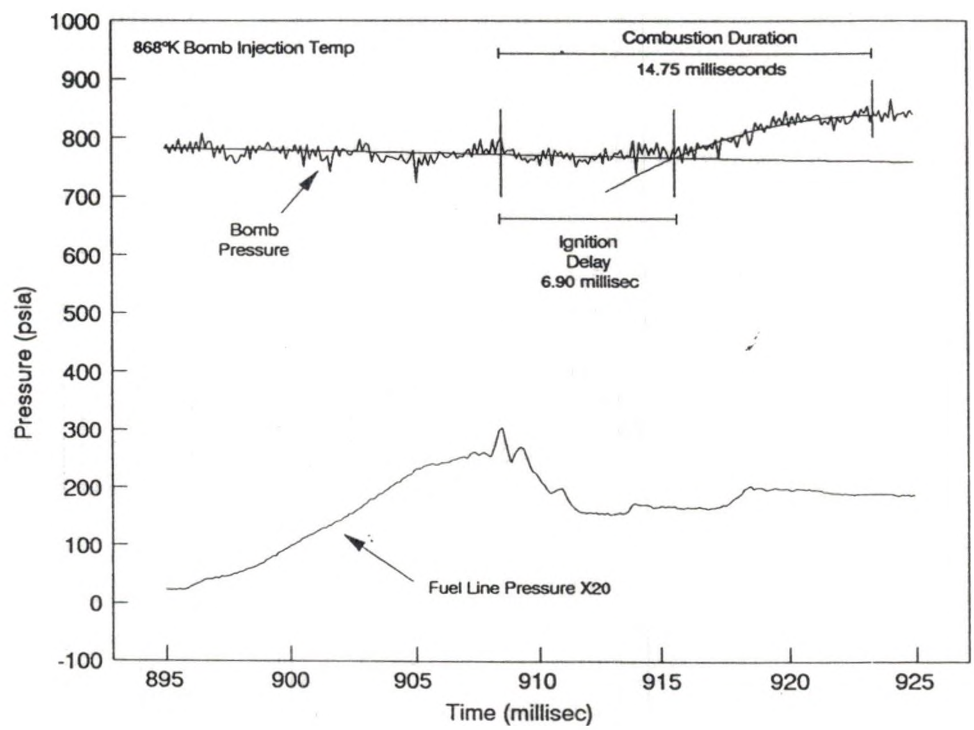

Figure 18. Otisca Slurry Test CB2OT93 Pressure Trace.

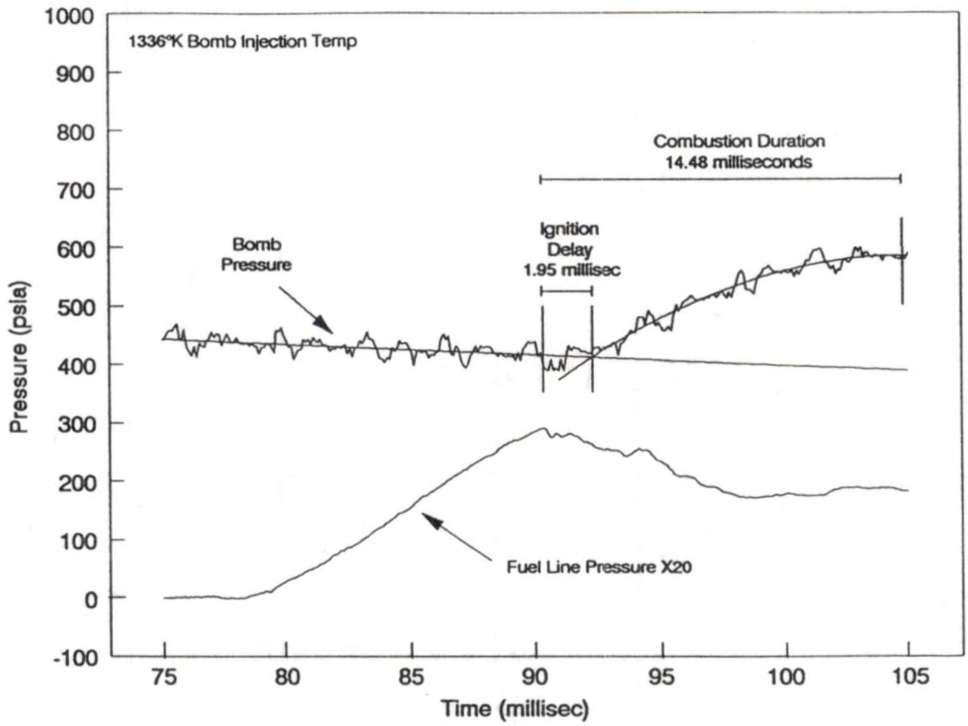

Figure 19. Otisca Slurry Test CB2OT94 Pressure Trace.

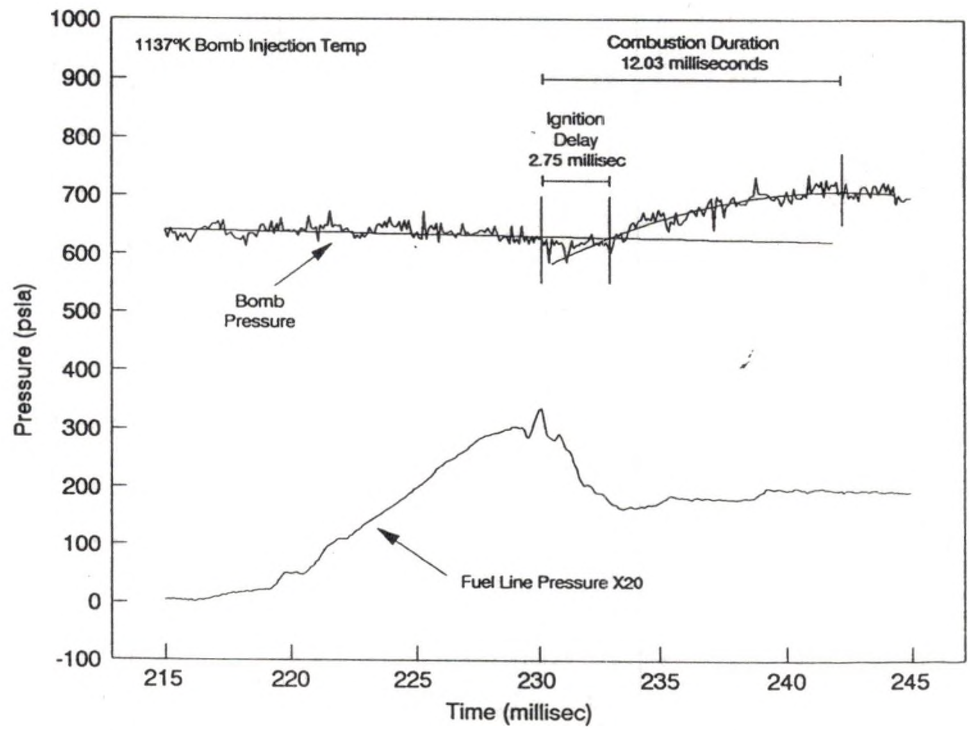

Figure 20. Otisca Slurry Test CB2OT97 Pressure Trace.

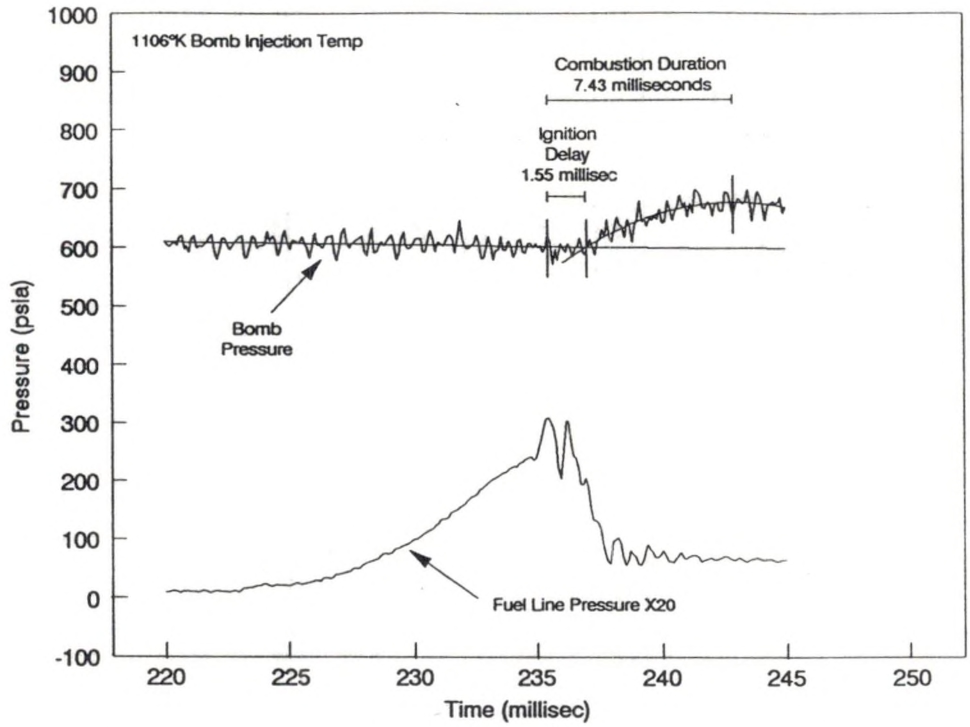

Figure 21. Otisca Slurry Test CB2OT99 Pressure Trace.

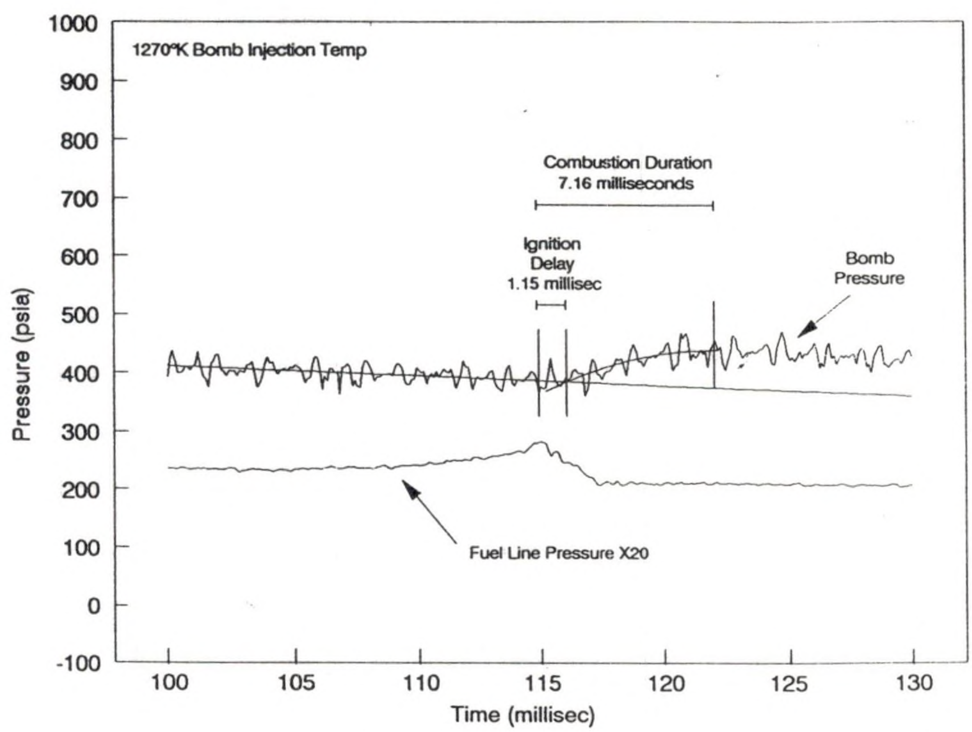

Figure 22. Otisca Slurry Test CB2OT102 Pressure Trace.

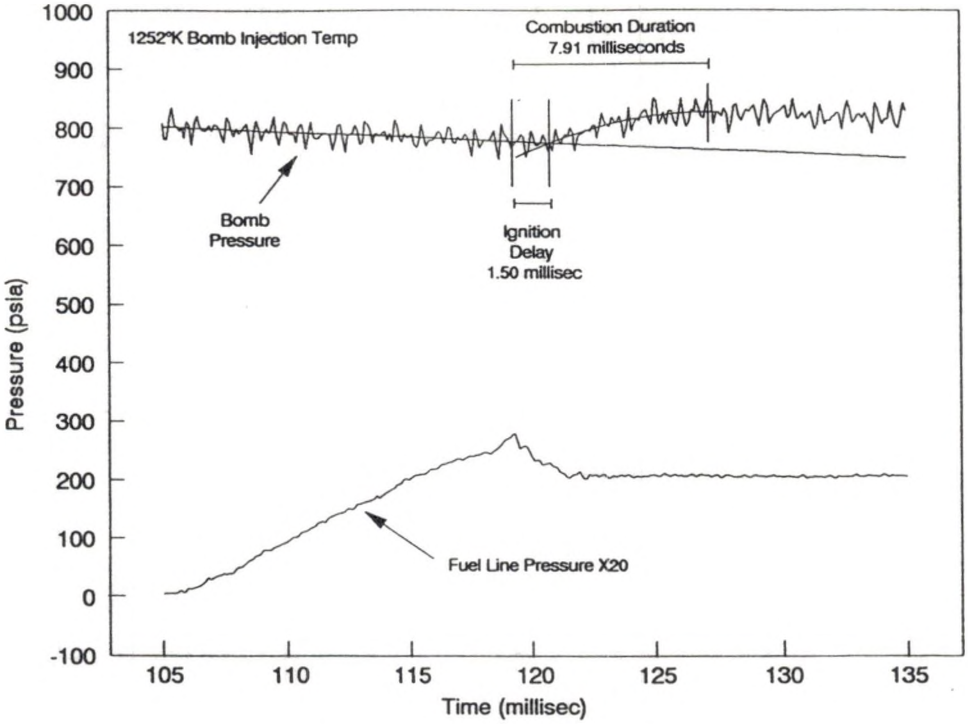

Figure 23. Otisca Slurry Test CB2OT103 Pressure Trace.

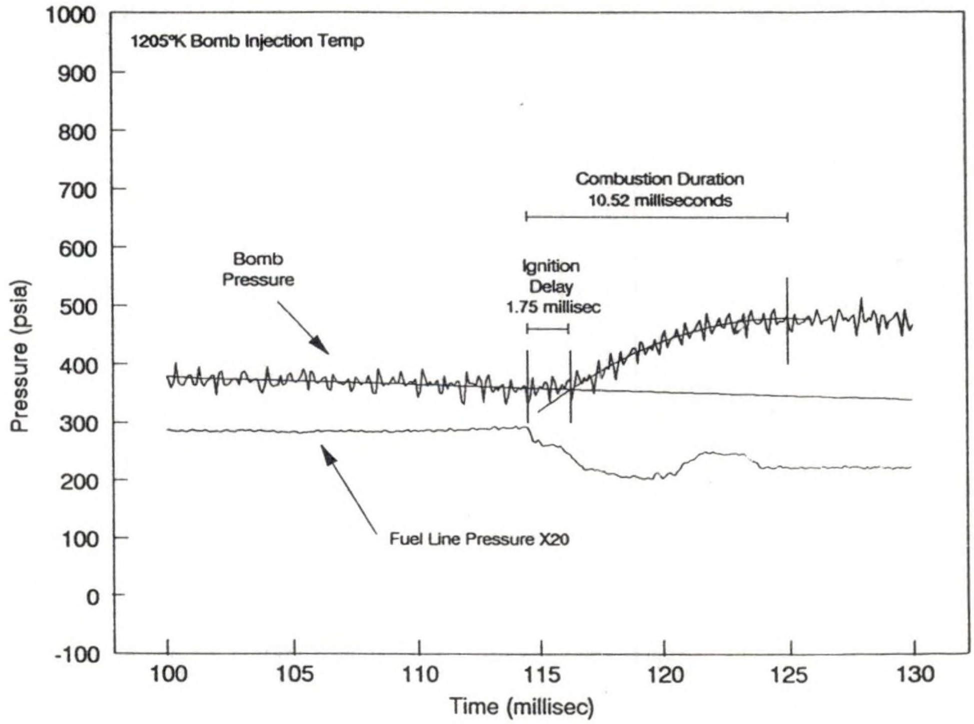

Figure 24. Otisca Slurry Test CB2OT104 Pressure Trace.

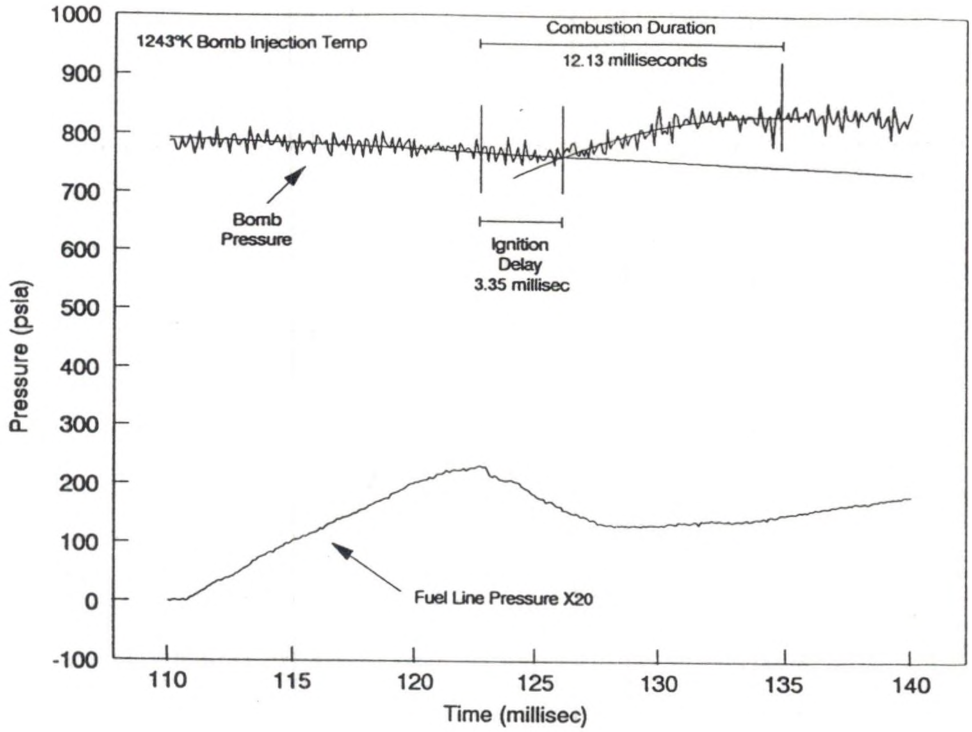

Figure 25. Otisca Slurry Test CB2OT105 Pressure Trace.

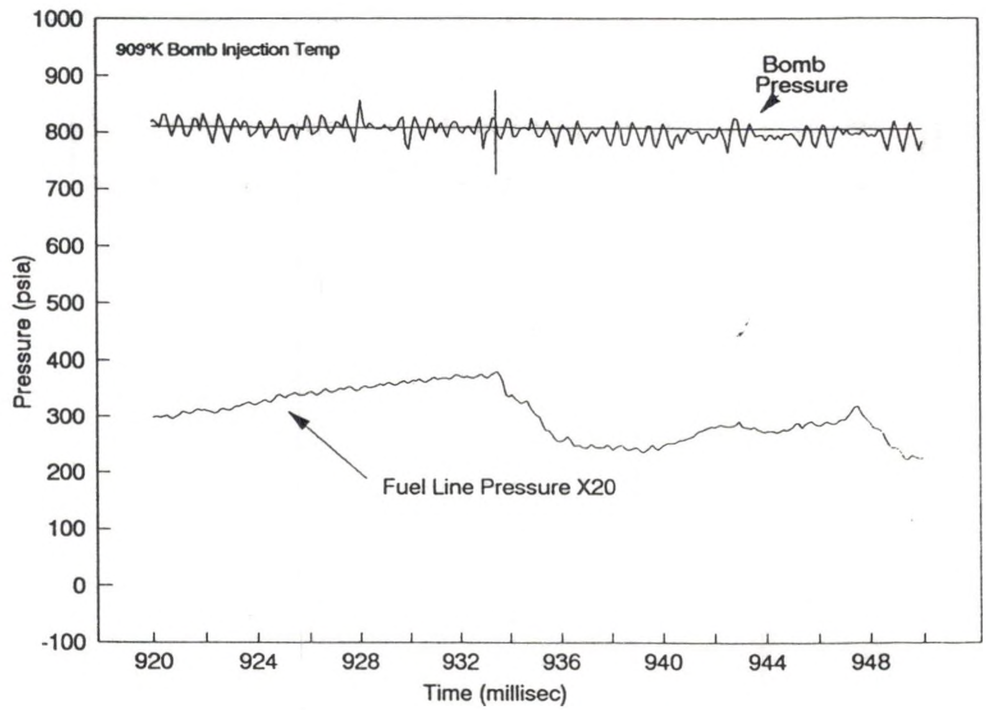

Figure 26. Otisca Slurry Test CB2OT106 Pressure Trace.

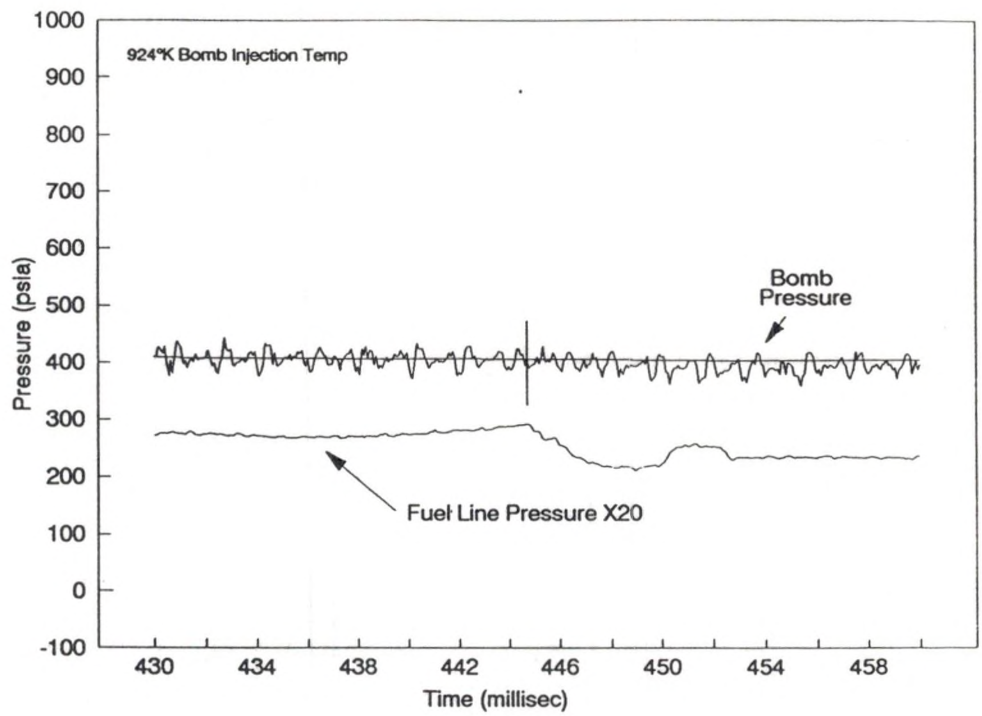

Figure 27. Otisca Slurry Test CB2OT107 Pressure Trace.

successful runs at 55 percent solids loading were completed because the fuel injector plugged. Therefore, a 2^2 factorial design with bomb pressure and temperature as the two variables was completed at a solids loading of 45.4%. A midpoint run was completed at about 50% solids loading after two unsuccessful tries. The problem with plugging of the fuel injector may be linked to the larger mass median diameter of the solids in the lignite slurry (5.88 microns) compared with that of the Otisca slurry (2.73 microns) as discussed in Chapter III.

The ignition delay results, shown in Table 10, were very promising in the runs where successful injection of the slurry was achieved. The ignition delays were all less than 3 milliseconds. These results indicate that injection at the lower bomb temperature did not have as dramatic an effect on

Table 10. Velva Lignite Slurry Test Conditions and Ignition Delay Results.

Trial	Slurry % Solids (%)	Fuel Injection Bomb Conditions: Moles (gmol)	Temp (°K)	Pressure (psia)	Ignition Delay (msec)	Combustion Duration (msec)	Design Run Match
CB2VL71	45.4	0.088	1241	383	1.08	9.55	2
CB2VL72	45.4	0.255	1021	908	2.22	7.93	3
CB2VL73	45.4	0.128	949	423	2.34	8.49	1
CB2VL74	45.4	0.176	1232	761	1.26	5.9	4
CB2VL76	55.4	0.176	No Fuel Injection - Plugged injector				No Match
CB2VL77	55.4	0.176	No Fuel Injection - Plugged injector				No Match
CB2VL78	55.4	0.176	No Fuel Injection - Plugged injector				No Match
CB2VL79	55.4	0.088	No Fuel Injection - Plugged injector				No Match
CB2VL112	49.3	0.156	1115	608	2.65	4.79	5

ignition delay as it did with the Otisca slurry. Also, the ignition delays with the Velva Lignite slurry were very similar to those with the diesel fuel. The combustion durations were also similar to those with diesel fuel and were all less than 10 milliseconds over the range of conditions tested. Pressure trace plots displaying the ignition delay results are presented in Figures 28 through 32.

An analysis was performed to determine the significance of the independent variables on ignition delay and combustion duration. The results of this analysis with respect to ignition delay are shown in Table 11. In doing this analysis, an ignition delay of 10 milliseconds was used in the low temperature, low percent solids Otisca slurry runs where ignition did not occur. The effects of slurry type (bituminous vs. lignite), bomb injection temperature, and slurry percent solids were significant at the 95% confidence level, while the effect of pressure was not significant. The interactions between slurry type and bomb injection temperature and between bomb injection temperature and percent solids were also significant.

The main effects of slurry type, temperature, and percent solids are shown in Table 12. This table shows the notable effect temperature has on the ignition delay. Increasing the bomb injection temperature from 900°K to 1300°K resulted in a reduction in the ignition delay for all cases. The ignition delay with the Velva lignite decreased 1.9 milliseconds with

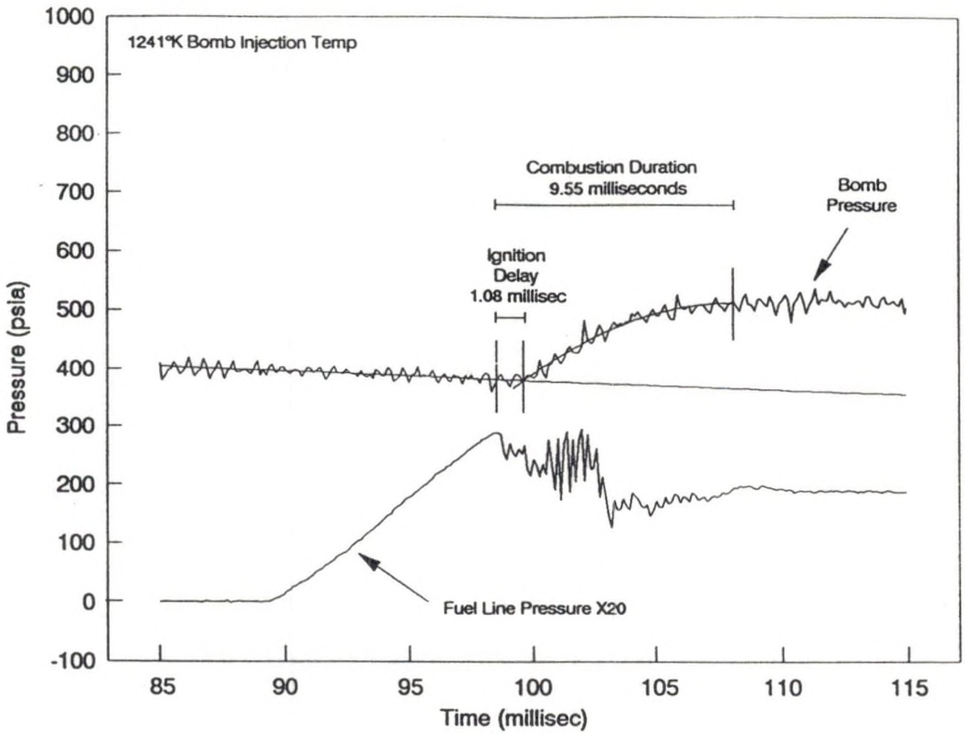

Figure 28. Velva Slurry Test CB2VL71 Pressure Trace.

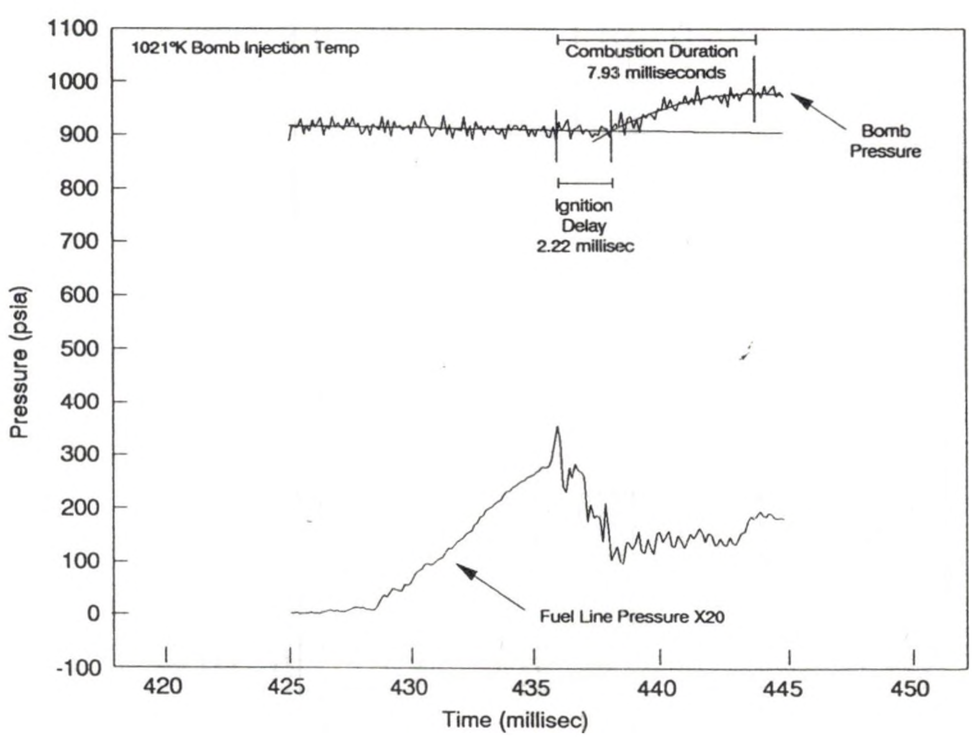

Figure 29. Velva Slurry Test CB2VL72 Pressure Trace.

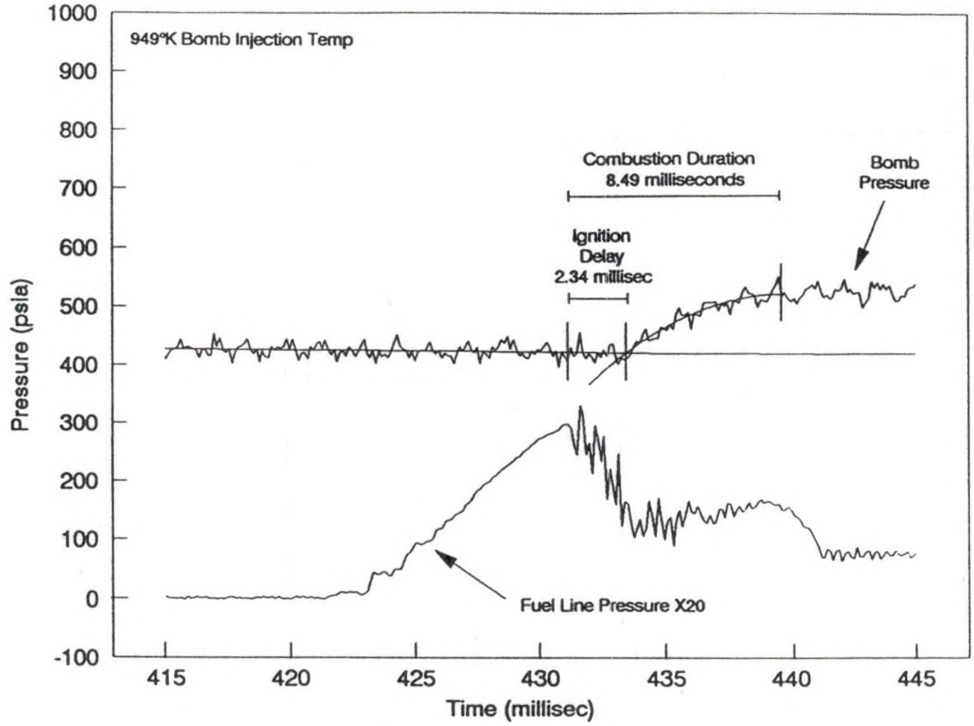

Figure 30. Velva Slurry Test CB2VL73 Pressure Trace.

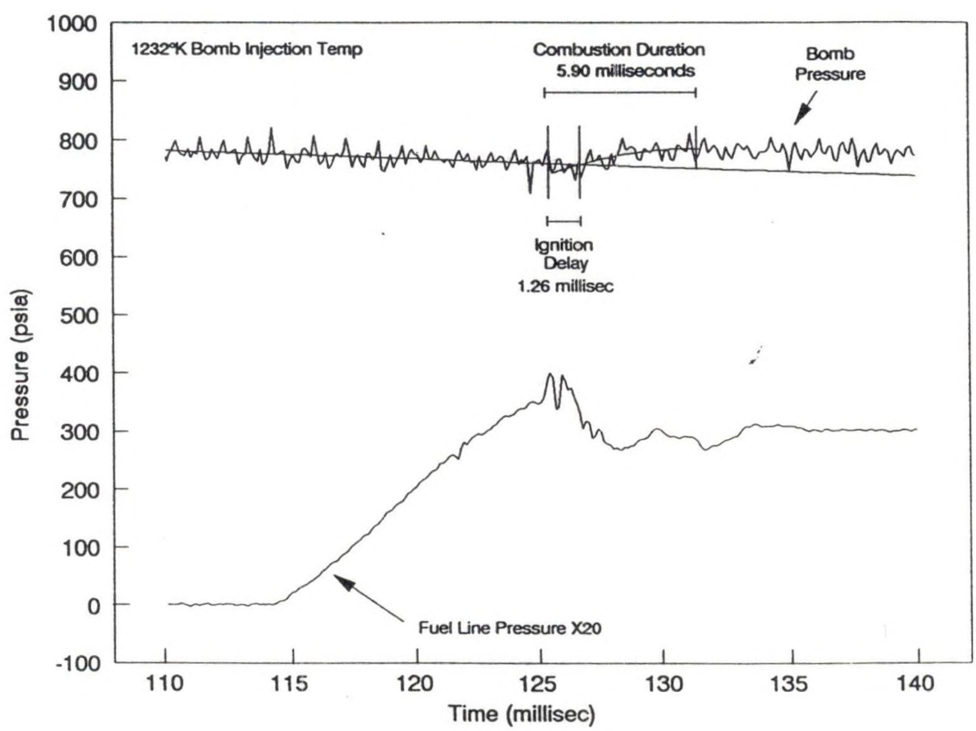

Figure 31. Velva Slurry Test CB2VL74 Pressure Trace.

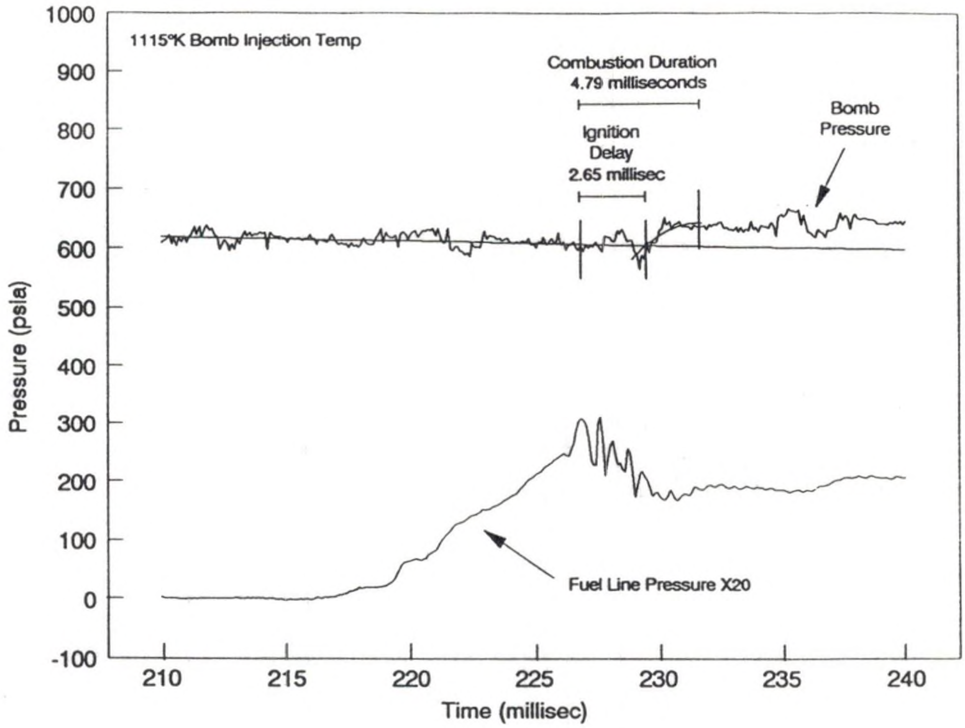

Figure 32. Velva Slurry Test CB2VL112 Pressure Trace.

Table 11. Slurry Fuel Ignition Delay Analysis.

Significance Test

Trial	Ignition Delay (msec) y	Normalized Slurry x0	Normalized Temp x1	Normalized % solids x3	(x1)(x3)	(x0)(x1)
CB2OT89	5.85	1	-0.995	0.68	-0.677	-0.995
CB2OT90	1.75	1	0.770	0.68	0.524	0.770
CB2OT91	1.45	1	0.505	0.68	0.343	0.505
CB2OT93	6.90	1	-1.160	0.68	-0.789	-1.160
CB2OT94	1.95	1	1.180	0.68	0.802	1.180
CB2OT97	2.75	1	0.185	-0.12	-0.022	0.185
CB2OT99	1.55	1	0.030	-0.12	-0.004	0.030
CB2OT102	1.15	1	0.850	-1.2	-1.020	0.850
CB2OT103	1.50	1	0.760	-1.2	-0.912	0.760
CB2OT104	1.75	1	0.525	-1.2	-0.630	0.525
CB2OT105	3.35	1	0.715	-1.2	-0.858	0.715
CB2VL71	1.08	-1	0.705	-0.92	-0.649	-0.705
CB2VL72	2.22	-1	-0.395	-0.92	0.363	0.395
CB2VL73	2.34	-1	-0.755	-0.92	0.695	0.755
CB2VL74	1.26	-1	0.660	-0.92	-0.607	-0.660
CB2VL112	2.65	-1	0.075	-0.14	-0.011	-0.075
CB2OT106	10	1	-0.955	-1.2	1.146	-0.955
CB2OT107	10	1	-0.880	-1.2	1.056	-0.880

y = Ignition delay
Regression Output:

Constant	2.656
Std Err of Y Est	1.144
R Squared	0.889
No. of Observations	18
Degrees of Freedom	12

X Coefficient(s)	1.395	-1.416	-0.893	1.345	-1.807
Std Err of Coef.	0.315	0.540	0.362	0.429	0.516
t value	4.424	-2.624	-2.465	3.135	-3.503

With 12 degrees of freedom, term is significant at 95% confidence level if t value is greater than 2.179

Table 12. Slurry Fuel Ignition Delay Calculation of Effects.

Eqn: y = 2.66 + 1.40(x0) - 1.42(x1) - 0.89(x3) + 1.34(x1)(x3) - 1.81(x0)(x1)

Going from low normalized Temp. (x1=-1) to high normalized temp. (x1=+1) with Velva Lignite slurry (x0=-1) and low normalized %solids (x3=-1) results in:
change in y = [(-1.42)(x1) + (1.34)(x1)(x3) - (1.81)(x0)(x1)]
-[(-1.42)(x1) + (1.34)(x1)(x3) - (1.81)(x0)(x1)]
change in y = [(-1.42)(+1) + (1.34)(+1)(-1) - (1.81)(-1)(+1)]
-[(-1.42)(-1) + (1.34)(-1)(-1) - (1.81)(-1)(-1)]
= -1.90 milliseconds

Going from low normalized Temp. (x1=-1) to high normalized temp. (x1=+1) with Otisca slurry (x0=+1) and at low normalized %solids (x3=-1) results in:
change in y = [(-1.42)(x1) + (1.34)(x1)(x3) - (1.81)(x0)(x1)]
-[(-1.42)(x1) + (1.34)(x1)(x3) - (1.81)(x0)(x1)]
change in y = [(-1.42)(+1) + (1.34)(+1)(-1) - (1.81)(+1)(+1)]
-[(-1.42)(-1) + (1.34)(-1)(-1) - (1.81)(+1)(-1)]
= -9.14 milliseconds

Going from low normalized Temp. (x1=-1) to high normalized temp. (x1=+1) with Otisca slurry (x0=+1) and at high normalized %solids (x3=+1) results in:
change in y = [(-1.42)(x1) + (1.34)(x1)(x3) - (1.81)(x0)(x1)]
-[(-1.42)(x1) + (1.34)(x1)(x3) - (1.81)(x0)(x1)]
change in y = [(-1.42)(+1) + (1.34)(+1)(+1) - (1.81)(+1)(+1)]
-[(-1.42)(-1) + (1.34)(-1)(+1) - (1.81)(+1)(-1)]
= -3.78 milliseconds

Going from Velva lignite slurry (x0=-1) to Otisca slurry (x0=+1) at lower normalized temperature (x1=-1) results in:
change in y = [(1.40)(x0) - (1.81)(x0)(x1)]-[(1.40)(x0) - (1.81)(x0)(x1)]
change in y = [(1.40)(+1) - (1.81)(+1)(-1)]-[(1.40)(-1) - (1.81)(-1)(-1)]
= 6.42 milliseconds

Going from Velva lignite slurry (x0=-1) to Otisca slurry (x0=+1) at higher normalized temperature (x1=+1) results in:
change in y = [(1.40)(x0) - (1.81)(x0)(x1)]-[(1.40)(x0) - (1.81)(x0)(x1)]
change in y = [(1.40)(+1) - (1.81)(+1)(+1)]-[(1.40)(-1) - (1.81)(-1)(+1)]
= -0.82 milliseconds

Going from low %solids slurry (x3=-1) to high %solids slurry (x3=+1) at lower normalized temperature (x1=-1) results in:
change in y = [(-0.89)(x3) + (1.34)(x1)(x3)]-[(-0.89)(x3) + (1.34)(x1)(x3)]
change in y = [(-0.89)(+1) + (1.34)(-1)(+1)]-[(-0.89)(-1) + (1.34)(-1)(-1)]
= -4.46 milliseconds

Going from low %solids slurry (x3=-1) to high %solids slurry (x3=+1) at higher normalized temperature (x1=+1) results in:
change in y = [(-0.89)(x3) + (1.34)(x1)(x3)]-[(-0.89)(x3) + (1.34)(x1)(x3)]
change in y = [(-0.89)(+1) + (1.34)(+1)(+1)]-[(-0.89)(-1) + (1.34)(+1)(-1)]
= 0.90 milliseconds

the temperature increase. With the Otisca slurry, the decrease was about 3.8 milliseconds with the 55 percent solids slurry and 9.1 milliseconds with the 45 percent solids slurry. Switching from the Velva lignite slurry to the Otisca slurry caused a 6.4 millisecond increase in ignition delay at a bomb temperature of 900°K. However, changing from the Velva lignite to the Otisca slurry caused a decrease in the ignition delay of 0.8 milliseconds at 1300°K. Increasing the slurry percent solids from 45 to 55 percent produced opposite affects at the two temperatures. The ignition delay decreased 4.5 milliseconds at 900°K and increased 0.9 milliseconds at 1300°K.

The analysis of combustion duration for the slurry fuels is presented in Table 13. The slurry type and bomb injection temperature were the only significant factors. Switching from the Velva lignite slurry to the Otisca slurry resulted in a 5.6 millisecond increase in combustion duration. The combustion duration decreased 6.7 milliseconds when the bomb temperature was increased from 900°K to 1300°K.

Summary of Ignition Delay Results

The ignition behavior of the Velva Lignite slurry was very similar to that of the diesel fuel for the range of temperatures and pressures tested. This indicates that ignition and combustion of the lignite slurry can be achieved quickly enough to be used in a diesel engine. Another important finding was the temperature effect on ignition delay

Table 13. Slurry Fuel Combustion Duration Analysis.

Significance testing

Trial	Combustion Duration (millisec) y	Normalized Slurry x0	Normalized Temp x1
CB2OT89	17.57	1	-0.995
CB2OT90	7.69	1	0.77
CB2OT91	13.20	1	0.505
CB2OT93	14.75	1	-1.16
CB2OT94	14.48	1	1.18
CB2OT97	12.03	1	0.185
CB2OT99	7.43	1	0.03
CB2OT102	7.16	1	0.85
CB2OT103	7.91	1	0.76
CB2OT104	10.52	1	0.525
CB2OT105	12.13	1	0.715
CB2VL71	9.55	-1	0.705
CB2VL72	7.93	-1	-0.395
CB2VL73	8.49	-1	-0.755
CB2VL74	5.90	-1	0.66
CB2VL112	4.79	-1	0.075
CB2OT106	20	1	-0.955
CB2OT107	20	1	-0.88

Regression Output:

Constant		10.301
Std Err of Y Est		3.212
R Squared		0.580
No. of Observations		18
Degrees of Freedom		15
X Coefficient(s)	2.775	-3.346
Std Err of Coef.	0.846	1.023
t value	3.050	-3.299

With 15 degrees of freedom, term is significant at 95% confidence level if t value is greater than 2.131

Calculation of Effects

Eqn: $y = 10.30 + 2.78(x0) - 3.35(x1)$

Going from Velva lignite slurry (x0=-1) to Otisca slurry (x0=+1)
change in y = (2.78)(+1)-(2.78)(-1)
= 5.56 milliseconds

Going from low normalized temp (x1=-1) to high normalized temp (x1=-1)
change in y = (-3.35)(+1)-(-3.35)(-1)
= -6.70 milliseconds

when using the Otisca slurry with the delays becoming unacceptable at lower bomb temperatures. The combustion duration results with the Otisca slurry were marginally unacceptable for use in a diesel engine. The reason for better ignition results with the Velva Lignite slurry compared to that of the Otisca slurry are likely due to the higher volatile matter content of the lignite.

Calorimeter Results

Diesel Fuel Results

The calorimeter data from the diesel fuel runs, presented in Table 14, show an average heat release of 979 calories with a standard deviation of 188 calories. The expected heat release with one shot of diesel fuel is 1010 calories. This indicated that relatively complete burnout of the diesel fuel

Table 14. Diesel Fuel Test Conditions and Calorimeter Results.

Trial	Fuel Injection Bomb Conditions Moles (gmol)	Temp (°K)	Pressure (psia)	Heat of Combustion (cal)	Match With Design Run #
CB2DF53	0.129	1322	596	1079	No Match
CB2DF61	0.149	1091	570	NA	5
CB2DF62	0.089	1149	360	1143	No Match
CB2DF63	0.156	1070	584	1070	5
CB2DF65	0.128	927	416	1135	1
CB2DF67	0.177	1283	792	1121	4
CB2DF68	0.255	1030	918	721	No Match
CB2DF69	0.156	1139	620	1127	5
CB3DF75	0.088	1212	375	938	2
CB3DF85	0.244	935	797	789	3
CB3DF86	0.156	1169	636	1071	5
CB2DF114	0.088	1267	390	571	2

in the bomb was occurring. Variations in the calorimeter data can be partially attributed to variations in the mass of fuel injected with one shot of fuel from the fuel injector.

An analysis of the effects of pressure and temperature on the heat of combustion for diesel fuel are shown in Table 15. The results indicate that neither bomb temperature or pressure had a significant effect on the heat of combustion when testing with the diesel fuel. However, the interaction of temperature with pressure was found to be significant. Increasing the bomb temperature from 900°K to 1300°K at 400 psia resulted in a decrease in the heat of reaction, while there was an increase in the heat of reaction at 800 psia.

Slurry Fuel Tests

The calorimeter results from the Otisca slurry testing are shown in Table 16. While some of the runs resulted in approximately the expected heat release from the slurry combustion, in other runs lower heat releases were measured indicating incomplete fuel combustion or only partial fuel injection. Because there was a time lag from the time the fuel injector was prepared for a test until injection for the run took place, there may have been a problem with getting a full fuel shot in some of the slurry runs. Moreover, the walls of the combustion bomb may not have been hot enough for combustion of any slurry impacting them, so only a portion of the injected slurry actually burned.

Table 15. Diesel Fuel Heat of Combustion Analysis.

Significance Test

Trial	Heat of Combustion (cal) y	Normalized Temp x1	Normalized Pressure x2	(x1)(x2)
CB2DF53	1079	1.11	-0.02	-0.022
CB2DF62	1143	0.245	-1.2	-0.294
CB2DF63	1070	-0.15	-0.08	0.012
CB2DF65	1135	-0.865	-0.92	0.796
CB2DF67	1121	0.915	0.96	0.878
CB2DF68	721	-0.35	1.59	-0.557
CB2DF69	1127	0.195	0.1	0.020
CB3DF75	938	0.56	-1.125	-0.630
CB3DF85	789	-0.825	0.985	-0.813
CB3DF86	1071	0.345	0.18	0.062
CB2DF114	571	0.835	-1.05	-0.877

Regression Output:

Constant		1010.383	
Std Err of Y Est		143.620	
R Squared		0.631	
No. of Observations		11	
Degrees of Freedom		7	
X Coefficient(s)	-0.449	-43.571	262.291
Std Err of Coef.	69.214	48.783	77.546
t value	-0.006	-0.893	3.382

With 7 degrees of freedom, term is significant
at 95% confidence level if t value is greater than 2.365

Calculation of Effects

Eqn: $y = 1010 - (0.4)(x1) - (44)(x2) + (262)(x1)(x2)$

Going from low normalized temp (x1=-1) to high normalized temp (x1=+1)
at low normalized pressure (x2=-1) results in:

change in y = [-(0.4)(x1)+(262)(x1)(x2)]-[-(0.4)(x1)+(262)(x1)(x2)

change in y = [-(0.4)(+1)+(262)(+1)(-1)]-[-(0.4)(-1)+(262)(-1)(-1)

= -525 calories

Going from low normalized temp (x1=-1) to high normalized temp (x1=+1)
at high normalized pressure (x2=+1) results in:

change in y = [-(0.4)(x1)+(262)(x1)(x2)]-[-(0.4)(x1)+(262)(x1)(x2)

change in y = [-(0.4)(+1)+(262)(+1)(+1)]-[-(0.4)(-1)+(262)(-1)(+1)

= 523 calories

Table 16. Otisca Slurry Test Conditions and Calorimeter Results.

Trial	Slurry % Solids (%)	Fuel Injection Bomb Conditions Moles (gmol)	Temp (°K)	Pressure (psia)	Heat of Combustion (cal)	Design Run Match
CB2OT89	53.4	0.129	901	406	65	5
CB2OT90	53.4	0.177	1254	775	219	8
CB2OT91	53.4	0.089	1204	374	599	6
CB2OT93	53.4	0.254	868	772	NA	7
CB2OT94	53.4	0.089	1336	415	595	6
CB2OT97	49.4	0.158	1127	624	670	9
CB2OT99	49.4	0.156	1106	603	422	9
CB2OT102	44.0	0.087	1272	387	423	2
CB2OT103	44.0	0.177	1256	777	-17	4
CB2OT104	44.0	0.085	1213	360	712	2
CB2OT105	44.0	0.177	1243	770	545	4
CB2OT106	44.0	0.255	909	808	-12	3
CB2OT107	44.0	0.126	924	407	-90	1

There was also a wide variation in the calorimeter results with the Velva lignite slurry. In general, lower than expected heat release was recorded with the Velva Lignite slurry. As with the Otisca slurry, this is likely due to impingement of the slurry on the walls of the bomb and incomplete fuel combustion or less mass than expected injected with a shot of slurry. The test conditions and calorimeter results for the Velva Lignite slurry testing are shown in Table 17.

Table 17. Velva Lignite Slurry Test Conditions and Calorimeter Results.

Trial	Slurry % Solids (%)	Fuel Injection Bomb Conditions Moles (gmol)	Temp (°K)	Pressure (psia)	Heat of Combustion (cal)	Design Run Match
CB2VL71	45.4	0.088	1240	383	514	2
CB2VL72	45.4	0.255	1022	910	51	3
CB2VL73	45.4	0.128	949	423	290	1
CB2VL74	45.4	0.176	1146	708	26	4
CB2VL76	55.4	0.176	No Fuel Injection		NA	No Match
CB2VL77	55.4	0.176	No Fuel Injection		NA	No Match
CB2VL78	55.4	0.176	No Fuel Injection		NA	No Match
CB2VL79	55.4	0.088	No Fuel Injection		NA	No Match
CB2VL112	49.3	0.156	1116	609	-28	5

A statistical analysis of the calorimeter data is shown in Table 18. Only the effect of temperature was significant when analyzing these data. In one of the low temperature Otisca slurry runs the calorimeter data was not available, and in the other three runs at the low temperature (two in which ignition did not occur) heat releases of near zero were recorded. Consequently, a significant effect of temperature was found with greater heat output at the higher temperature condition.

Summary of Calorimeter Results

The calorimeter results with the diesel fuel indicate that relatively consistent and complete injection and combustion of the fuel was obtained. The calorimeter results with both slurry fuels were inconsistent with many of the runs producing a lower than expected heat of combustion. This is

Table 18. Slurry Fuel Heat of Combustion Analysis.

Significance Test

Trial	Heat of Combustion (cal) y	Normalized Temp x1
CB2OT89	65	-0.995
CB2OT90	219	0.77
CB2OT91	599	0.52
CB2OT94	595	1.18
CB2OT97	670	0.135
CB2OT99	422	0.03
CB2OT102	423	0.86
CB2OT103	-17	0.78
CB2OT104	712	0.565
CB2OT105	545	0.715
CB2OT106	-12	-0.955
CB2OT107	-90	-0.88
CB2VL71	514	0.7
CB2VL72	51	-0.39
CB2VL73	290	-0.755
CB2VL74	26	0.23
CB2VL112	-28	0.08

Regression Output:

Constant		258.561
Std Err of Y Est		239.620
R Squared		0.324
No. of Observations		17
Degrees of Freedom		15
X Coefficient(s)	227.208	
Std Err of Coef.	84.684	
t value	2.683	

With 15 degrees of freedom, term is significant at 95% confidence interval if t value is greater than 2.131

Calculation of Effects

Eqn: $y = 259 + 227(x1)$

Going from low normalized temp. (x1=-1) to high normalized temp. (x1=+1)

change in $y = (227)(+1) - (227)(-1)$

$= 454$ calories

likely because of incomplete fuel burnout due to wall impingement of the slurry or because of lower than expected slurry injection with a shot of fuel. The walls of the combustion bomb may not have been hot enough for combustion of any slurry impacting them, even though they were hot enough to burn any diesel fuel that impacted them. Because there was a time lag from the time the fuel injector was prepared for a test until injection for the run took place, there may have been a problem with getting a full fuel shot in some of the slurry runs.

CHAPTER V. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In general, the results indicate that if acceptable injection of a coal water slurry prepared from a lignite coal is achieved, adequate ignition and burnout of the fuel can be obtained under diesel engine conditions. In looking at the ignition delay results, the lignite slurry provided faster ignition and behaved more like the diesel fuel than did the bituminous slurry under the conditions tested. These tests indicate that there is a minimum cylinder temperature required for use of these slurry fuels and this temperature is fuel dependent. Therefore, some care must be taken to ensure that the fuel chosen for such an application will ignite and burn out at the expected engine cylinder temperature. More specific conclusions from this study are discussed below.

Baseline testing with diesel fuel showed:

1. No significant problems with the fuel injection system were encountered when running with diesel fuel.
2. Consistent combustion of the diesel fuel in the simulated diesel engine cylinder was achieved.

3. Ignition delays were all between 1 and 2 milliseconds over the range of bomb injection temperatures (900 to 1300°K) and pressures (360 to 900 psia) tested.
4. The time required to obtain complete combustion of the diesel fuel was generally between 8 and 11 milliseconds.
5. The average heat of combustion was 979 calories for one shot of fuel. The expected heat of combustion for one shot of 0.0913 grams of the diesel fuel is 1010 calories, which agrees well with the heat measured.

Results from testing with the bituminous coal-water slurry supplied by Otisca Labs showed:

1. Only minor problems with the fuel injection system were experienced.
2. The bomb temperature at the time of fuel injection had a significant effect on fuel combustion and ignition delay. At a slurry solids concentration of 44.0%, the injected slurry did not ignite at a bomb temperature of 900°F. At a slurry solids concentration of 53.4%, the ignition delay was significantly longer with fuel injected at a bomb temperature of 900°F than at higher temperatures. The ignition delays were unacceptable under these conditions.
3. Acceptable ignition delays were recorded at solids loadings between 44.0 and 53.4%, bomb temperatures between 1100 and 1300°F, and bomb pressures between 350

and 800 psia. Ignition delays under these conditions generally ranged from 1 to 3 milliseconds.

4. The combustion duration ranged from 7 to 15 milliseconds.
5. Consistent calorimeter results were not obtained when testing with the Otisca slurry. The variations are likely due to variations in the mass of fuel injected with a pulse of the fuel pump or incomplete fuel burnout due to impingement of the slurry on the combustion bomb walls.

Results from testing the Velva lignite coal-water slurry were:

1. Adequate fuel injection was not achieved at a slurry solids concentration of 55.4%. Four runs were attempted at this solids loading with all resulting in the fuel injector plugging. Successful injection at solids loading of about 50% was observed in only one of four tries. The increased problems with injection of the Velva lignite slurry may be due to the larger particle size distribution (when compared to the Otisca slurry) of this slurry.
2. Slurry injection adequate to achieve fuel combustion was observed with a solids concentration of 45.4%. However, the calorimeter data indicates that a consistent mass of slurry spray may not have been injected or there was not total burnout of the slurry in some cases.
3. With the 45.4% solids Velva lignite slurry, the ignition delay was not significantly affected by the bomb pressure

and temperature over the range of conditions tested. In all runs the ignition delays were about the same as was found for diesel fuel, and all were acceptable.

4. The combustion duration results were all less than 10 milliseconds.
5. As with the Otisca slurry testing, consistent calorimeter results were not obtained when testing with the Velva lignite slurry. The variations are likely due to variations in the mass of fuel injected with a pulse of the fuel pump or incomplete burnout of the fuel. Therefore, the results did not give a definitive indication of fuel burnout.

Recommendations

This study was intended as the initial step in determining the suitability of a specific coal-water slurry and coal-water slurries in general for use in a diesel engine. Numerous steps would need to be taken before the ultimate goal of successfully using a coal-water slurry in a diesel engine is achieved. The probable next step is to test a slurry in a continuous diesel test facility for a short period. Some recommendations for further testing or ways to make using coal slurries in a diesel engine more attractive are discussed below:

1. Increase the fuel injector tolerances to allow for easier use of slurry fuels and to reduce plugging of the injector.
2. Try a finer grind of lignite slurry to make the injection of a higher percent solids slurry easier.
3. The lignite slurry should be tested over a wider range of conditions to determine where decreasing the temperature results in unacceptable ignition delay.
4. The lignite slurry showed acceptable ignition properties, but using a coal-methanol slurry rather than a coal-water slurry may be a better option if greater energy is required.
5. With a bituminous slurry, a method of enhancing ignition and combustion of the fuel may be required. Using methanol as the slurry fluid rather than water, or using a glow plug in the engine cylinder, are possibilities.

APPENDICES

Appendix A - Notation

a_1 First coefficient in Equation 1.

b_1 Second coefficient in Equation 1.

t_o Time at break point of data in regression analysis.

P pressure.

P_o Pressure at time t_o.

b_2 First coefficient in Equation 2.

c_2 Second coefficient in Equation 2.

t_c Time at complete fuel combustion.

x_0 Normalized slurry type.

x_1 Normalized temperature.

x_2 Normalized pressure.

x_3 Normalized slurry percent solids.

Appendix B - Data Reduction Procedure

A personal computer-based data acquisition system was used in this study. A program written in QuickBASIC™ was used to control the sequences of the experiments and to record and store the data. The data acquisition system produced relatively large computer PRINT files which included time, bomb pressure, and fuel line pressure for each test run. The data were generally recorded every 0.10 or 0.12 milliseconds.

A raw data print file was imported into a Lotus 1-2-3® spreadsheet for data reduction. The important run data not recorded in the print file were added to the spreadsheet. This information included the initial concentration of the $H_2/O_2/N_2$ gas charge and the initial bomb pressure and temperature. This was needed to calculate the moles of gas in the bomb and the bomb temperature at the time of fuel injection. The bomb temperature was calculated using the volume of the bomb, the moles of gas in the bomb and the measured pressure of the bomb. The ideal gas law was used in this calculation.

The bomb pressure data were the focus of the data reduction procedure. These data were used to determine time of fuel ignition and the duration of the combustion event.

Using this information in conjunction with the fuel line pressure trace, allowed the ignition delay and the duration of the combustion event to be calculated.

The fuel line pressure trace was used to determine the time of fuel injection. The fuel line pressure would increase as the fuel pump was activated. With the increase in pressure the pintle in the fuel injector was forced open spraying a shot of fuel into the combustion bomb. Opening the pintle nozzle relieves the pressure in the fuel line and this is seen in the fuel line pressure trace. The time of fuel injection was determined as the moment the fuel line pressure began to decrease after the increase in pressure associated with activation of the fuel pump. The fuel injector pintle generally opened at a fuel line pressure of about 6000 psia. Fuel line pressure will affect the atomization quality of the fuel spray and the combustion qualities of the fuel. Fuel line pressure was not a variable in this study. The fuel injector was used as purchased, and no adjustments were made throughout the study. The injection pressure was relatively high and adequate for reasonable spray atomization.

The time of ignition and degree of fuel combustion were determined using the bomb pressure trace. The bomb pressure increased rapidly with combustion of the initial gas charge. The extent of this increase depended on the concentration of H_2 in the gas charge and its pressure. After the initial pressure rise with combustion of the gas charge, the bomb pressure would slowly decrease because of cooling of the bomb. Upon injection and ignition of the test fuel the pressure rose fairly rapidly. After combustion of the fuel was complete, the pressure again began to decrease slowly. A FOR-NEXT loop in the DAS program determined the elapsed time between the ignition of the gas charge and injection of the fuel. This FOR-NEXT loop, along with the conditions of the initial gas charge, was used to obtain the appropriate pressure and temperature injection conditions.

The time of fuel ignition and duration of combustion were determined statistically. The focus of the data reduction was on a segment of the data beginning prior to the injection of the fuel and ending after combustion of the fuel is complete. This segment of data is systematically broken into two subsets at a time, t_0. The first subset was fit by the equation, pressure = $a_1 + b_1$(time). Using this equation a pressure, p_0, was calculated at t_0. The second subset of data was fit using the equation, $(\text{pressure}-p_0)=b_2(\text{time}-t_0)+c_2(\text{time}-t_0)^2$. The sum of squares was calculated for each curve fit and the total sum of squares of the two combined was determined. This was done over a range of time clearly covering the ignition of the fuel. The time, t_0, which resulted in the lowest sum of squares from this procedure was taken as the time of ignition of the fuel. Using this time and the fuel injection time determined from the fuel line pressure trace, an ignition delay was calculated.

The equation from the second subset of data (the pressure change due to combustion of the fuel) was used to determine the time when combustion was complete. When the first derivative of this equation equaled 0, the curve was at a maximum and the pressure had begun to flatten out indicating that combustion was no longer going on. The following equations illustrate the application of this approach to these results. Because the second equation is of the form:

$$(p-p_0) = b_2(t-t_0) + c_2(t-t_0)^2.$$

The first derivative of this equation set to 0 is represented by the following equation:

$$d(p-p_0)/dt = d[b_2(t-t_0) + c_2(t-t_0)^2]/dt = b_2 + 2c_2(t-t_0).$$

At $t = t_c$ (the time at which the curve is a maximum), the derivative equals zero. Solving for t_c gives us:

$$t_c = [-b_2/(2c_2)] + t_0$$

Because b, c, and t_0 are known for each regression, t_c can be easily calculated.

A confidence interval(5) on the time of ignition for each run was determined for the 95% confidence level. This was done using the total sum of squares calculated at each of the different break point times. The following equation was used to determine the sum of squares at the 95% confidence interval.

$$S_{95\%} = S_{ti}(1 + t_v^2(0.025)/v)$$

Where: $S_{95\%}$ = The sum of squares at the 95% confidence interval.
S_{ti} = Sum of Squares at time of ignition.

t_v = t value at 95% confidence level and one degree of freedom = 12.706

v = degrees of freedom from the ignition time calculation.

The times, before and after the ignition time when the sum of squares equaled this value were the lower and upper times for the 95% confidence interval. Table 19 shows the ignition time 95% confidence interval for each run. Plots of these confidence intervals for the individual runs are shown in Figures 33 through 60.

The ignition time calculations for all of the test runs are shown in Tables 20 through 46. A table showing the results from Test CB2DF53 was included in Chapter IV and is not included in this Appendix. After determining the time of ignition for a test run, the pressure at the time of fuel injection was calculated using the linear equation (in time) for the first subset of data and with the injection time as the time. The injection temperature was than calculated using this pressure and the ideal gas law. Also included in these tables are the range of data included in the regression analysis.

Table 19. Ignition Time 95% Confidence Intervals.

Test Run #	Ignition Time (millisec)	95% Confidence Interval Time- (millisec)	Time+ (millisec)	Interval (millisec)
CB2DF53	137.10	136.91	137.18	0.27
CB2DF61	190.54	190.39	190.68	0.29
CB2DF62	124.14	123.80	124.32	0.52
CB2DF63	202.42	202.21	202.64	0.43
CB2DF65	432.50	432.21	432.70	0.49
CB2DF67	104.22	104.01	104.45	0.44
CB2DF68	437.06	436.99	437.18	0.19
CB2DF69	182.92	182.82	183.07	0.25
CB3DF75	94.50	94.22	94.68	0.46
CB3DF85	438.62	438.38	438.76	0.38
CB3DF86	182.26	182.04	182.39	0.35
CB2DF114	125.05	124.75	125.25	0.50
			Average =	0.38
CB2OT89	541.85	541.20	542.46	1.26
CB2OT90	134.85	134.13	135.03	0.90
CB2OT91	127.65	127.10	128.09	0.99
CB2OT93	915.54	914.67	916.23	1.56
CB2OT94	92.35	92.03	92.61	0.58
CB2OT97	232.95	232.58	233.31	0.73
CB2OT99	237.05	236.63	237.38	0.75
CB2OT102	116.15	115.22	116.93	1.71
CB2OT103	120.75	119.82	121.44	1.62
CB2OT104	116.25	115.86	116.59	0.73
CB2OT105	126.05	125.52	126.87	1.35
			Average =	1.11
CB2VL71	99.66	99.50	99.87	0.37
CB2VL72	438.14	437.55	438.60	1.05
CB2VL73	433.46	433.21	433.71	0.50
CB2VL74	126.66	125.98	127.44	1.46
CB2VL112	229.55	229.28	229.77	0.49
			Average =	0.77

Table 20. Diesel Fuel Test CB2DF61 Data Reduction Results.

First data set minimum time = 118.8 milliseconds.
Second data set maximum time = 194.8 milliseconds.

Injection Time = 188.68 millisec
Injection Press = 570 psia
Injection Temp = 1091 °K

Ignition Time = 190.54 millisec

Ignition Delay = 1.86 millisec
Comb. Duration = 5.29 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
189.22	57177	12254	69432	1088	568	737	-0.891	26.1	2.415	183.81
189.34	57190	11817	69008	1088	568	737	-0.890	29.8	1.834	181.21
189.46	57748	10766	68513	1088	568	736	-0.887	33.8	1.163	174.93
189.58	57822	10069	67891	1088	568	736	-0.885	38.3	0.344	134.03
189.7	57897	9328	67224	1088	568	736	-0.884	43.1	-0.611	225.01
189.82	57972	8567	66540	1088	568	736	-0.883	48.4	-1.719	203.90
189.94	58323	7494	65817	1088	568	735	-0.880	54.1	-3.001	198.96
190.06	58883	6088	64972	1088	568	735	-0.877	60.4	-4.511	196.76
190.18	59070	4972	64042	1088	568	735	-0.875	67.4	-6.299	195.53
190.3	59145	4061	63206	1088	568	734	-0.874	75.1	-8.367	194.79
190.42	59222	3410	62632	1088	568	734	-0.872	83.3	-10.724	194.30
190.54	59652	2704	62356	1088	568	734	-0.870	92.0	-13.400	193.97
190.66	59697	2882	62579	1088	568	734	-0.869	101.5	-16.456	193.74
190.78	60361	3126	63486	1088	568	733	-0.865	111.4	-19.856	193.59
190.9	60789	4393	65182	1088	568	733	-0.862	122.0	-23.694	193.47
191.02	62603	5099	67702	1088	568	732	-0.856	133.0	-27.978	193.40
191.14	63721	7470	71191	1088	569	731	-0.852	144.8	-32.837	193.34
191.26	65956	9956	75913	1089	569	730	-0.845	157.1	-38.222	193.31
191.38	70054	11621	81675	1089	569	729	-0.836	170.0	-44.278	193.30
191.5	72729	16097	88826	1090	569	728	-0.829	183.6	-51.106	193.30
191.62	78119	19444	97563	1091	570	727	-0.819	197.5	-58.583	193.31
191.74	83453	24477	107930	1091	570	725	-0.810	211.9	-66.852	193.32

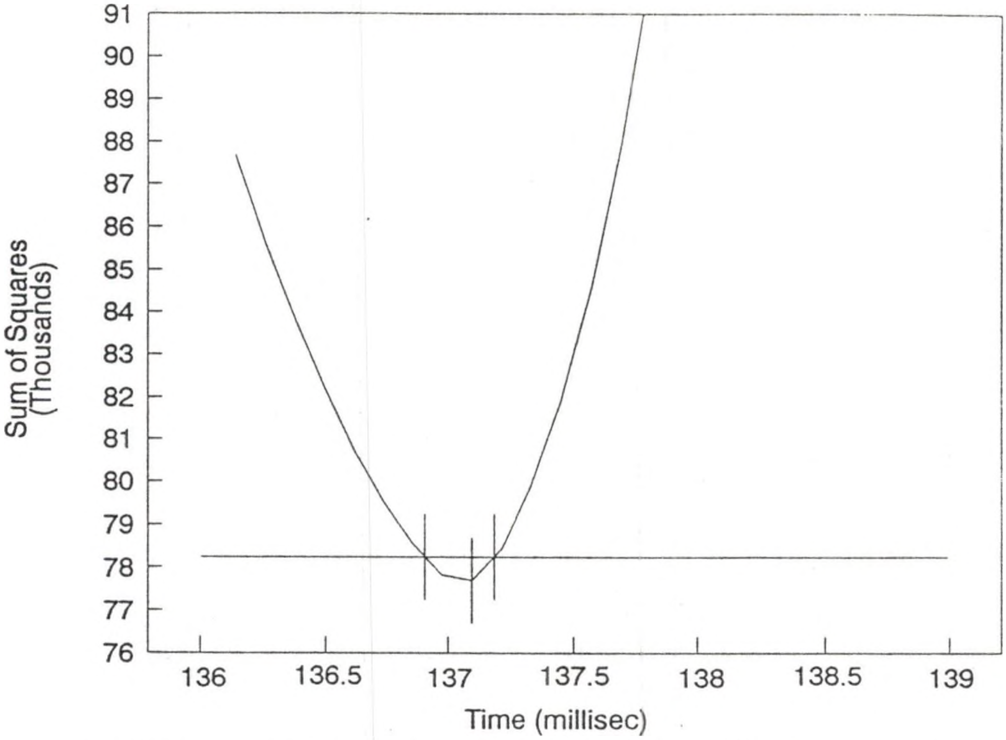

Figure 33. Diesel Fuel Test CB2DF53 Ignition Time Confidence Interval

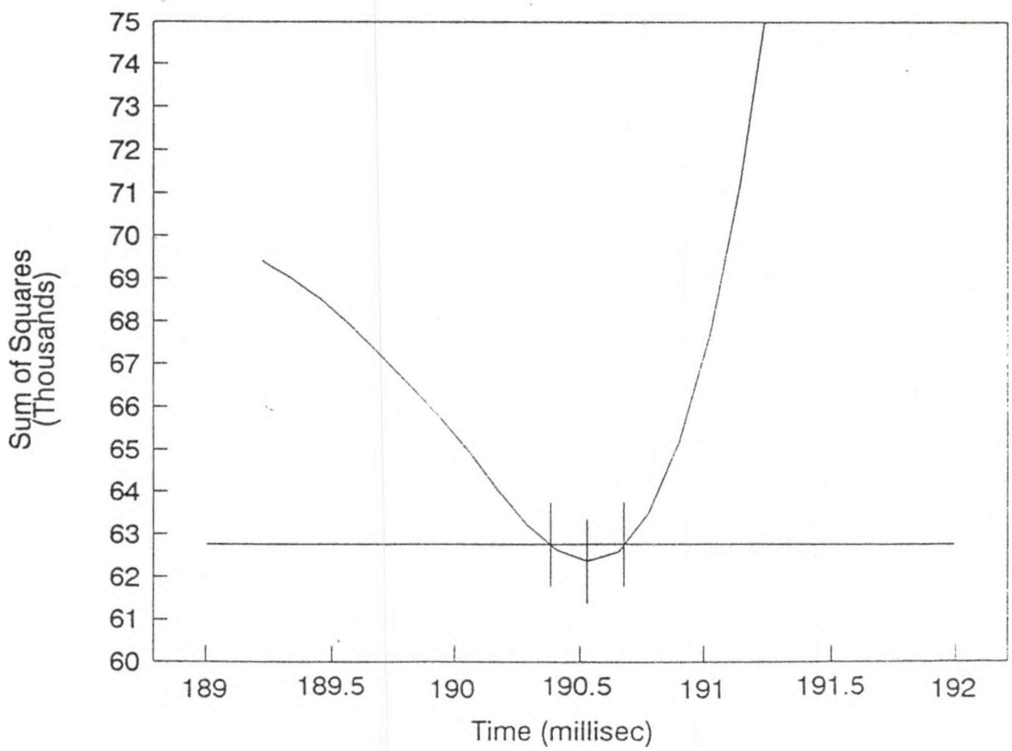

Figure 34. Diesel Fuel Test CB2DF61 Ignition Time Confidence Interval

Table 21. Diesel Fuel Test CB2DF62 Data Reduction Results.

First data set mimimum time = 90 milliseconds.
Second data set maximum time = 130.08 milliseconds.

Injection Time = 123.00 millisec
Injection Press = 360 psia
Injection Temp = 1149 °K

Ignition Time = 124.14 millisec

Ignition Delay = 1.14 millisec
Comb. Duration = 9.26 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
122.70	42123	14591	56714	1149	359	473	-0.925	14.6	0.871	114.32
122.82	42147	14150	56297	1148	359	473	-0.928	16.1	0.717	111.62
122.94	42551	13365	55916	1149	359	472	-0.915	17.4	0.569	107.65
123.06	42560	12864	55424	1149	359	472	-0.913	19.0	0.386	98.43
123.18	42570	12344	54913	1148	359	472	-0.911	20.7	0.183	66.75
123.30	42741	11654	54395	1149	359	471	-0.903	22.4	-0.032	476.92
123.42	42764	11049	53814	1148	359	471	-0.906	24.3	-0.288	165.66
123.54	42869	10416	53285	1148	359	470	-0.899	26.2	-0.551	147.30
123.66	43055	9711	52766	1147	359	471	-0.908	28.4	-0.864	140.08
123.78	43359	9013	52372	1148	359	470	-0.897	30.4	-1.168	136.80
123.90	43361	8628	51989	1147	359	470	-0.898	32.7	-1.524	134.63
124.02	43374	8372	51746	1147	359	470	-0.896	35.1	-1.902	133.24
124.14	43386	8266	51653	1147	359	470	-0.893	37.5	-2.309	132.26
124.26	43650	8226	51876	1146	359	471	-0.903	40.2	-2.766	131.52
124.38	43769	8651	52420	1146	359	470	-0.897	42.7	-3.209	131.03
124.50	43890	9518	53407	1145	358	471	-0.903	45.4	-3.705	130.62
124.62	44089	10702	54791	1145	358	470	-0.895	47.9	-4.184	130.34
124.74	44761	11675	56436	1146	359	468	-0.879	50.3	-4.673	130.13
124.86	45076	13384	58460	1147	359	467	-0.869	52.9	-5.204	129.95
124.98	48030	12488	60517	1149	359	464	-0.837	55.3	-5.714	129.81
125.10	50705	11880	62585	1151	360	461	-0.807	57.8	-6.292	129.69
125.22	53850	10772	64622	1153	361	458	-0.774	60.5	-6.933	129.58
125.34	55919	10821	66740	1154	361	455	-0.748	63.5	-7.671	129.48
125.46	56453	12825	69278	1155	361	454	-0.735	66.9	-8.513	129.39

Table 22. Diesel Fuel CB2DF63 Data Reduction Results.

First data set minimum Time = 180.04 Milliseconds.
Second data set maximum Time = 205.96 milliseconds.

Injection Time = 200.98 millisec
Injection press = 584 psia
Injection Temp = 1070 °K

Ignition Time = 202.42 millisec

Ignition Delay = 1.44 millisec
Comb. Duration = 9.55 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
201.10	24041	16448	40489	1068	583	757	-0.868	21.2	1.408	193.56
201.22	24057	15654	39710	1068	583	756	-0.862	23.4	1.164	191.17
201.34	24249	14661	38910	1068	583	752	-0.840	25.6	0.906	187.22
201.46	24259	13679	37938	1068	583	753	-0.844	28.2	0.588	177.52
201.58	24450	12570	37020	1068	583	749	-0.823	30.6	0.264	143.56
201.70	24526	11456	35982	1069	583	746	-0.810	33.3	-0.110	353.94
201.82	24593	10275	34868	1068	583	749	-0.822	36.4	-0.553	234.76
201.94	25113	8827	33940	1067	582	755	-0.856	39.9	-1.059	220.77
202.06	25115	8262	33377	1067	582	754	-0.854	43.1	-1.553	215.93
202.18	26094	6815	32909	1068	582	746	-0.808	46.0	-2.037	213.47
202.30	26174	6230	32404	1068	583	743	-0.795	49.5	-2.625	211.72
202.42	26175	5967	32142	1068	583	743	-0.794	53.2	-3.283	210.53
202.54	26176	6118	32294	1068	582	743	-0.792	57.1	-3.990	209.70
202.66	26612	6177	32789	1068	583	737	-0.763	60.8	-4.706	209.12
202.78	27538	5937	33475	1069	583	729	-0.721	64.6	-5.470	208.69
202.90	27764	6764	34528	1070	584	726	-0.700	68.8	-6.343	208.33
203.02	28476	7531	36007	1071	584	719	-0.663	73.0	-7.255	208.05
203.14	30162	7585	37746	1072	585	708	-0.608	77.2	-8.214	207.84
203.26	30969	8963	39931	1073	585	701	-0.570	81.8	-9.301	207.66
203.38	31293	11647	42939	1074	586	697	-0.546	86.7	-10.494	207.51
203.50	32851	13761	46612	1075	586	687	-0.495	91.3	-11.696	207.41
203.62	37136	13343	50479	1077	588	671	-0.410	95.8	-12.924	207.32
203.74	40416	14254	54669	1079	589	657	-0.336	100.6	-14.317	207.25
203.86	42290	17309	59599	1081	590	647	-0.282	105.9	-15.881	207.20

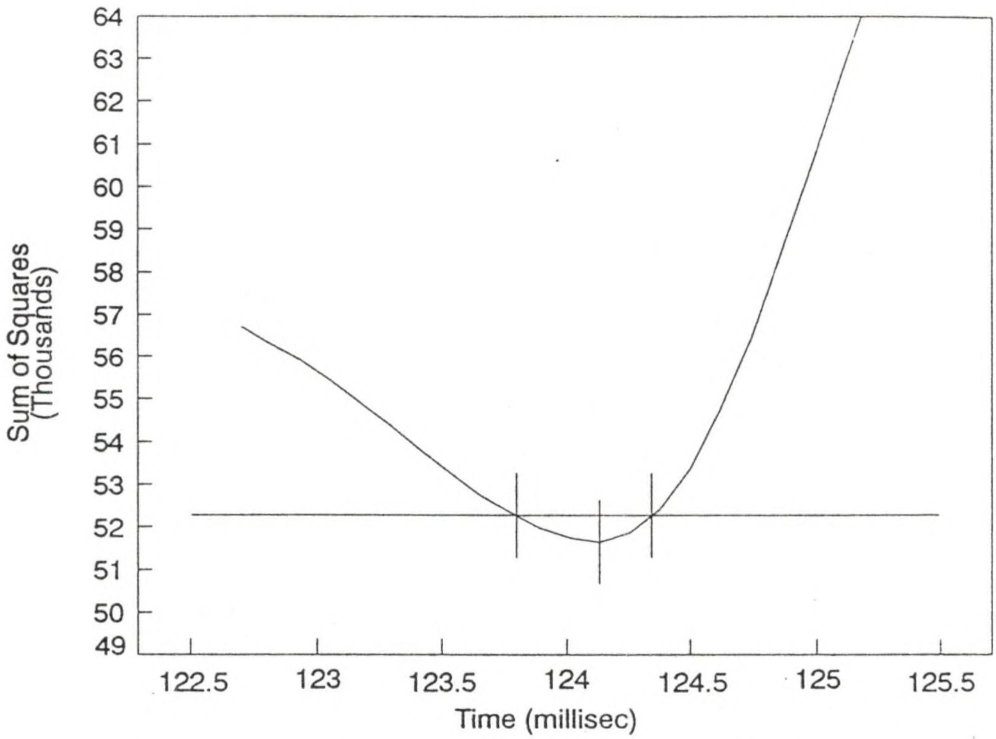

Figure 35. Diesel Fuel Test CB2DF62 Ignition Time 95% Confidence Interval

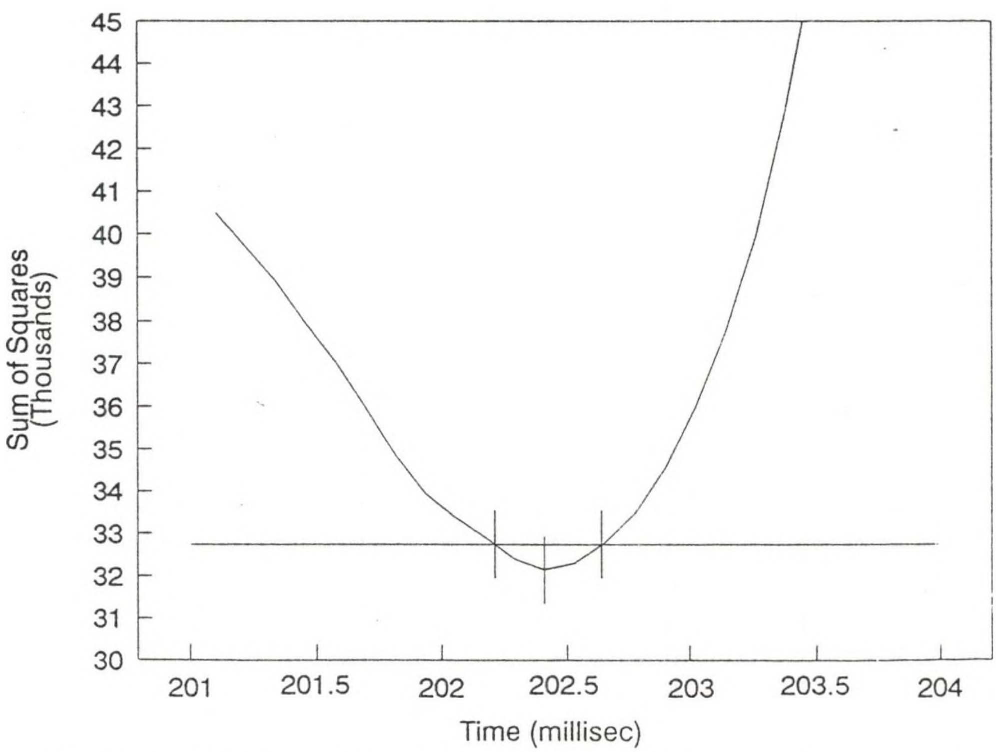

Figure 36. Diesel Fuel Test CB2DF63 Ignition Time 95% Confidence Interval

Table 23. Diesel Fuel Test CB2DF65 Data Reduction Results.

First data set minimum time = 380 milliseconds.
Second data set maximum time = 435.08 milliseconds.

Injection Time = 431.24 millisec
Injection Press = 416 psia
Injection Temp = 927 °K

Ignition Time = 432.50 millisec

Ignition Delay = 1.26 millisec
Comb. Duration = 9.97 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
431.30	62110	20529	82639	927	416	515	-0.230	26.8	-0.241	486.88
431.42	62117	19077	81194	926	416	516	-0.231	28.5	-0.422	465.20
431.54	62419	17378	79797	927	416	514	-0.226	30.2	-0.609	456.35
431.66	62426	15881	78307	927	416	514	-0.227	32.0	-0.818	451.24
431.78	62584	14336	76920	926	416	515	-0.230	34.0	-1.045	448.04
431.90	62590	13156	75746	926	416	516	-0.231	36.0	-1.281	445.93
432.02	62797	11997	74794	926	416	517	-0.234	38.0	-1.536	444.40
432.14	63108	10990	74098	926	416	515	-0.230	40.0	-1.790	443.32
432.26	63165	10361	73526	926	416	514	-0.228	42.1	-2.067	442.45
432.38	63221	9967	73188	926	416	514	-0.226	44.3	-2.361	441.76
432.50	63598	9479	73077	927	416	512	-0.221	46.5	-2.668	441.21
432.62	63604	9672	73276	927	416	511	-0.220	48.8	-3.002	440.75
432.74	63755	10140	73895	927	416	510	-0.217	51.2	-3.349	440.38
432.86	63840	11143	74983	927	416	509	-0.215	53.6	-3.716	440.07
432.98	63892	12777	76669	927	416	508	-0.213	56.1	-4.101	439.82
433.10	65188	13585	78774	928	417	505	-0.204	58.5	-4.489	439.61
433.22	66464	14772	81236	928	417	501	-0.194	61.0	-4.902	439.44
433.34	68522	15490	84012	929	417	497	-0.183	63.5	-5.335	439.29
433.46	70546	16576	87122	930	418	492	-0.172	66.1	-5.799	439.16
433.58	72116	18581	90697	931	418	488	-0.162	68.8	-6.295	439.05
433.70	72531	22577	95108	931	418	486	-0.157	71.7	-6.828	438.95
433.82	73382	27074	100456	932	418	483	-0.149	74.6	-7.373	438.88
433.94	75485	31099	106584	933	419	479	-0.138	77.3	-7.927	438.82

Table 24. Diesel Fuel Test CB2DF67 Data Reduction Results.

First data set minimum time = 90 milliseconds.
Second data set maximum time = 109.92 milliseconds.

Injection Time = 102.84 millisec
Injection Press = 793 psia
Injection Temp = 1284 °K

Ignition Time = 104.22 millisec

Ignition Delay = 1.38 millisec
Comb. Duration = 10.17 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
102.78	19453	20034	39488	1283	792	958	-1.614	18.90	1.790	97.50
102.90	19770	18506	38276	1281	791	965	-1.691	21.49	1.514	95.80
103.02	19872	17341	37213	1280	791	969	-1.734	24.02	1.233	93.28
103.14	19872	16404	36275	1280	790	969	-1.733	26.46	0.952	89.23
103.26	19878	15464	35342	1280	790	968	-1.723	28.99	0.646	80.83
103.38	19934	14494	34428	1280	790	965	-1.693	31.55	0.322	54.33
103.50	19940	13505	33445	1279	790	966	-1.702	34.46	-0.064	370.96
103.62	19941	12637	32578	1279	790	966	-1.699	37.45	-0.477	142.89
103.74	19976	11858	31834	1279	790	964	-1.676	40.47	-0.913	125.90
103.86	20193	10993	31186	1280	790	959	-1.621	43.46	-1.366	119.77
103.98	20349	10224	30574	1280	790	954	-1.575	46.66	-1.873	116.43
104.10	20551	9503	30054	1281	791	949	-1.524	50.01	-2.426	114.41
104.22	20601	9092	29692	1281	791	947	-1.499	53.70	-3.056	113.01
104.34	20877	8978	29855	1279	790	953	-1.557	58.06	-3.811	111.96
104.46	21474	8984	30458	1280	791	945	-1.473	61.58	-4.471	111.35
104.58	22190	9086	31276	1282	791	936	-1.382	65.22	-5.185	110.87
104.70	24194	7931	32125	1284	793	922	-1.233	68.64	-5.905	110.51
104.82	25532	7523	33055	1285	794	910	-1.113	72.51	-6.741	110.20
104.94	26193	8107	34300	1287	794	903	-1.030	76.87	-7.704	109.93
105.06	26423	9779	36202	1287	795	898	-0.982	81.66	-8.789	109.71
105.18	26589	12461	39050	1288	795	894	-0.942	86.62	-9.948	109.53
105.30	27336	15395	42731	1289	796	886	-0.857	91.26	-11.104	109.41
105.42	29388	17549	46937	1291	797	873	-0.720	95.54	-12.246	109.32

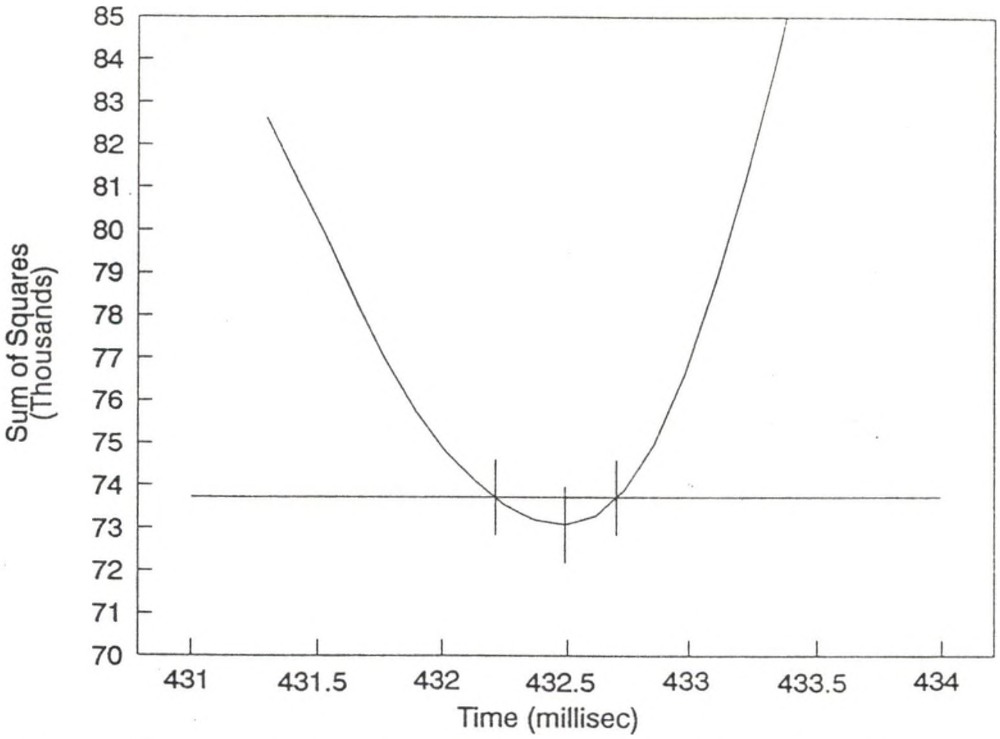

Figure 37. Diesel Fuel Test CB2DF65 Ignition Time 95% Confidence Interval

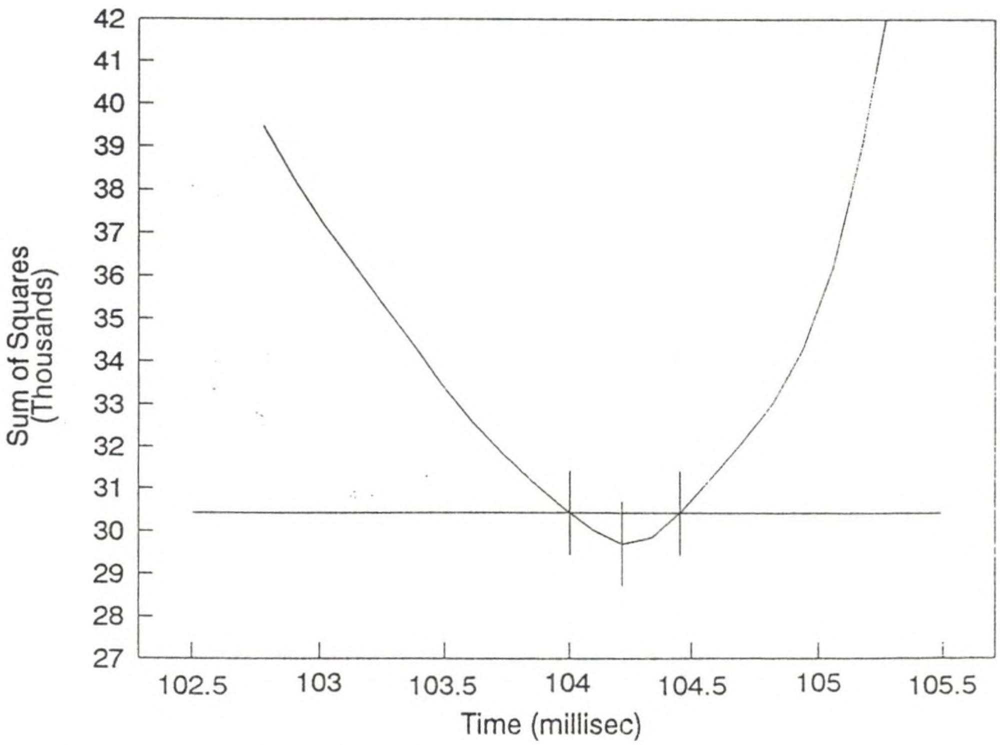

Figure 38. Diesel Fuel Test CB2DF67 Ignition Time 95% Confidence Interval

Table 25. Diesel Fuel Test CB2DF68 Data Reduction Results.

First data set minimum time = 425 milliseconds.
Second data set maximum time = 444.92 milliseconds.

Injection Time = 435.08 millisec
Injection Press = 918 psia
Injection Temp = 1030 °K

Ignition Time = 437.06 millisec

Ignition Delay = 1.98 millisec
Comb. Duration = 9.23 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
436.10	8091	27724	35816	1030	918	533	0.883	53.7	-2.18	448.40
436.22	8097	23256	31353	1031	918	527	0.897	56.4	-2.51	447.47
436.34	8119	18854	26973	1030	918	539	0.870	59.3	-2.86	446.69
436.46	8221	15036	23257	1031	919	515	0.926	62.0	-3.21	446.11
436.58	8271	11331	19602	1031	919	531	0.887	65.1	-3.62	445.59
436.70	8294	8471	16766	1031	919	520	0.913	68.1	-4.02	445.18
436.82	8384	6159	14542	1032	919	499	0.962	71.1	-4.43	444.84
436.94	8384	4596	12980	1032	920	501	0.957	74.4	-4.89	444.55
437.06	8502	3880	12381	1032	920	478	1.011	77.5	-5.35	444.31
437.18	8796	3821	12617	1033	921	442	1.094	80.6	-5.81	444.11
437.30	8853	5069	13922	1034	921	427	1.130	83.9	-6.32	443.94
437.42	9983	6037	16020	1035	923	360	1.287	86.7	-6.79	443.80
437.54	10576	8547	19123	1037	924	312	1.399	89.9	-7.31	443.68
437.66	11670	11498	23168	1038	925	248	1.547	92.8	-7.83	443.58
437.78	12285	16308	28594	1040	926	201	1.657	96.0	-8.40	443.50
437.90	15215	19262	34477	1042	929	101	1.891	98.7	-8.91	443.44
438.02	17246	24268	41514	1044	931	18	2.082	101.5	-9.47	443.38
438.14	20056	29364	49420	1047	933	-76	2.303	104.2	-10.03	443.33
438.26	23165	35143	58308	1049	935	-175	2.532	106.9	-10.61	443.30
438.38	28805	38629	67434	1053	938	-304	2.834	109.2	-11.16	443.27
438.50	33590	43921	77512	1056	941	-422	3.107	111.7	-11.74	443.25

Table 26. Diesel Fuel Test CB2DF69 Data Reduction Results.

First data set minimum Time = 160 milliseconds.
First data set maximum time = 190 milliseconds.

Injection Time = 181.54 millisec
Injection Press = 620 psia
Injection Temp = 1139 °K

Ignition Time = 182.98 millisec

Ignition Delay = 1.44 millisec
Comb. Duration = 8.40 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
182.02	66131	24248	90379	1164	634	599	0.187	30.4	-0.50	212.20
182.14	15727	14482	30209	1137	619	773	-0.847	40.0	-1.54	195.09
182.26	15729	12590	28319	1137	619	773	-0.845	42.4	-1.86	193.67
182.38	15857	10739	26596	1137	619	770	-0.829	44.8	-2.18	192.65
182.5	15896	9047	24943	1137	619	769	-0.820	47.3	-2.54	191.84
182.62	15954	7550	23504	1137	619	771	-0.831	50.1	-2.93	191.18
182.74	16043	6450	22494	1137	619	768	-0.818	52.8	-3.33	190.68
182.86	16045	5790	21835	1137	619	768	-0.816	55.7	-3.76	190.27
182.98	16133	5524	21658	1137	619	766	-0.803	58.6	-4.20	189.94
183.1	16134	5950	22083	1137	619	766	-0.804	61.6	-4.69	189.67
183.22	16222	6997	23219	1137	619	764	-0.791	64.6	-5.18	189.45
183.34	16425	8635	25060	1137	619	761	-0.773	67.6	-5.70	189.27
183.46	16952	10623	27576	1138	620	756	-0.743	70.5	-6.22	189.13
183.58	17299	13635	30935	1138	620	752	-0.718	73.6	-6.78	189.01
183.7	20213	14389	34602	1140	621	740	-0.649	76.3	-7.31	188.92
183.82	21519	17454	38972	1142	621	732	-0.603	79.3	-7.90	188.84
183.94	26032	17466	43498	1144	623	718	-0.519	81.9	-8.47	188.78
184.06	27979	20769	48748	1145	624	709	-0.464	85.0	-9.12	188.72
184.18	32478	21804	54281	1148	625	695	-0.381	87.9	-9.77	188.68
184.3	37208	22938	60146	1150	626	681	-0.298	90.8	-10.46	188.64
184.42	39480	27446	66926	1152	627	671	-0.240	94.1	-11.23	188.61
184.54	44883	29171	74053	1154	628	657	-0.152	97.1	-11.99	188.59
184.66	49392	32428	81820	1157	630	643	-0.073	100.3	-12.82	188.57
184.78	55437	34576	90014	1160	631	628	0.019	103.4	-13.66	188.57
184.9	60522	38396	98919	1162	633	614	0.101	106.7	-14.58	188.56

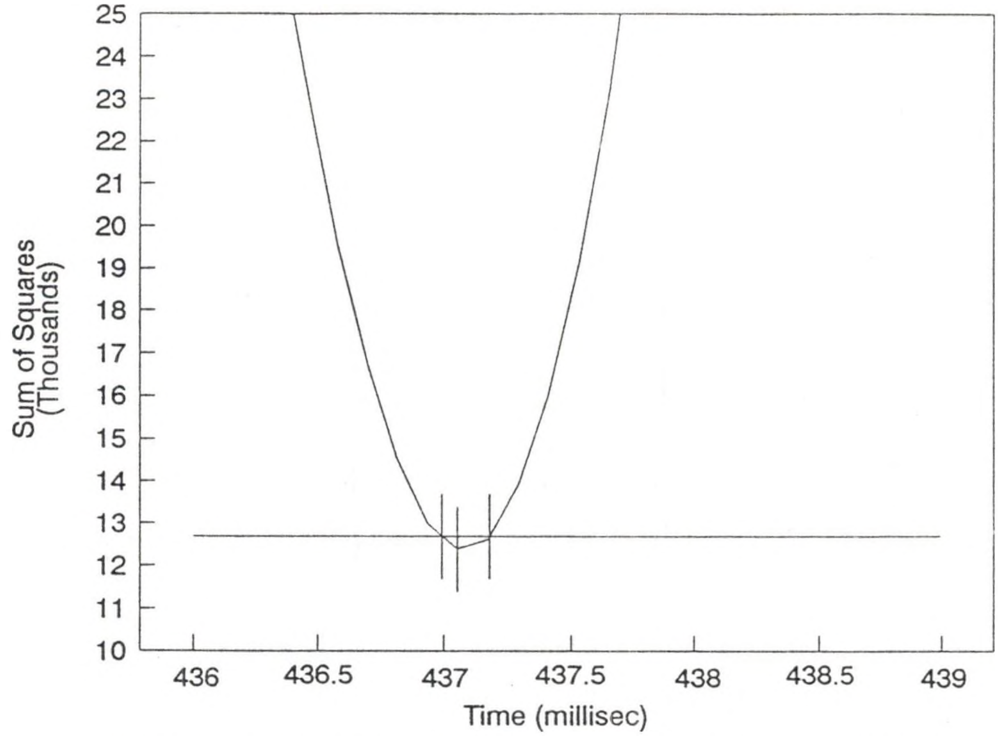

Figure 39. Diesel Fuel Test CB2DF68 Ignition Time 95% Confidence Interval

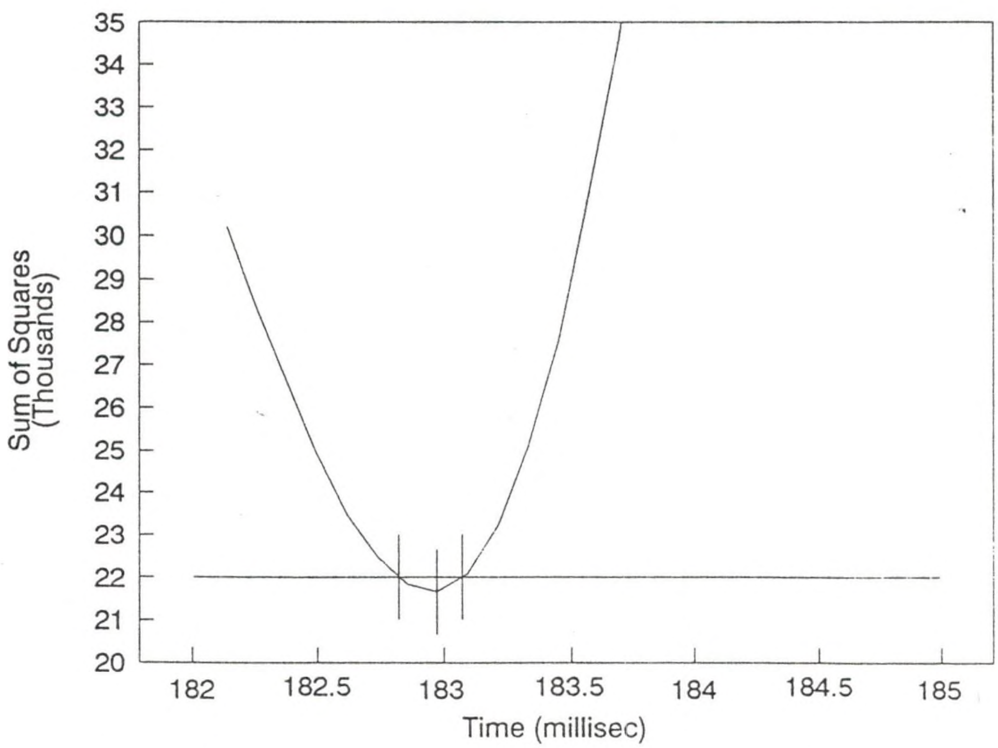

Figure 40. Diesel Fuel Test CB2DF69 Ignition Time 95% Confidence Interval

Table 27. Diesel Fuel Test CB3DF75 Data Reduction Results.

First data set minimum time = 82.08 milliseconds.
Second data set maximum time = 102 milliseconds.

Injection time = 93.48 millisec
Injection Press = 374 psia
Injection Temp = 1209 °K

Ignition Time = 94.5 millisec

Ignition delay = 1.02 millisec
Comb. Duration = 8.23 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
93.18	13248	22477	35726	1203	372	525	-1.643	24.2	-0.568	114.45
93.3	13248	21506	34754	1202	372	525	-1.644	25.6	-0.726	110.93
93.42	14573	19620	34193	1207	373	508	-1.440	26.4	-0.828	109.36
93.54	14587	18505	33092	1207	373	506	-1.419	27.9	-1.003	107.44
93.66	14662	17406	32068	1207	373	502	-1.373	29.3	-1.180	106.08
93.78	15070	16076	31146	1209	374	493	-1.267	30.6	-1.349	105.13
93.9	15131	14895	30026	1210	374	489	-1.226	32.2	-1.556	104.25
94.02	15189	13740	28930	1211	374	486	-1.188	33.9	-1.778	103.55
94.14	15195	12638	27833	1210	374	487	-1.199	35.8	-2.036	102.93
94.26	16315	10635	26950	1205	373	501	-1.362	38.4	-2.373	102.35
94.38	16675	9994	26669	1207	373	493	-1.272	40.0	-2.611	102.04
94.5	16797	9815	26611	1205	373	498	-1.323	42.2	-2.929	101.71
94.62	16835	10137	26972	1205	373	495	-1.295	44.2	-3.221	101.47
94.74	17192	10361	27553	1207	373	488	-1.210	45.9	-3.500	101.29
94.86	17302	11161	28463	1208	373	484	-1.164	47.8	-3.813	101.13
94.98	18027	11497	29524	1211	374	474	-1.047	49.4	-4.102	101.00
95.1	18324	12605	30929	1212	375	467	-0.974	51.3	-4.431	100.89
95.22	18881	13721	32602	1215	376	459	-0.876	53.1	-4.759	100.80
95.34	20081	14305	34387	1219	377	447	-0.734	54.6	-5.075	100.72
95.46	20223	16624	36847	1220	377	443	-0.686	56.7	-5.467	100.65
95.58	21323	18121	39444	1223	378	431	-0.555	58.4	-5.813	100.60
95.7	21818	20826	42645	1226	379	424	-0.468	60.3	-6.203	100.56
95.82	25403	20002	45405	1232	381	404	-0.240	61.3	-6.500	100.54

Table 28. Diesel Fuel Test CB3DF85 Data Reduction Results.

First data set minimum time = 400.4 milliseconds.
Second data set maximum time = 446 milliseconds.

Injection Time = 436.64 millisec
Injection Press = 797 psia
Injection Temp = 935 °K

Ignition Time = 438.62 millisec

Ignition Delay = 1.98 millisec
Comb. Duration = 11.86 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
436.7	48850	41598	90448	935	797	1008	-0.484	22.5	1.32	428.18
436.82	48869	39290	88160	935	797	1007	-0.481	24.4	1.17	426.37
436.94	48926	36670	85596	935	797	1009	-0.485	26.4	0.99	423.62
437.06	49668	33149	82817	934	796	1015	-0.500	28.6	0.79	419.01
437.18	49766	30473	80239	934	796	1017	-0.505	30.8	0.59	411.06
437.3	50326	27294	77620	933	796	1022	-0.518	33.1	0.36	391.89
437.42	50356	24924	75281	933	796	1021	-0.515	35.4	0.14	312.05
437.54	50692	22159	72851	933	796	1025	-0.524	37.8	-0.11	605.30
437.66	50808	19901	70710	933	796	1023	-0.519	40.2	-0.37	492.52
437.78	50826	17736	68562	933	795	1023	-0.521	42.8	-0.65	470.77
437.9	50888	15738	66626	933	796	1022	-0.517	45.4	-0.94	461.97
438.02	51548	13247	64795	933	796	1016	-0.504	48.0	-1.25	457.24
438.14	51588	11404	62992	933	796	1018	-0.507	50.9	-1.60	454.06
438.26	51832	9732	61564	933	796	1015	-0.499	53.8	-1.96	452.00
438.38	51920	8571	60491	933	796	1016	-0.504	56.9	-2.35	450.46
438.5	52346	7606	59952	933	796	1012	-0.494	59.9	-2.76	449.37
438.62	52377	7508	59885	933	796	1011	-0.491	63.1	-3.19	448.50
438.74	53022	7345	60367	934	796	1006	-0.478	66.3	-3.64	447.84
438.86	53654	7695	61348	934	796	1001	-0.466	69.6	-4.12	447.30
438.98	53877	9190	63067	934	796	998	-0.459	73.1	-4.64	446.86
439.1	55223	10248	65470	935	797	991	-0.441	76.5	-5.17	446.50

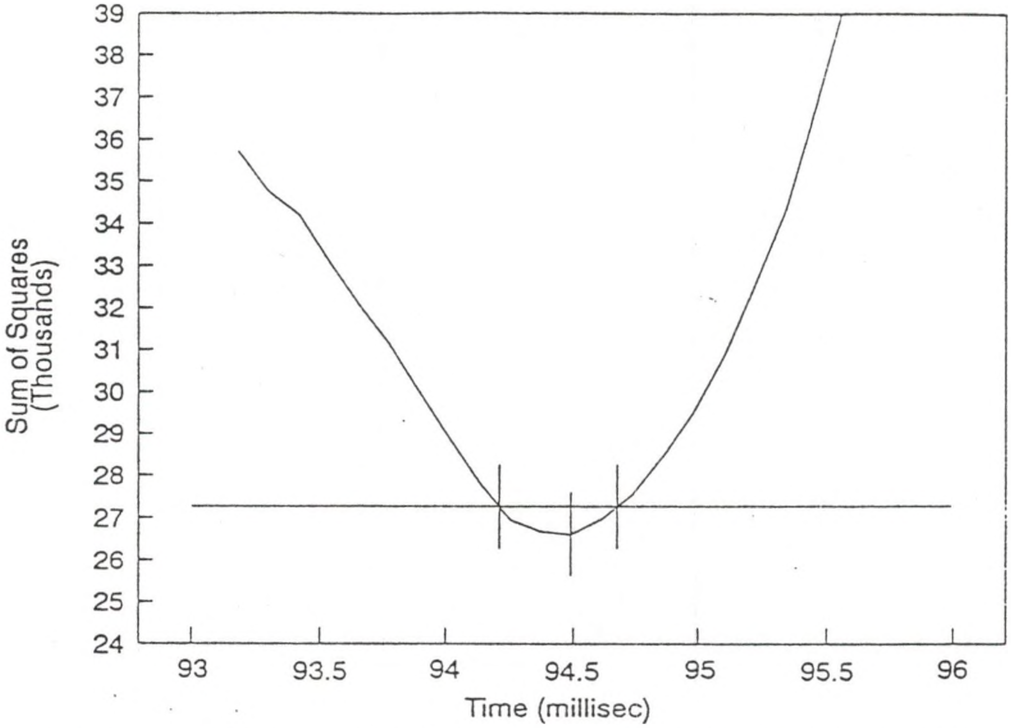

Figure 41. Diesel Fuel Test CB3DF75 Ignition Time 95% Confidence Interval

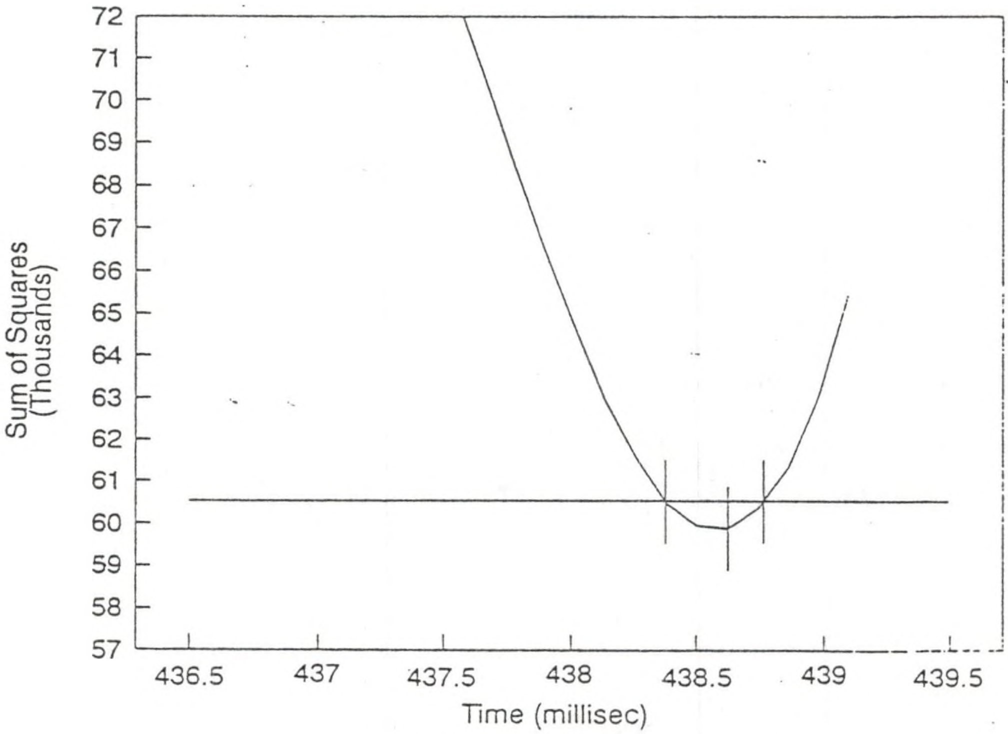

Figure 42. Diesel Fuel Test CB3DF85 Ignition Time 95% Confidence Interval

Table 29. Diesel Fuel Test CB3DF86 Data Reduction Results.

First data set minimum time = 150 milliseconds.
Second data set maximum time = 192.04 milliseconds.

Injection Time = 181.00 millisec
Injection Press = 636 psia
Injection Temp = 1168 °K

Ignition Time = 182.26 millisec

Ignition Delay = 1.26 millisec
Comb. Duration = 10.49 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
181.06	39673	25786	65459	1167	635	808	-0.956	31.2	-0.951	197.45
181.18	39943	23382	63325	1167	635	806	-0.944	32.4	-1.070	196.33
181.3	39974	21110	61084	1167	635	807	-0.948	33.8	-1.205	195.34
181.42	40002	19071	59073	1166	635	807	-0.952	35.3	-1.345	194.53
181.54	40173	17161	57335	1166	634	809	-0.961	36.8	-1.495	193.84
181.66	40370	15632	56002	1166	634	807	-0.951	38.2	-1.639	193.31
181.78	40727	14095	54821	1166	635	805	-0.938	39.6	-1.787	192.85
181.9	41664	12089	53754	1167	635	802	-0.916	40.9	-1.939	192.46
182.02	41706	11064	52770	1167	635	801	-0.912	42.5	-2.109	192.10
182.14	41748	10392	52139	1167	635	800	-0.907	44.1	-2.288	191.78
182.26	41927	10116	52043	1166	635	802	-0.916	45.8	-2.482	191.49
182.38	42065	10470	52535	1166	635	800	-0.908	47.4	-2.671	191.26
182.5	42412	11051	53463	1167	635	798	-0.896	49.1	-2.864	191.06
182.62	43525	11184	54708	1167	635	795	-0.873	50.6	-3.057	190.90
182.74	43968	12424	56393	1168	635	792	-0.859	52.3	-3.266	190.74
182.86	43969	14940	58909	1167	635	792	-0.860	54.1	-3.494	190.60
182.98	44409	17697	62107	1168	636	790	-0.846	55.8	-3.716	190.48
183.1	45827	19946	65772	1169	636	786	-0.821	57.4	-3.937	190.39
183.22	46467	23719	70186	1169	636	784	-0.804	59.1	-4.172	190.30
183.34	48853	26131	74984	1170	637	779	-0.773	60.7	-4.402	190.23
183.46	51901	28251	80151	1172	638	773	-0.737	62.3	-4.638	190.17
183.58	53888	32080	85967	1173	638	768	-0.709	63.9	-4.890	190.12
183.7	55492	37075	92567	1173	639	764	-0.683	65.7	-5.153	190.07

Table 30. Diesel Fuel Test CB2DF114 Data Reduction Results.

First data set minimum time = 80 milliseconds.
Second data set maximum time = 133 milliseconds.

Injection Time = 123.60 millisec
Injection Press = 390 psia
Injection Temp = 1267 °K

Ignition Time = 125.05 millisec

Ignition Delay = 1.45 millisec
Comb. Duration = 7.96 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
123.75	80112	24003	104115	1265	389	561	-1.391	19.9	-0.805	136.11
123.85	80886	22268	103154	1264	389	562	-1.400	20.9	-0.916	135.26
123.95	80892	21498	102390	1263	389	562	-1.401	21.8	-1.022	134.62
124.05	80898	20791	101689	1263	389	562	-1.402	22.8	-1.132	134.10
124.15	80950	20115	101065	1262	388	563	-1.404	23.7	-1.249	133.65
124.25	81235	19305	100540	1262	388	562	-1.399	24.6	-1.362	133.29
124.35	81956	18043	99999	1263	388	561	-1.391	25.5	-1.479	132.98
124.45	82569	16827	99396	1263	389	561	-1.383	26.5	-1.603	132.70
124.55	82664	16086	98750	1263	389	560	-1.380	27.5	-1.742	132.45
124.65	82827	15314	98141	1263	388	560	-1.376	28.6	-1.887	132.22
124.75	82835	14743	97578	1262	388	560	-1.375	29.7	-2.043	132.02
124.85	82884	14268	97152	1262	388	560	-1.377	30.9	-2.210	131.84
124.95	82894	14018	96912	1261	388	560	-1.377	32.1	-2.378	131.69
125.05	82897	13955	96852	1261	388	560	-1.377	33.3	-2.556	131.56
125.15	83080	13997	97077	1260	388	560	-1.381	34.6	-2.744	131.45
125.25	83093	14493	97586	1260	388	560	-1.380	35.8	-2.929	131.36
125.35	83209	15106	98315	1259	387	560	-1.377	37.0	-3.116	131.28
125.45	83325	15948	99273	1259	387	560	-1.374	38.2	-3.311	131.22
125.55	83516	16954	100470	1259	387	559	-1.370	39.4	-3.510	131.16
125.65	83634	18319	101953	1259	387	559	-1.367	40.6	-3.717	131.11
125.75	83953	19750	103703	1259	387	559	-1.361	41.8	-3.927	131.08
125.85	85231	20356	105587	1260	388	558	-1.351	43.0	-4.134	131.05
125.95	86643	20952	107596	1260	388	557	-1.341	44.2	-4.351	131.02

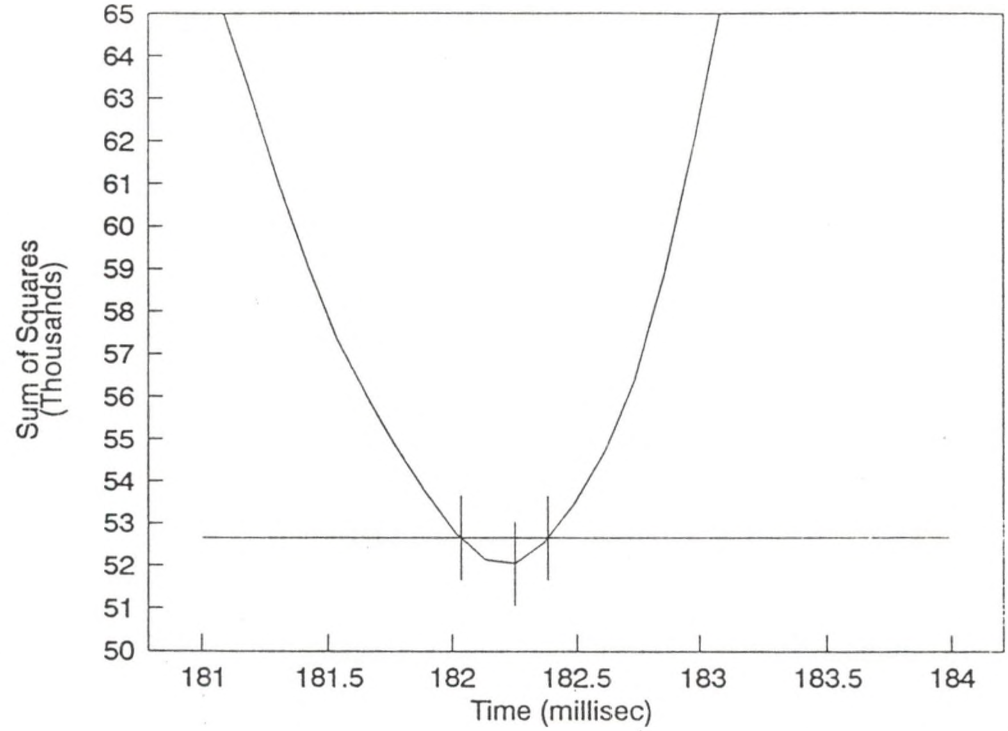

Figure 43. Diesel Fuel Test CB3DF86 Ignition Time 95% Confidence Interval

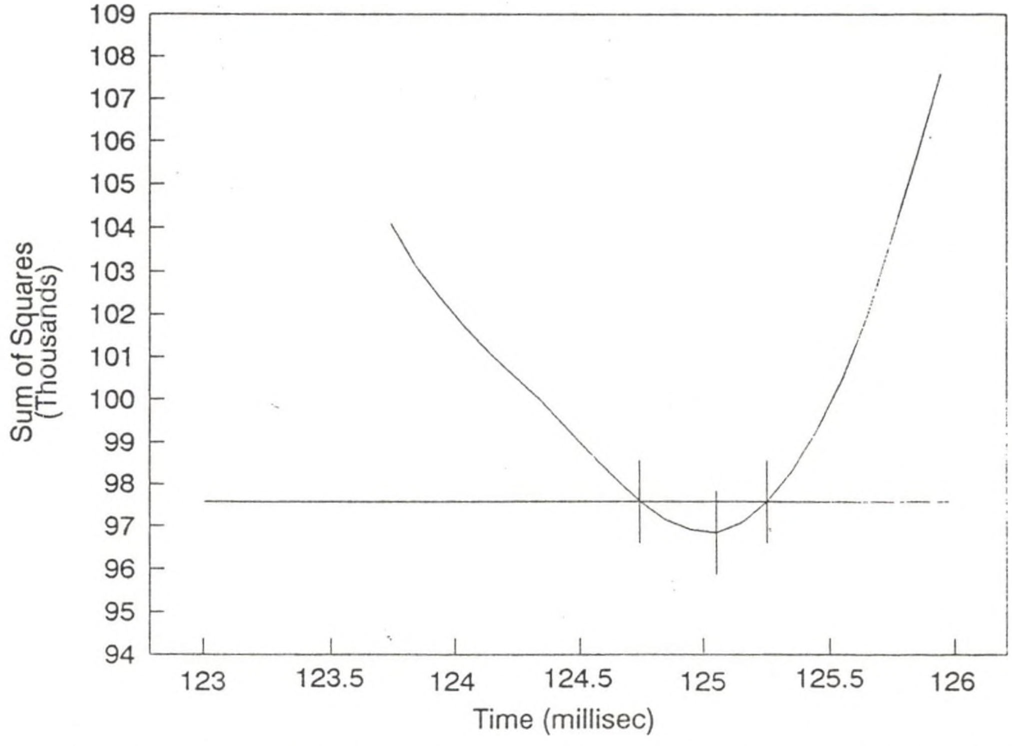

Figure 44. Diesel Fuel Test CB2DF114 Ignition Time 95% Confidence Interval

Table 31. Otisca Slurry Test CB2OT89 Data Reduction Results.

First data set minimum time = 525 milliseconds.
Second data set minimum time = 550 milliseconds.

Injection Time = 536.00 millisec
Injection Press = 406 psia
Injection Temp = 901 °K

Ignition Time = 541.85 millisec

Ignition Delay = 5.85 millisec
Comb. Duration = 17.57 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
540.05	24643	20377	45019	897	405	535	-0.242	9.73	0.258	521.20
540.15	24679	20105	44784	897	405	527	-0.226	10.19	0.221	517.07
540.25	25089	19304	44393	896	404	554	-0.278	10.94	0.158	505.53
540.35	25109	19071	44180	896	404	548	-0.267	11.45	0.115	490.40
540.45	25119	18816	43935	896	404	552	-0.274	12.04	0.062	443.49
540.55	25180	18521	43701	895	404	563	-0.294	12.71	0.003	-1808.07
540.65	25180	18351	43531	895	404	563	-0.295	13.31	-0.052	668.71
540.75	25281	18100	43381	895	404	576	-0.319	14.02	-0.119	599.90
540.85	25489	17816	43305	895	404	558	-0.284	14.49	-0.164	585.04
540.95	26064	17160	43223	897	404	528	-0.228	14.87	-0.203	577.51
541.05	26611	16494	43105	898	405	499	-0.173	15.28	-0.247	571.93
541.15	27355	15605	42960	899	406	466	-0.111	15.68	-0.292	568.00
541.25	27364	15322	42686	899	406	462	-0.104	16.37	-0.366	563.60
541.35	27454	14954	42407	899	406	473	-0.125	17.22	-0.457	560.17
541.45	27801	14424	42225	898	405	495	-0.167	18.19	-0.562	557.64
541.55	27802	14372	42174	898	405	494	-0.164	18.94	-0.647	556.18
541.65	27970	14188	42158	899	405	479	-0.136	19.58	-0.724	555.17
541.75	28198	13947	42145	899	406	462	-0.104	20.21	-0.803	554.34
541.85	28295	13849	42144	900	406	451	-0.083	20.93	-0.893	553.57
541.95	28507	13652	42158	901	406	435	-0.053	21.62	-0.982	552.96
542.05	28709	13473	42182	901	407	419	-0.023	22.34	-1.077	552.42
542.15	28725	13526	42251	901	407	415	-0.015	23.20	-1.190	551.89
542.25	28853	13515	42368	902	407	403	0.008	23.99	-1.299	551.48
542.35	28927	13614	42541	903	407	394	0.025	24.83	-1.417	551.11
542.45	28963	13834	42796	903	407	387	0.037	25.73	-1.544	550.78
542.55	28996	14155	43151	903	407	381	0.048	26.64	-1.676	550.50
542.65	29035	14678	43712	903	407	388	0.036	27.71	-1.828	550.23
542.75	29281	15027	44308	904	408	372	0.066	28.52	-1.955	550.05

Table 32. Otisca Slurry Fuel Test CB2OT90 Data Reduction Results.

First data set minimum time = 115 milliseconds.
Second data set maximum time = 143 milliseconds.

Injection Time = 133.1 millisec
Injection Press = 776 psia
Injection Temp = 1254 °K

Ignition Time = 134.85 millisec

Ignition Delay = 1.75 millisec
Comb. Duration = 7.69 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
134.05	27058	14560	41617	1249	772	971	-1.481	25.4	-1.71	141.51
134.15	27060	14198	41258	1248	772	970	-1.478	26.3	-1.83	141.37
134.25	27071	13954	41025	1248	772	971	-1.484	27.3	-1.95	141.24
134.35	27098	13879	40976	1248	772	972	-1.492	28.3	-2.09	141.13
134.45	28235	12757	40993	1248	772	965	-1.439	28.9	-2.19	141.06
134.55	29032	11938	40970	1249	773	960	-1.394	29.7	-2.30	140.99
134.65	30454	10445	40899	1250	773	953	-1.336	30.3	-2.41	140.93
134.75	30948	9830	40778	1251	773	949	-1.302	31.2	-2.55	140.86
134.85	30951	9795	40746	1250	773	949	-1.304	32.3	-2.71	140.79
134.95	30954	9988	40942	1250	773	949	-1.307	33.4	-2.88	140.74
135.05	30974	10443	41417	1250	773	950	-1.314	34.5	-3.06	140.69
135.15	31099	11176	42276	1249	773	952	-1.330	35.7	-3.25	140.65
135.25	31219	12120	43339	1249	773	950	-1.314	36.7	-3.41	140.63
135.35	31650	12880	44529	1250	773	947	-1.284	37.6	-3.58	140.61
135.45	31956	13963	45919	1250	773	944	-1.259	38.5	-3.75	140.59
135.55	32989	14346	47336	1251	774	938	-1.213	39.3	-3.91	140.58
135.65	33991	14854	48845	1252	774	933	-1.169	40.2	-4.07	140.58
135.75	34962	15501	50463	1253	775	927	-1.125	41.0	-4.25	140.58
135.85	36376	15734	52110	1254	775	921	-1.073	41.8	-4.42	140.58
135.95	37603	16254	53857	1254	776	915	-1.026	42.6	-4.60	140.58
136.05	39571	16001	55572	1256	777	908	-0.965	43.4	-4.78	140.58
136.15	40399	17122	57521	1256	777	903	-0.927	44.3	-4.99	140.59
136.25	41201	18454	59655	1257	777	899	-0.889	45.2	-5.21	140.59
136.35	42630	19215	61845	1258	778	893	-0.840	46.1	-5.41	140.60
136.45	43800	20408	64207	1259	779	887	-0.795	47.0	-5.63	140.62
136.55	45528	21089	66617	1260	779	881	-0.741	47.8	-5.85	140.63

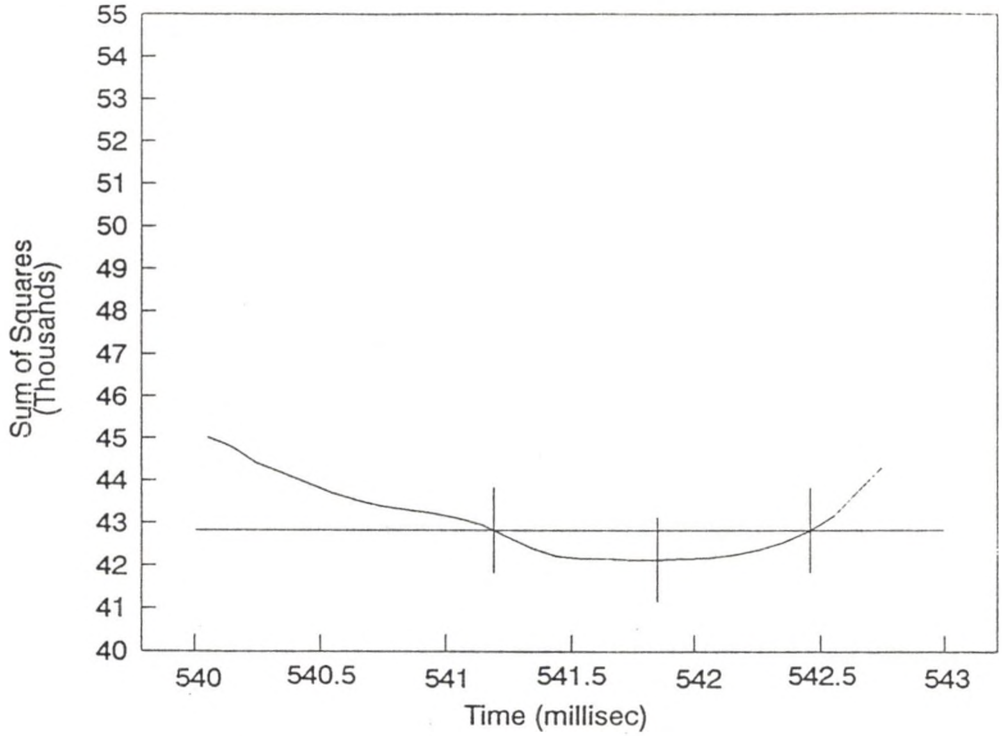

Figure 45. Otisca Slurry Test CB2OT89 Ignition Time 95% Confidence Interval

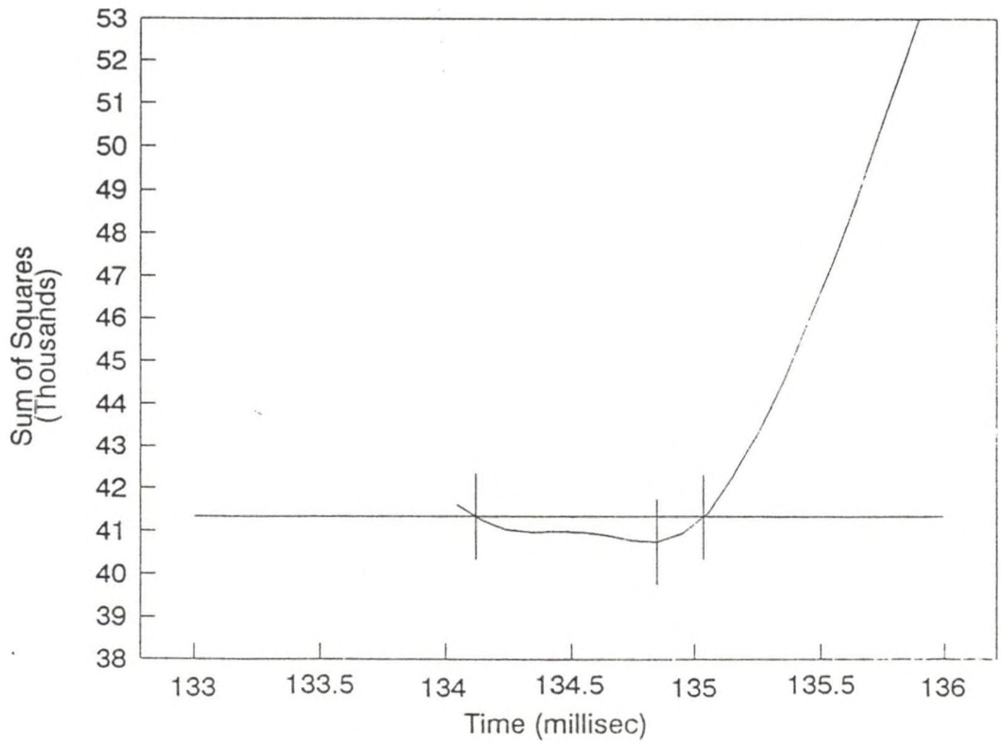

Figure 46. Otisca Slurry Test CB2OT90 Ignition Time 95% Confidence Interval

Table 33. Otisca Slurry Fuel Test CB2OT91 Data Reduction Results.

First data set minimum time = 90 milliseconds.
Second data set maximum time = 138 milliseconds.

Injection Time = 126.20 millisec
Injection Press = 373 psia
Injection Temp = 1201 °K

Ignition Time = 127.65 millisec

Ignition Delay = 1.45 millisec
Comb. Duration = 13.20 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
125.55	63630	40797	104428	1200	372	527	-1.229	14.9	-0.304	150.13
125.65	63642	39441	103083	1200	372	527	-1.227	15.3	-0.330	148.86
125.75	63644	38069	101713	1200	372	527	-1.228	15.8	-0.359	147.72
125.85	63675	36752	100427	1199	372	526	-1.225	16.2	-0.387	146.76
125.95	63694	35395	99089	1199	372	527	-1.227	16.6	-0.417	145.87
126.05	63754	34127	97881	1199	372	526	-1.224	17.0	-0.447	145.12
126.15	63789	32887	96676	1199	372	526	-1.221	17.5	-0.477	144.45
126.25	63907	31615	95522	1199	372	525	-1.216	17.9	-0.508	143.86
126.35	63969	30392	94361	1198	372	525	-1.213	18.3	-0.540	143.32
126.45	64088	29152	93240	1198	372	525	-1.208	18.8	-0.573	142.84
126.55	64207	27928	92136	1198	372	524	-1.203	19.2	-0.607	142.39
126.65	64374	26687	91061	1199	372	524	-1.197	19.7	-0.642	141.99
126.75	64409	25569	89978	1198	372	523	-1.194	20.2	-0.678	141.61
126.85	64410	24523	88933	1198	372	523	-1.195	20.7	-0.718	141.26
126.95	64600	23370	87970	1197	371	524	-1.201	21.2	-0.760	140.92
127.05	64841	22367	87207	1196	371	525	-1.208	21.8	-0.804	140.61
127.15	65072	21604	86677	1195	371	525	-1.214	22.4	-0.848	140.34
127.25	65081	21297	86378	1195	371	525	-1.216	22.9	-0.891	140.10
127.35	65164	21075	86239	1195	371	525	-1.212	23.4	-0.933	139.90
127.45	65527	20670	86197	1195	371	524	-1.203	23.9	-0.974	139.71
127.55	66676	19512	86188	1196	371	523	-1.189	24.3	-1.013	139.56
127.65	67498	18688	86187	1196	371	521	-1.177	24.8	-1.055	139.40
127.75	68428	17779	86207	1197	371	520	-1.164	25.3	-1.098	139.26
127.85	68695	17594	86289	1197	371	519	-1.157	25.8	-1.145	139.11
127.95	69236	17221	86458	1198	372	518	-1.148	26.3	-1.192	138.98
128.05	69498	17233	86731	1198	372	518	-1.141	26.8	-1.242	138.86
128.15	69622	17539	87161	1198	372	517	-1.136	27.4	-1.294	138.74

Table 34. Otisca Slurry Fuel Test CB2OT93 Data Reduction Results.

First data set minimum time = 890.04 milliseconds.
Second data set maximum time = 924 milliseconds.

Injection Time = 908.64 millisec
Injection Press = 772 psia
Injection Temp = 868 °K

Ignition Time = 915.54 millisec

Ignition Delay = 6.90 millisec
Comb. Duration = 14.75 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
913.26	26068	15164	41233	859	765	1704	-1.029	8.70	-0.094	959.57
913.38	26128	15050	41178	859	765	1695	-1.019	9.07	-0.125	949.54
913.5	26357	14766	41123	860	765	1678	-0.999	9.40	-0.155	943.90
913.62	26357	14695	41053	860	765	1677	-0.999	9.86	-0.195	938.89
913.74	26416	14588	41003	860	765	1669	-0.989	10.28	-0.233	935.79
913.86	26423	14541	40964	860	765	1666	-0.986	10.74	-0.276	933.31
913.98	27442	13486	40927	860	765	1630	-0.946	11.00	-0.303	932.10
914.1	28044	12824	40868	859	765	1657	-0.976	11.71	-0.370	929.93
914.22	28916	11944	40859	860	765	1624	-0.940	12.01	-0.403	929.12
914.34	28969	11855	40823	860	765	1616	-0.931	12.50	-0.454	928.10
914.46	29674	11108	40782	860	766	1588	-0.899	12.86	-0.496	927.44
914.58	29693	11015	40708	860	765	1583	-0.894	13.42	-0.557	926.64
914.7	30044	10600	40645	861	766	1563	-0.872	13.89	-0.611	926.07
914.82	30088	10478	40566	861	766	1556	-0.864	14.48	-0.678	925.49
914.94	30893	9596	40488	861	766	1526	-0.831	14.91	-0.734	925.09
915.06	30894	9473	40368	861	766	1528	-0.832	15.61	-0.817	924.61
915.18	31320	8960	40280	861	766	1507	-0.809	16.16	-0.888	924.27
915.3	31391	8779	40170	862	766	1498	-0.799	16.83	-0.974	923.94
915.42	31407	8694	40101	861	766	1502	-0.804	17.63	-1.075	923.62
915.54	31647	8436	40082	862	766	1487	-0.787	18.28	-1.165	923.39
915.66	31681	8405	40086	862	766	1481	-0.780	19.04	-1.268	923.16
915.78	32091	8014	40104	862	767	1461	-0.758	19.69	-1.365	922.99
915.9	32168	8030	40198	862	767	1470	-0.768	20.63	-1.494	922.80
916.02	32800	7521	40321	862	767	1446	-0.741	21.28	-1.597	922.68
916.14	32809	7694	40503	862	767	1443	-0.738	22.16	-1.728	922.55
916.26	33204	7513	40717	862	767	1424	-0.717	22.90	-1.849	922.45

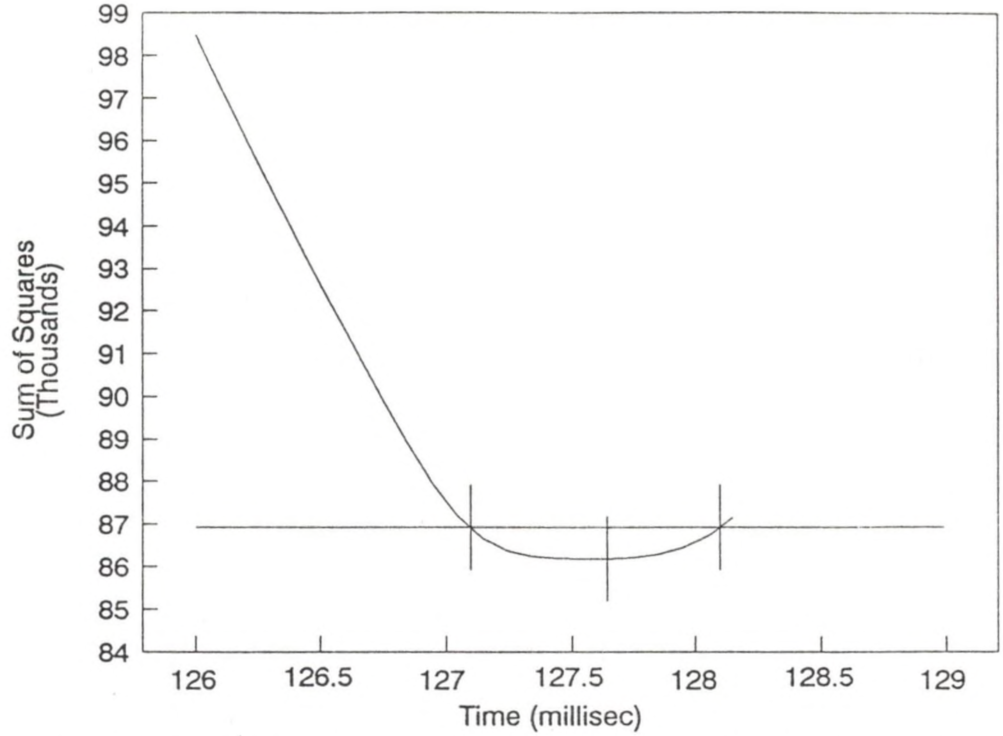

Figure 47. Otisca Slurry Test CB2OT91 Ignition Time Confidence Interval

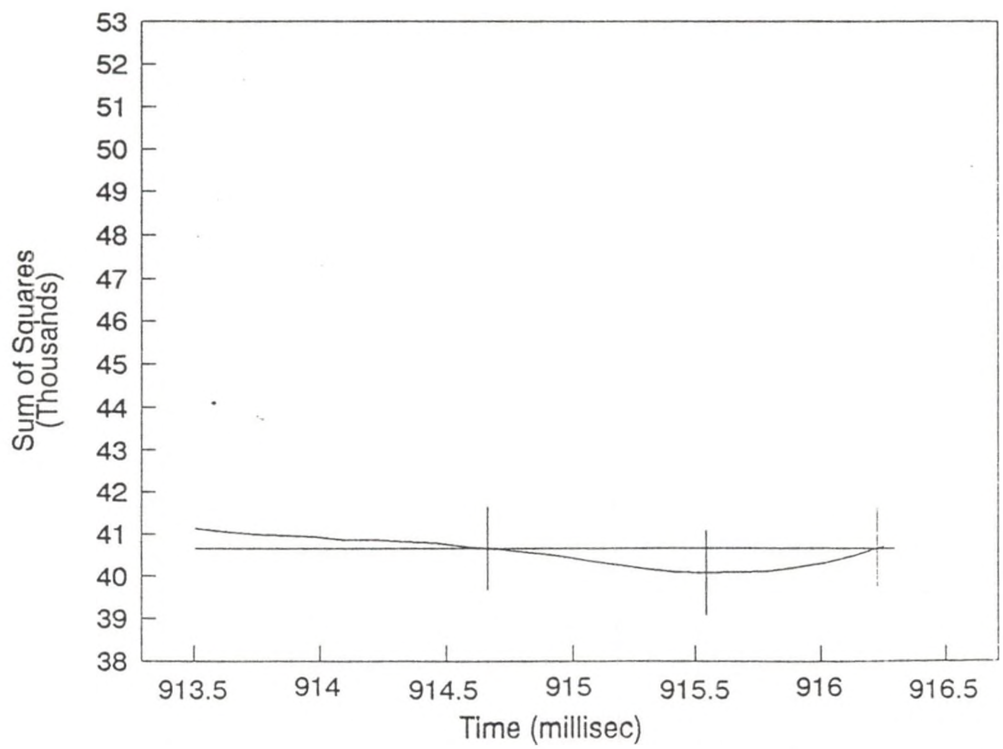

Figure 48. Otisca Slurry Test CB2OT93 Ignition Time Confidence Interval

Table 35. Otisca Slurry Fuel Test CB2OT94 Data Reduction Results.

First data set minimum time = 78 milliseconds.
Second data set maximum time = 105 milliseconds.

Injection Time = 90.4 millisec
Injection Press = 415 psia
Injection Temp = 1336 °K

Ignition Time = 92.35 millisec

Ignition Delay = 1.95 millisec
Comb. Duration 14.48 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
91.25	22287	24559	46846	1321	410	612	-2.21	21.6	-0.593	109.45
91.35	22288	23617	45904	1320	410	612	-2.21	22.2	-0.639	108.73
91.45	22740	22517	45257	1321	410	607	-2.14	22.7	-0.675	108.23
91.55	22861	21664	44525	1322	411	604	-2.11	23.2	-0.718	107.71
91.65	23214	20686	43900	1323	411	599	-2.05	23.7	-0.757	107.28
91.75	23397	19861	43258	1324	411	595	-2.00	24.2	-0.801	106.85
91.85	23631	19047	42678	1324	411	591	-1.96	24.7	-0.846	106.47
91.95	23697	18425	42122	1324	411	589	-1.93	25.3	-0.895	106.09
92.05	23799	17883	41681	1325	411	586	-1.90	25.9	-0.946	105.76
92.15	23863	17486	41350	1325	412	584	-1.88	26.5	-0.998	105.44
92.25	23899	17262	41161	1325	411	583	-1.86	27.2	-1.054	105.15
92.35	23936	17212	41147	1325	411	582	-1.84	27.8	-1.110	104.88
92.45	24158	17118	41277	1325	412	578	-1.80	28.4	-1.164	104.66
92.55	24374	17157	41531	1326	412	575	-1.76	29.0	-1.218	104.45
92.65	24678	17223	41901	1327	412	571	-1.71	29.6	-1.273	104.27
92.75	24763	17708	42471	1327	412	568	-1.68	30.2	-1.334	104.08
92.85	25054	18120	43174	1328	413	565	-1.64	30.8	-1.392	103.93
92.95	25244	18831	44075	1329	413	561	-1.60	31.5	-1.454	103.78
93.05	25588	19527	45115	1330	413	557	-1.55	32.1	-1.514	103.64
93.15	25851	20513	46364	1331	413	554	-1.51	32.7	-1.577	103.52
93.25	26373	21341	47714	1332	414	549	-1.45	33.3	-1.637	103.41
93.35	26791	22478	49269	1334	414	545	-1.40	33.9	-1.700	103.31
93.45	26791	24639	51430	1333	414	545	-1.40	34.6	-1.778	103.19
93.55	27199	26397	53595	1335	415	540	-1.35	35.3	-1.844	103.11
93.65	27673	28297	55970	1336	415	536	-1.29	35.8	-1.910	103.03

Table 36. Otisca Slurry Fuel Test CB2OT97 Data Reduction Results.

First Data Set Minimum time = 200 milliseconds.
Second Data Set Maximum time = 240 milliseconds.

Injection Time =	230.2	millisec
Injection Press =	631	psia
Injection Temp =	1137	°K
Ignition Time =	232.95	millisec
Ignition Delay =	2.75	millisec
Comb. Duration =	12.03	millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
230.05	46024	29014	75038	1146	636	744	-0.472	-2.100	1.066	231.04
230.15	46139	28900	75039	1146	635	746	-0.479	-1.717	1.044	230.97
230.25	46149	28937	75086	1146	635	746	-0.481	-1.354	1.023	230.91
230.35	46564	28372	74936	1145	635	749	-0.494	-0.879	0.992	230.79
230.45	46623	28252	74875	1145	635	750	-0.499	-0.455	0.964	230.69
230.55	48998	25408	74406	1144	634	757	-0.530	0.208	0.914	230.44
230.65	49044	25240	74284	1144	634	757	-0.535	0.653	0.882	230.28
230.75	49409	24618	74027	1143	634	760	-0.547	1.186	0.842	230.05
230.85	49487	24337	73824	1143	634	761	-0.552	1.682	0.803	229.80
230.95	49748	23782	73529	1142	633	763	-0.563	2.240	0.757	229.47
231.05	49867	23379	73246	1142	633	765	-0.569	2.790	0.711	229.09
231.15	50293	22561	72854	1141	633	767	-0.582	3.417	0.655	228.54
231.25	52470	19802	72272	1140	632	773	-0.611	4.205	0.584	227.65
231.35	53179	18671	71850	1139	632	777	-0.627	4.883	0.521	226.66
231.45	53226	18312	71539	1139	632	778	-0.631	5.464	0.466	225.59
231.55	53672	17461	71133	1139	631	780	-0.644	6.148	0.400	223.86
231.65	53863	16903	70766	1138	631	782	-0.652	6.806	0.334	221.46
231.75	54122	16266	70387	1138	631	784	-0.662	7.496	0.263	217.51
231.85	54191	15852	70043	1137	631	785	-0.667	8.159	0.193	210.72
231.95	54364	15313	69677	1137	630	787	-0.674	8.871	0.116	193.62
232.05	54428	14908	69336	1137	630	788	-0.679	9.572	0.037	103.72
232.15	54456	14547	69003	1136	630	788	-0.682	10.279	-0.044	348.06
232.25	54501	14196	68697	1136	630	788	-0.678	10.940	-0.124	276.35
232.35	54730	13580	68310	1136	630	789	-0.687	11.767	-0.224	258.57
232.45	54785	13187	67973	1136	630	790	-0.691	12.564	-0.324	251.82
232.55	55002	12644	67646	1135	629	792	-0.700	13.427	-0.434	248.00
232.65	55022	12358	67380	1135	629	793	-0.702	14.242	-0.542	245.78
232.75	55228	11913	67141	1135	629	794	-0.710	15.139	-0.662	244.18
232.85	55272	11703	66975	1134	629	795	-0.714	15.999	-0.781	243.09
232.95	55542	11339	66881	1134	629	797	-0.723	16.935	-0.912	242.23
233.05	56197	10735	66932	1133	628	800	-0.737	17.929	-1.052	241.57
233.15	56266	10853	67119	1133	628	801	-0.741	18.796	-1.179	241.12
233.25	56343	11020	67363	1133	628	800	-0.737	19.554	-1.295	240.80
233.35	56346	11339	67685	1133	628	800	-0.736	20.374	-1.422	240.51
233.45	56473	11584	68056	1133	628	798	-0.730	21.139	-1.546	240.29
233.55	56505	12063	68568	1133	628	799	-0.733	22.030	-1.688	240.07
233.65	56515	12715	69229	1132	628	799	-0.734	22.888	-1.828	239.91

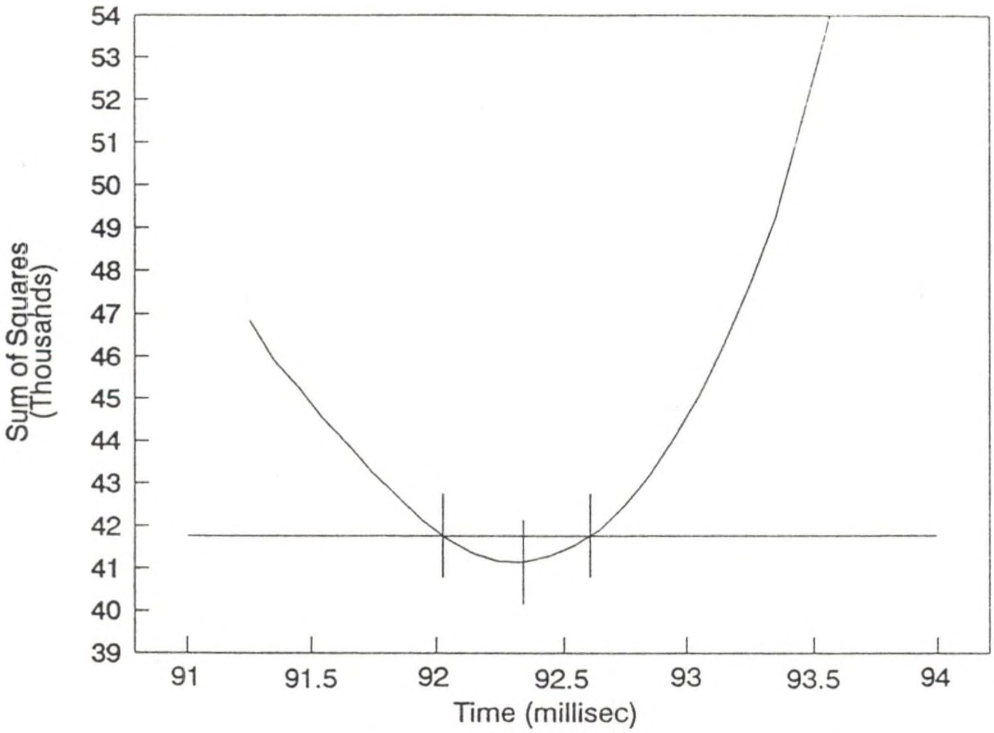

Figure 49. Otisca Slurry Test CB2OT94 Ignition Time confidence Interval

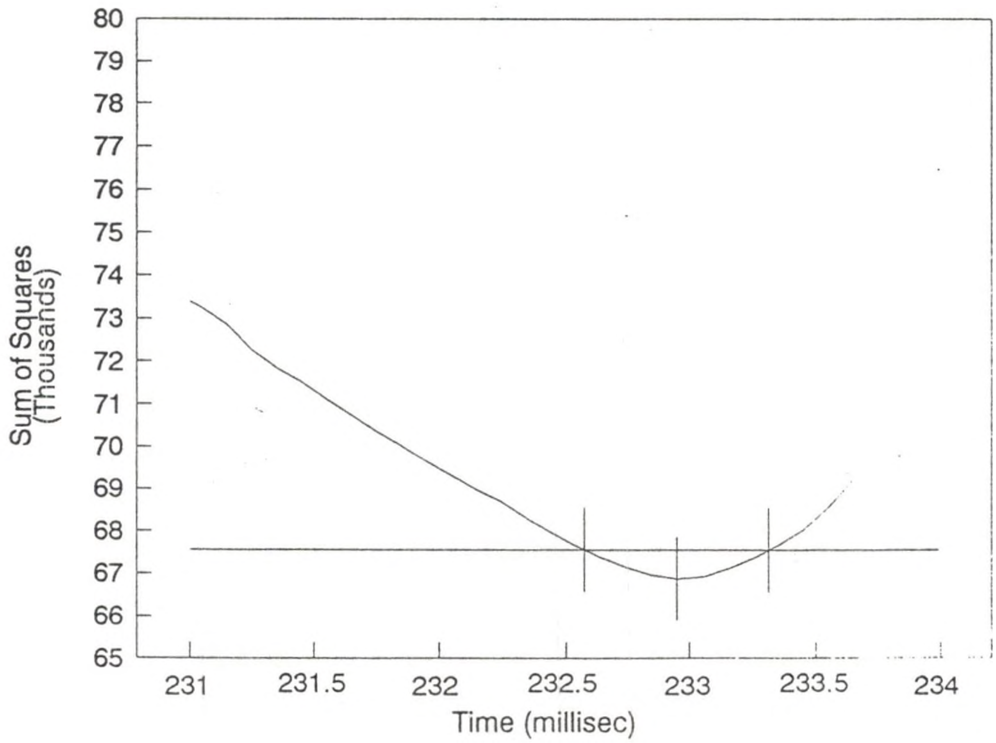

Figure 50. Otisca Slurry Test CB2OT97 Ignition Time Confidence Interval

Table 37. Otisca Slurry Fuel Test CB2OT99 Data Reduction Results.

Minimum time = 215 milliseconds in row 13.
Maximum time = 240 milliseconds in row 263.

Injection Time = 235.5 millisec
Injection Press = 603 psia
Injection Temp = 1106 °K

Ignition Time = 237.05 millisec

Ignition Delay = 1.55 millisec
Comb. Duration = 7.43 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
235.05	34372	30310	64683	1109	605	679	-0.317	11.0	-0.284	254.35
235.15	34383	29612	63994	1108	605	680	-0.322	11.5	-0.342	251.99
235.25	34385	28948	63332	1108	605	680	-0.320	12.1	-0.401	250.31
235.35	34496	28033	62529	1108	605	683	-0.335	12.7	-0.471	248.87
235.45	34504	27299	61803	1108	604	684	-0.339	13.4	-0.539	247.84
235.55	34865	26394	61259	1108	605	678	-0.312	13.8	-0.595	247.15
235.65	34904	25621	60526	1109	605	676	-0.303	14.4	-0.666	246.47
235.75	35956	23461	59418	1107	604	686	-0.348	15.3	-0.768	245.74
235.85	35981	22653	58635	1107	604	688	-0.355	16.0	-0.853	245.26
235.95	36568	21184	57752	1106	604	695	-0.388	16.9	-0.956	244.81
236.05	36593	20541	57134	1106	604	694	-0.382	17.6	-1.040	244.50
236.15	36597	19875	56471	1106	604	694	-0.384	18.3	-1.135	244.22
236.25	36684	19122	55806	1106	603	697	-0.397	19.1	-1.239	243.97
236.35	36712	18547	55259	1106	603	696	-0.390	19.9	-1.336	243.78
236.45	36715	17984	54699	1106	603	696	-0.392	20.6	-1.444	243.60
236.55	36989	17178	54166	1105	603	701	-0.414	21.6	-1.569	243.43
236.65	36990	16807	53797	1105	603	701	-0.415	22.4	-1.684	243.30
236.75	37000	16504	53504	1105	603	700	-0.411	23.2	-1.800	243.19
236.85	37242	16022	53264	1105	603	696	-0.392	23.9	-1.911	243.10
236.95	37323	15725	53048	1105	603	698	-0.403	24.8	-2.049	243.01
237.05	37511	15501	53012	1105	603	702	-0.420	25.8	-2.195	242.93
237.15	37512	15632	53143	1105	603	702	-0.419	26.7	-2.331	242.87
237.25	37690	15664	53354	1105	603	698	-0.402	27.4	-2.459	242.82
237.35	37691	16004	53695	1105	603	698	-0.402	28.3	-2.605	242.78
237.45	37875	16430	54306	1104	603	702	-0.418	29.3	-2.769	242.74
237.55	37996	17037	55033	1105	603	699	-0.405	30.1	-2.909	242.72
237.65	38245	17610	55855	1105	603	695	-0.386	30.8	-3.049	242.70
237.75	39140	17524	56664	1106	603	687	-0.352	31.4	-3.180	242.69
237.85	39541	18040	57581	1107	604	682	-0.329	32.2	-3.327	242.69
237.95	41655	16703	58358	1108	605	670	-0.276	32.7	-3.452	242.68
238.05	41926	17387	59312	1108	605	666	-0.258	33.5	-3.618	242.68
238.15	41965	18535	60500	1109	605	665	-0.251	34.4	-3.800	242.67

Table 38. Otisca Slurry Fuel Test CB2OT102 Data Reduction Results.

First data set minimum time = 80 milliseconds.
Second data set maximum time = 122.4 milliseconds.

Injection Time = 114.90 millisec
Injection Press = 386 psia
Injection Temp = 1270 °K

Ignition Time = 116.05 millisec

Ignition Delay = 1.15 millisec
Comb. Duration = 7.16 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
115.05	63757	18060	81818	1268	386	582	-1.710	10.2	-0.324	130.85
115.15	63947	17733	81680	1267	385	583	-1.717	11.0	-0.420	128.22
115.25	64057	17543	81600	1266	385	584	-1.722	11.7	-0.517	126.58
115.35	64194	17358	81552	1266	385	583	-1.717	12.3	-0.602	125.58
115.45	65839	15639	81478	1267	385	581	-1.697	12.8	-0.677	124.91
115.55	66019	15301	81320	1267	385	581	-1.691	13.5	-0.784	124.17
115.65	66020	15119	81138	1266	385	581	-1.691	14.3	-0.911	123.52
115.75	66047	14935	80982	1265	385	581	-1.694	15.2	-1.049	123.01
115.85	66112	14767	80879	1264	385	581	-1.697	16.2	-1.196	122.60
115.95	66112	14723	80835	1264	384	581	-1.697	17.0	-1.342	122.30
116.05	66165	14659	80824	1264	384	581	-1.694	17.9	-1.490	122.06
116.15	66171	14675	80846	1263	384	581	-1.693	18.8	-1.651	121.85
116.25	66228	14680	80908	1263	384	581	-1.689	19.7	-1.817	121.68
116.35	66611	14363	80974	1263	384	580	-1.680	20.6	-1.984	121.54
116.45	67117	13897	81014	1263	384	579	-1.670	21.5	-2.164	121.42
116.55	67326	13715	81041	1263	384	578	-1.664	22.5	-2.369	121.30
116.65	67535	13537	81073	1263	384	578	-1.657	23.6	-2.591	121.20
116.75	67745	13367	81112	1263	384	577	-1.651	24.7	-2.831	121.11
116.85	68336	12964	81299	1262	384	578	-1.662	26.1	-3.123	121.03
116.95	68478	13248	81726	1261	384	578	-1.667	27.4	-3.399	120.98
117.05	68886	13340	82226	1261	384	578	-1.658	28.5	-3.645	120.95
117.15	70487	12178	82665	1262	384	576	-1.641	29.4	-3.890	120.93
117.25	71697	11346	83044	1263	384	575	-1.626	30.5	-4.173	120.90
117.35	71858	11602	83461	1262	384	574	-1.620	31.8	-4.512	120.88
117.45	72020	11949	83969	1262	384	574	-1.615	33.2	-4.869	120.86
117.55	72028	12614	84642	1262	384	574	-1.614	34.7	-5.253	120.85

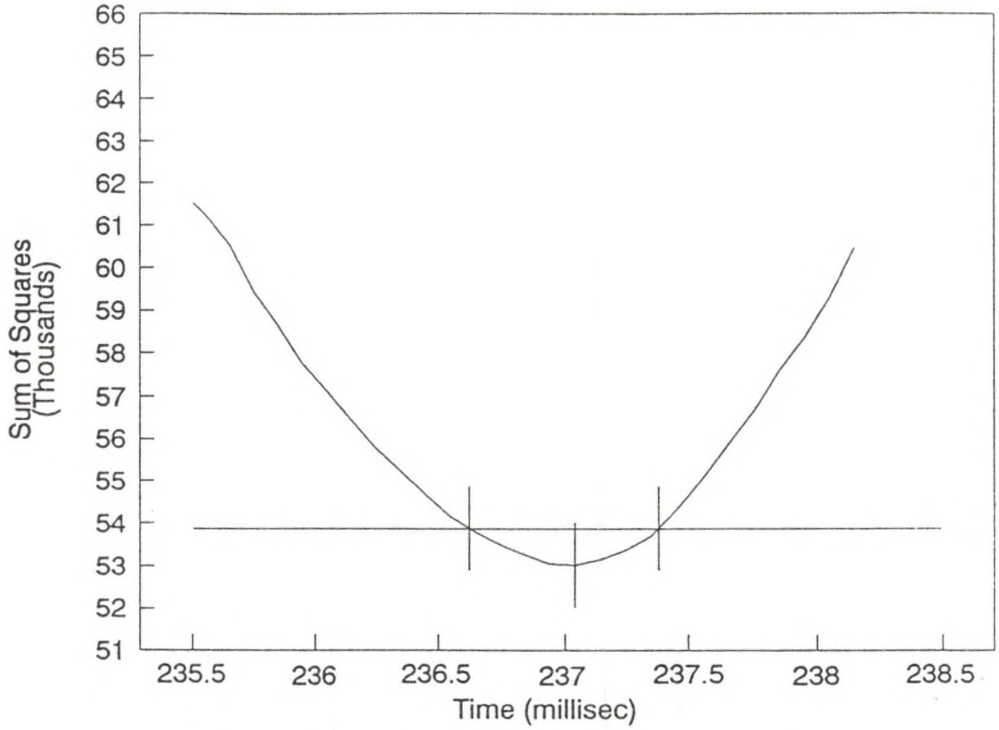

Figure 51. Otisca Slurry Test CB2OT99 Ignition Time Confidence Interval

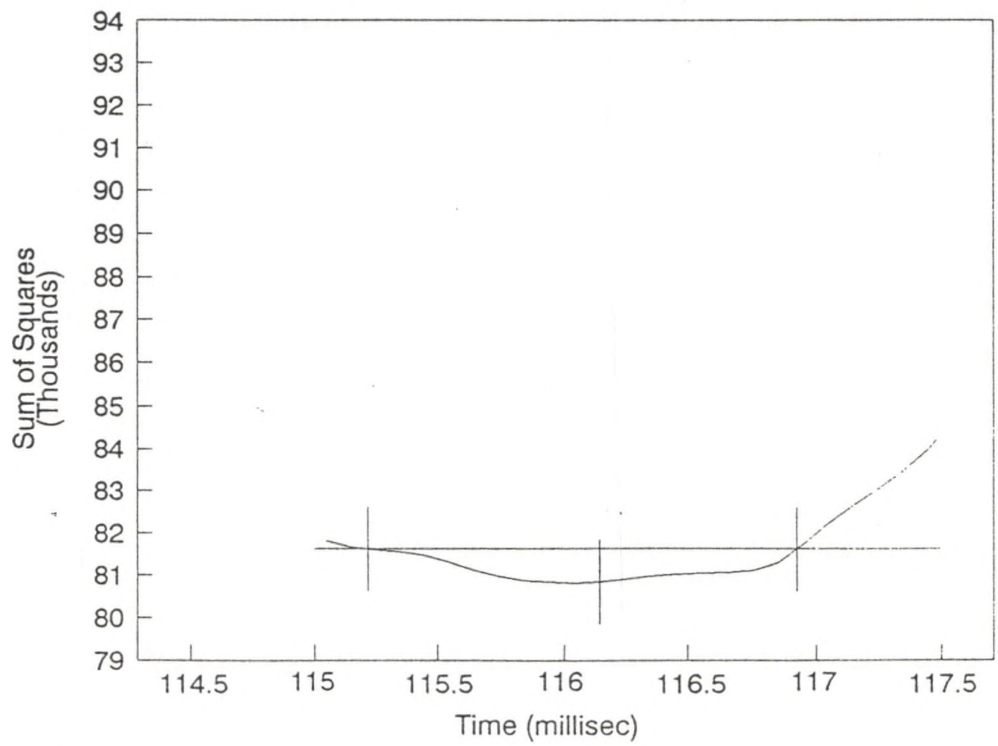

Figure 52. Otisca Slurry Test CB2OT102 Ignition Time Confidence Interval

Table 39. Otisca Slurry Fuel Test CB2OT103 Data Reduction Results.

First data set minimum time = 100 milliseconds.
Second data set maximum time = 123.1 milliseconds.

Injection Time = 119.25 millisec
Injection Press = 775 psia
Injection Temp = 1252 °K

Ignition Time = 120.75 millisec

Ignition Delay = 1.50 millisec
Comb. Duration = 7.91 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
119.05	35519	13166	48685	1257	778	986	-1.749	2.99	0.693	116.89
119.15	35519	13089	48608	1257	778	986	-1.749	3.52	0.640	116.41
119.25	35652	12842	48494	1256	778	988	-1.768	4.20	0.567	115.55
119.35	35703	12699	48401	1256	777	990	-1.779	4.85	0.495	114.46
119.45	35704	12625	48329	1256	777	989	-1.777	5.42	0.431	113.15
119.55	35714	12539	48254	1256	777	989	-1.772	6.00	0.362	111.27
119.65	35890	12298	48187	1256	777	987	-1.752	6.50	0.301	108.84
119.75	35957	12130	48087	1256	777	985	-1.739	7.11	0.220	103.61
119.85	36605	11306	47911	1255	776	989	-1.778	8.17	0.078	67.29
119.95	36771	11049	47820	1254	776	992	-1.797	9.07	-0.047	216.55
120.05	37221	10552	47773	1254	776	988	-1.766	9.57	-0.122	159.30
120.15	37417	10268	47685	1254	776	986	-1.745	10.23	-0.225	142.90
120.25	37452	10099	47551	1254	776	987	-1.754	11.20	-0.377	135.11
120.35	37483	9959	47442	1253	776	988	-1.762	12.20	-0.538	131.69
120.45	37483	9879	47363	1253	776	988	-1.762	13.15	-0.699	129.85
120.55	37699	9595	47293	1253	776	986	-1.741	13.95	-0.846	128.80
120.65	37721	9478	47199	1253	776	985	-1.735	14.95	-1.031	127.90
120.75	37919	9211	47129	1252	775	987	-1.754	16.25	-1.268	127.16
120.85	37922	9214	47136	1252	775	987	-1.757	17.38	-1.487	126.70
120.95	38102	9134	47235	1251	774	989	-1.775	18.69	-1.740	126.32
121.05	38759	8570	47329	1252	775	985	-1.740	19.46	-1.915	126.13
121.15	38869	8553	47421	1252	775	984	-1.726	20.53	-2.152	125.92
121.25	38871	8703	47574	1252	775	984	-1.728	21.81	-2.434	125.73
121.35	38946	8831	47777	1252	775	983	-1.717	22.96	-2.704	125.60
121.45	39190	8804	47994	1252	775	981	-1.696	24.06	-2.976	125.49
121.55	39347	8893	48239	1252	775	979	-1.680	25.25	-3.281	125.40

Table 40. Otisca Slurry Fuel Test CB2OT104 Data Reduction Results.

First data set minimum time = 80 milliseconds.
Second data set maximum time = 124 milliseconds.

Injection Time = 114.5 millisec
Injection Press = 358 psia
Injection Temp = 1205 °K

Ignition Time = 116.25 millisec

Ignition Delay = 1.75 millisec
Comb. Duration = 10.52 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
115.05	54741	19337	74078	1208	359	510	-1.309	16.0	-0.182	158.91
115.15	54741	18855	73596	1208	359	510	-1.309	16.8	-0.268	146.47
115.25	54923	18224	73146	1208	359	509	-1.303	17.6	-0.354	140.15
115.35	55032	17631	72663	1208	359	509	-1.298	18.5	-0.446	136.03
115.45	55488	16659	72147	1206	359	510	-1.308	19.5	-0.560	132.86
115.55	56007	15769	71775	1207	359	509	-1.297	20.3	-0.656	131.04
115.65	56194	15153	71347	1207	359	508	-1.291	21.2	-0.764	129.54
115.75	56262	14650	70912	1206	358	508	-1.294	22.3	-0.890	128.27
115.85	56263	14320	70583	1206	358	508	-1.295	23.3	-1.017	127.32
115.95	56345	13983	70328	1206	358	508	-1.291	24.3	-1.145	126.58
116.05	56346	13785	70131	1205	358	508	-1.290	25.4	-1.285	125.95
116.15	56548	13461	70009	1205	358	507	-1.284	26.5	-1.424	125.45
116.25	56876	13036	69912	1206	358	507	-1.275	27.5	-1.569	125.02
116.35	57191	12759	69950	1205	358	507	-1.283	28.8	-1.742	124.62
116.45	57233	12952	70185	1204	358	507	-1.281	30.0	-1.906	124.31
116.55	58346	12098	70444	1205	358	506	-1.266	31.0	-2.062	124.07
116.65	58677	12059	70736	1205	358	505	-1.257	32.2	-2.238	123.84
116.75	58762	12390	71151	1205	358	505	-1.253	33.4	-2.429	123.63
116.85	59209	12460	71669	1206	358	504	-1.244	34.7	-2.621	123.46
116.95	59407	12911	72318	1206	358	503	-1.238	36.0	-2.829	123.31
117.05	60082	12976	73059	1206	359	502	-1.226	37.2	-3.038	123.17
117.15	60402	13537	73939	1207	359	501	-1.219	38.5	-3.264	123.06
117.25	60467	14725	75192	1206	358	502	-1.222	40.1	-3.517	122.95
117.35	60995	15652	76647	1206	358	501	-1.212	41.4	-3.752	122.86
117.45	63466	14605	78071	1208	359	499	-1.191	42.6	-3.980	122.80
117.55	63772	15966	79738	1208	359	498	-1.184	44.0	-4.248	122.73
117.65	64415	17205	81620	1208	359	497	-1.173	45.4	-4.519	122.68

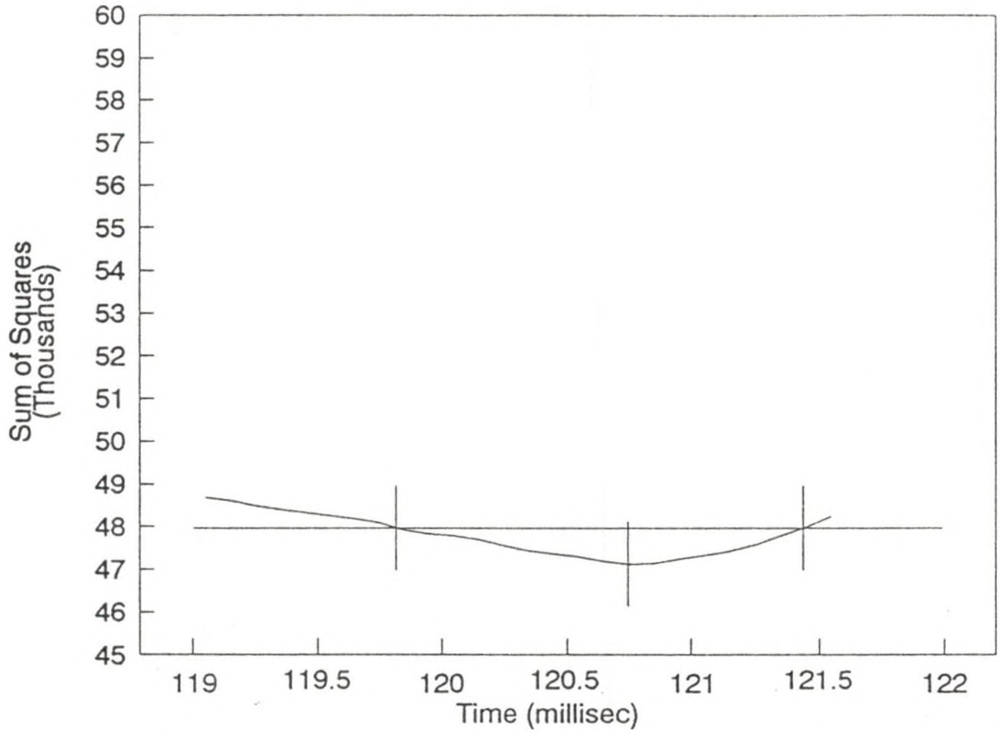

Figure 53. Otisca Slurry Test CB2OT103 Ignition Time Confidence Interval

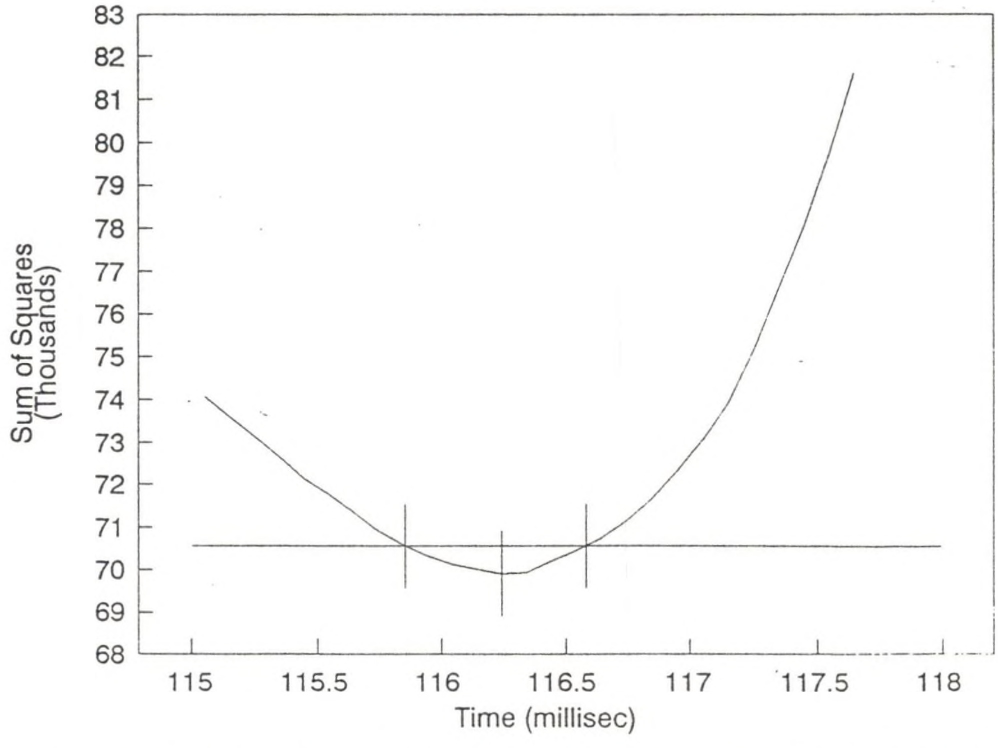

Figure 54. Otisca Slurry Test CB2OT104 Ignition Time Confidence Interval

Table 41. Otisca Slurry Fuel Test CB2OT105 Data Reduction Results.

First data set minimum time= 90 milliseconds.
Second data set maximum time= 135.5 milliseconds.

Injection Time = 122.70 millisec
Injection Press = 769 psia
Injection Temp = 1243 °K

Ignition Time = 126.05 millisec

Ignition Delay = 3.35 millisec
Comb. Duration = 12.13 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
124.05	47545	25852	73397	1238	766	1004	-1.913	6.54	-0.002	2053.67
124.15	47559	25510	73069	1238	766	1004	-1.915	6.91	-0.031	235.26
124.25	47738	25062	72800	1238	766	1003	-1.908	7.22	-0.057	187.77
124.35	47750	24695	72446	1237	766	1003	-1.910	7.61	-0.089	166.98
124.45	48081	23975	72057	1237	765	1004	-1.919	8.07	-0.128	156.12
124.55	48862	22970	71832	1237	766	1003	-1.905	8.35	-0.153	151.87
124.65	48866	22611	71476	1237	765	1003	-1.904	8.76	-0.189	147.87
124.75	48927	22164	71091	1236	765	1003	-1.908	9.21	-0.229	144.86
124.85	48958	21777	70735	1236	765	1003	-1.911	9.67	-0.270	142.73
124.95	49092	21343	70435	1236	765	1003	-1.905	10.06	-0.308	141.29
125.05	49197	20876	70072	1235	764	1003	-1.910	10.55	-0.354	139.94
125.15	49206	20566	69771	1235	764	1003	-1.909	11.00	-0.398	138.97
125.25	49251	20216	69467	1235	764	1004	-1.912	11.50	-0.447	138.11
125.35	49294	19913	69207	1234	764	1004	-1.915	12.01	-0.498	137.41
125.45	49294	19703	68997	1234	764	1004	-1.915	12.50	-0.548	136.86
125.55	49459	19356	68815	1234	764	1003	-1.909	12.94	-0.595	136.42
125.65	49494	19132	68626	1234	763	1003	-1.906	13.43	-0.648	136.01
125.75	49745	18724	68468	1233	763	1004	-1.913	14.02	-0.710	135.62
125.85	50012	18370	68383	1233	763	1003	-1.906	14.48	-0.763	135.34
125.95	50054	18246	68300	1233	763	1003	-1.903	14.99	-0.822	135.07
126.05	50065	18197	68263	1232	763	1003	-1.904	15.56	-0.886	134.83
126.15	50142	18137	68279	1232	763	1002	-1.900	16.09	-0.949	134.63
126.25	50424	17886	68310	1232	763	1002	-1.892	16.59	-1.010	134.46
126.35	50503	17860	68363	1232	763	1001	-1.888	17.14	-1.078	134.30
126.45	51072	17347	68419	1232	763	1000	-1.878	17.63	-1.143	134.16
126.55	51737	16715	68452	1232	763	999	-1.866	18.14	-1.211	134.04
126.65	51760	16744	68504	1232	763	999	-1.864	18.76	-1.292	133.91
126.75	51764	16868	68632	1232	762	999	-1.863	19.41	-1.378	133.80
126.85	51961	16849	68810	1232	762	998	-1.857	20.01	-1.460	133.70
126.95	51966	17104	69069	1232	762	998	-1.856	20.68	-1.552	133.61
127.05	52168	17219	69387	1232	762	997	-1.850	21.31	-1.641	133.54
127.15	52169	17652	69821	1231	762	997	-1.850	22.00	-1.740	133.47
127.25	53152	17091	70244	1231	762	996	-1.836	22.56	-1.826	133.43
127.35	53181	17591	70772	1231	762	996	-1.834	23.26	-1.930	133.37
127.45	53389	17989	71378	1231	762	995	-1.828	23.93	-2.033	133.33
127.55	53985	18029	72013	1231	762	994	-1.817	24.55	-2.134	133.30
127.65	54677	17995	72672	1232	762	993	-1.806	25.18	-2.240	133.27

Table 42. Velva Lignite Slurry Fuel Test CB2VL71.

First data set minimum time = 75 milliseconds.
Second data set maximum time = 109.68 milliseconds.

Injection Time = 98.58 millisec
Injection Press = 383 psia
Injection Temp = 1241 °K

Ignition Time = 99.66 millisec

Ignition Delay = 1.08 millisec
Comb. Duration = 9.55 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
97.26	13188	33273	46461	1246	385	545	-1.654	13.5	-0.115	155.58
97.38	13225	31979	45204	1246	385	545	-1.645	14.1	-0.166	139.92
97.5	13228	30555	43784	1245	384	545	-1.648	14.8	-0.223	130.78
97.62	13269	29178	42447	1245	384	544	-1.639	15.5	-0.279	125.44
97.74	13271	27686	40957	1244	384	544	-1.641	16.3	-0.342	121.54
97.86	13274	26218	39492	1244	384	544	-1.638	17.1	-0.407	118.82
97.98	13338	24559	37897	1243	383	545	-1.649	17.9	-0.480	116.64
98.1	13356	23117	36473	1242	383	545	-1.644	18.7	-0.551	115.10
98.22	13506	21603	35109	1242	383	543	-1.627	19.5	-0.621	113.92
98.34	13558	20079	33637	1242	383	542	-1.618	20.3	-0.698	112.90
98.46	14061	17824	31885	1240	383	545	-1.647	21.4	-0.795	111.93
98.58	14140	16299	30438	1239	382	546	-1.659	22.4	-0.887	111.19
98.7	14151	15039	29190	1239	382	545	-1.654	23.3	-0.977	110.62
98.82	14260	13772	28032	1239	382	544	-1.641	24.2	-1.068	110.15
98.94	14260	12588	26848	1238	382	544	-1.640	25.2	-1.169	109.72
99.06	14261	11508	25769	1237	382	544	-1.642	26.2	-1.275	109.35
99.18	14382	10450	24831	1236	381	546	-1.656	27.3	-1.391	109.01
99.3	14400	9765	24165	1236	381	545	-1.650	28.4	-1.502	108.74
99.42	14529	9123	23651	1236	381	544	-1.637	29.4	-1.614	108.52
99.54	14616	8644	23260	1236	381	543	-1.625	30.4	-1.733	108.32
99.66	14618	8437	23054	1235	381	543	-1.624	31.5	-1.861	108.13
99.78	14620	8503	23123	1235	381	543	-1.622	32.7	-1.993	107.97
99.9	14714	8737	23450	1235	381	542	-1.611	33.8	-2.126	107.84
100.02	14807	9229	24036	1234	381	541	-1.600	34.9	-2.263	107.72
100.14	14830	10133	24962	1234	381	541	-1.594	36.0	-2.408	107.62
100.26	14926	11305	26230	1234	381	540	-1.583	37.2	-2.554	107.54
100.38	16260	11301	27561	1236	381	536	-1.542	38.1	-2.686	107.47
100.5	16523	12713	29236	1236	381	535	-1.524	39.2	-2.839	107.41
100.62	16541	14902	31444	1236	381	534	-1.520	40.4	-3.004	107.35
100.74	17223	16653	33876	1237	382	532	-1.491	41.5	-3.158	107.31

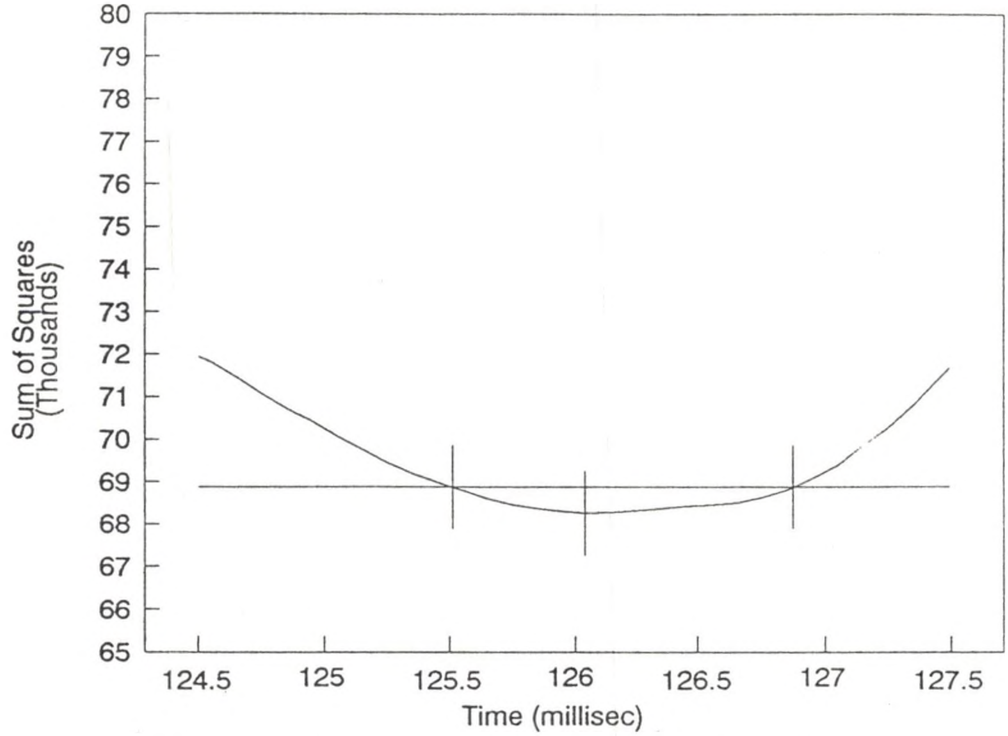

Figure 55. Otisca Slurry Test CB2OT105 Ignition Time Confidence Interval

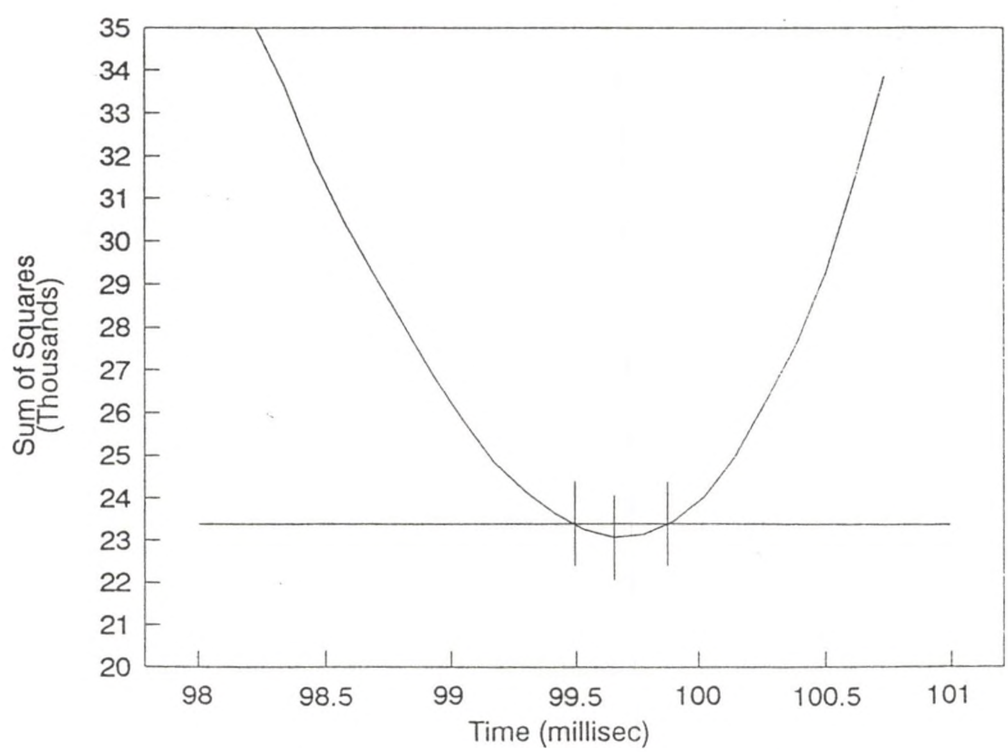

Figure 56. Velva Lignite Slurry Test CB2VL71 Ignition Time Confidence Interval

Table 43. Velva Lignite Slurry Test CB2VL72 Data Reduction Results.

First data set minimum time = 425 milliseconds.
Second data set maximum time = 443.96 milliseconds.

Injection Time = 435.92 millisec
Injection Press = 908 psia
Injection Temp = 1021 K

Ignition Time = 438.14 millisec

Ignition Delay = 2.22 millisec
Comb. Duration = 7.93 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
436.1	13355	11827	25181	-356	909	1226	-0.727	6.26	0.522	430.10
436.22	13358	11679	25037	-361	909	1230	-0.737	6.97	0.453	428.53
436.34	13463	11492	24954	-333	909	1206	-0.679	7.46	0.405	427.14
436.46	13931	11007	24939	-275	910	1155	-0.561	7.75	0.375	426.14
436.58	14233	10343	24576	-321	910	1195	-0.654	8.94	0.241	418.04
436.7	14242	10140	24382	-313	910	1188	-0.638	9.73	0.149	404.09
436.82	14266	9913	24179	-301	910	1177	-0.613	10.52	0.051	334.26
436.94	14402	9594	23996	-272	910	1152	-0.554	11.22	-0.042	572.04
437.06	14456	9180	23636	-290	910	1168	-0.590	12.41	-0.198	468.40
437.18	14464	8885	23349	-283	910	1162	-0.576	13.42	-0.340	456.92
437.3	14469	8545	23013	-288	910	1166	-0.587	14.60	-0.510	451.60
437.42	14658	7982	22640	-320	909	1194	-0.651	16.10	-0.728	448.48
437.54	14677	7703	22380	-330	909	1202	-0.671	17.43	-0.931	446.90
437.66	14758	7413	22171	-350	908	1220	-0.711	18.91	-1.163	445.79
437.78	14880	7170	22050	-326	909	1199	-0.662	19.96	-1.347	445.19
437.9	14914	7004	21918	-313	909	1188	-0.637	21.20	-1.567	444.66
438.02	14927	6882	21809	-306	909	1181	-0.622	22.55	-1.814	444.24
438.14	15098	6704	21802	-333	908	1205	-0.676	24.35	-2.133	443.85
438.26	15136	6782	21917	-320	908	1194	-0.651	25.70	-2.399	443.62
438.38	15387	6668	22054	-289	909	1166	-0.587	26.87	-2.651	443.45
438.5	15417	6846	22263	-278	909	1157	-0.565	28.35	-2.963	443.28
438.62	16775	5613	22388	-208	910	1095	-0.422	29.11	-3.183	443.19
438.74	16886	5770	22656	-228	910	1113	-0.462	31.17	-3.620	443.05
438.86	17340	5623	22964	-189	911	1078	-0.383	32.42	-3.946	442.97
438.98	17993	5253	23246	-142	911	1038	-0.288	33.65	-4.289	442.90
439.1	17994	5694	23688	-140	911	1036	-0.284	35.60	-4.772	442.83
439.22	18386	5798	24184	-105	912	1006	-0.214	37.07	-5.195	442.79
439.34	18441	6589	25030	-118	912	1017	-0.240	39.29	-5.766	442.75

Table 44. Velva Lignite Slurr Test CB2VL73 Data Reduction Results.

First data set minimum time = 390.08 milliseconds.
Second data set maximum time = 440 milliseconds.

Injection Time = 431.12 millisec
Injection Press = 423 psia
Injection Temp = 949 K

Ignition Time = 433.46 millisec

Ignition Delay = 2.34 millisec
Comb. Duration = 8.49 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
432.74	51701	11006	62707	947	423	551	-0.296	22.5	-1.07	443.30
432.86	51878	10199	62077	947	423	549	-0.291	23.9	-1.27	442.26
432.98	52109	9280	61389	948	423	546	-0.285	25.4	-1.50	441.46
433.1	52156	8489	60644	947	423	547	-0.288	27.1	-1.76	440.80
433.22	52581	7445	60026	947	422	551	-0.296	28.9	-2.04	440.29
433.34	52652	6985	59637	946	422	552	-0.299	30.7	-2.33	439.91
433.46	52828	6646	59474	946	422	554	-0.304	32.5	-2.64	439.61
433.58	52894	6703	59597	946	422	555	-0.307	34.3	-2.96	439.39
433.7	52903	7106	60009	946	422	556	-0.308	36.1	-3.28	439.21
433.82	53023	7632	60655	946	422	554	-0.304	37.9	-3.61	439.07
433.94	53458	7999	61457	946	422	551	-0.296	39.6	-3.94	438.96
434.06	53704	8749	62453	947	422	548	-0.290	41.4	-4.30	438.87
434.18	54631	8945	63576	947	423	544	-0.279	43.1	-4.67	438.80
434.3	56404	8311	64715	948	423	538	-0.264	44.9	-5.06	438.74
434.42	56795	9233	66028	949	423	535	-0.256	46.9	-5.51	438.68
434.54	57306	10292	67598	949	424	531	-0.248	48.9	-5.97	438.64
434.66	57900	11546	69446	950	424	528	-0.239	51.0	-6.46	438.60
434.78	58483	13134	71617	950	424	524	-0.231	53.1	-6.97	438.58
434.9	60402	13550	73952	951	424	518	-0.215	55.0	-7.49	438.57
435.02	62032	14432	76464	952	425	512	-0.201	57.1	-8.04	438.57
435.14	63257	16001	79258	953	425	507	-0.188	59.2	-8.64	438.57
435.26	65428	16826	82254	954	426	500	-0.172	61.3	-9.25	438.57
435.38	66809	18763	85573	955	426	495	-0.159	63.5	-9.91	438.58
435.5	70490	18493	88982	956	427	487	-0.138	65.5	-10.56	438.60
435.62	76110	16140	92250	958	427	476	-0.111	67.6	-11.27	438.62
435.74	79624	15894	95518	959	428	468	-0.091	70.0	-12.10	438.63
435.86	83066	15782	98847	961	429	460	-0.071	72.6	-13.01	438.65
435.98	87039	15156	102195	962	429	451	-0.049	75.3	-14.01	438.67

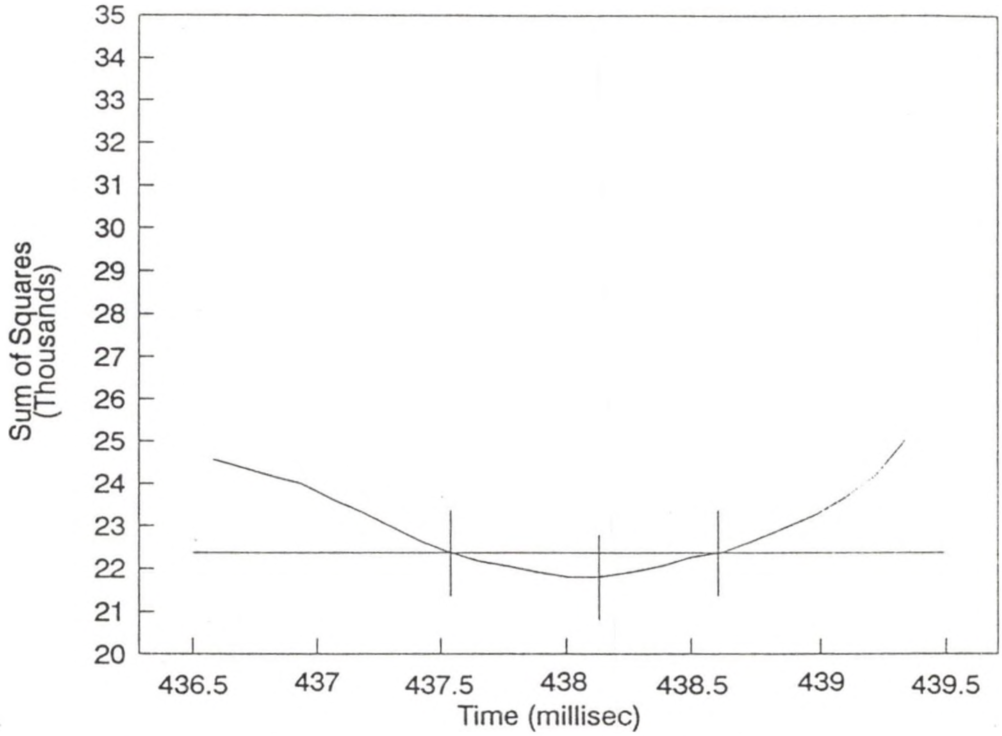

Figure 57. Velva Lignite Slurry Test CB2VL72 Ignition Time Confidence Interval

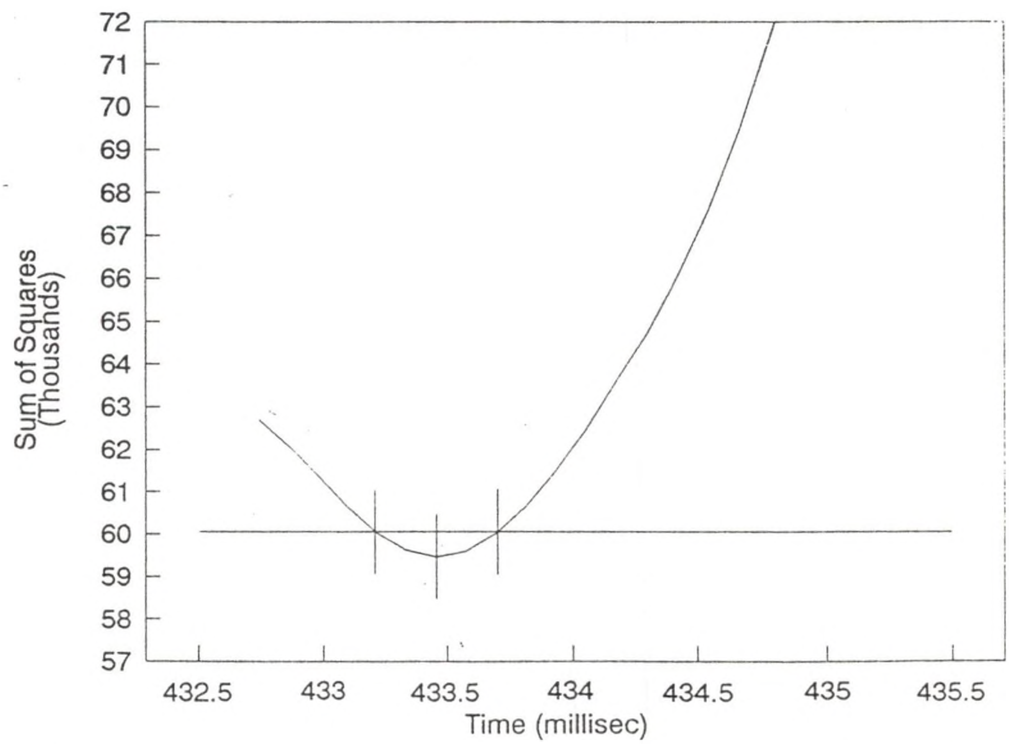

Figure 58. Velva Lignite Slurry Test CB2VL73 Ignition Time Confidence Interval

Table 45. Velva Lignite Slurry Test CB2VL74 Data Reduction Results.

First data set minimum time = 100.08 milliseconds.
Second data set maximum time = 132 milliseconds.

Injection Time = 125.40 millisec
Injection Press = 761 psia
Injection Temp = 1232 °K

Ignition Time = 126.66 millisec

Ignition Delay = 1.26 millisec
Comb. Duration = 5.90 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coeff	Data Set #2 c Coeff	Comb. Complete (msec)
125.1	34979	11118	46097	1234	762	939	-1.420	2.00	0.354	122.27
125.22	35008	11037	46045	1233	761	940	-1.426	2.50	0.298	121.02
125.34	35197	10824	46020	1234	761	938	-1.411	2.82	0.259	119.90
125.46	35849	10165	46014	1234	762	935	-1.382	3.08	0.223	118.54
125.58	36086	9780	45866	1233	761	937	-1.399	3.86	0.114	108.65
125.7	36185	9554	45739	1233	761	938	-1.410	4.61	0.007	-204.42
125.82	36237	9411	45648	1233	761	937	-1.402	5.20	-0.085	156.27
125.94	36290	9244	45534	1233	761	937	-1.394	5.85	-0.195	140.96
126.06	36562	8778	45340	1232	760	938	-1.412	6.85	-0.358	135.64
126.18	36708	8472	45180	1231	760	940	-1.425	7.81	-0.521	133.67
126.3	36709	8344	45053	1231	760	940	-1.424	8.64	-0.675	132.70
126.42	36752	8159	44912	1231	760	940	-1.430	9.62	-0.859	132.02
126.54	37542	7262	44803	1230	759	944	-1.459	10.87	-1.090	131.53
126.66	37560	7216	44776	1229	759	943	-1.455	11.69	-1.261	131.30
126.78	38060	6749	44809	1228	758	946	-1.477	12.86	-1.493	131.09
126.9	38085	6849	44933	1228	758	946	-1.482	13.75	-1.682	130.99
127.02	38233	6838	45070	1228	758	945	-1.470	14.40	-1.840	130.93
127.14	38962	6204	45166	1229	758	942	-1.444	14.93	-1.990	130.89
127.26	38986	6287	45272	1228	758	941	-1.439	15.85	-2.220	130.83
127.38	39049	6354	45403	1228	758	941	-1.431	16.75	-2.459	130.79
127.5	39335	6193	45528	1229	758	939	-1.415	17.59	-2.700	130.76
127.62	39358	6321	45679	1228	758	938	-1.411	18.66	-3.002	130.73
127.74	39406	6528	45934	1228	758	939	-1.417	19.87	-3.339	130.72
127.86	39451	6884	46335	1227	758	940	-1.423	20.94	-3.649	130.73
127.98	39867	6872	46739	1228	758	938	-1.404	21.49	-3.858	130.77

Table 46. Velva Lignite Slurry Test CB2VL112 Data Reduction Results.

First Data Set Minimum time = 150 milliseconds
Second Data Set Maximum time = 233 milliseconds

Injection Time = 226.90 millisec
Injection Press = 608 psia
Injection Temp = 1115 °K

Ignition Time = 229.55 millisec

Ignition Delay = 2.65 millisec
Comb. Duration = 4.79 millisec

to (msec)	Data Set #1 SS	Data Set #2 SS	Total SS	Temp (°K)	Po (psia)	Data Set #1 a Coeff	Data Set #1 b Coeff	Data Set #2 b Coef	Data Set #2 c Coeff	Comb. Complete (msec)
228.15	110475	11110	121586	1113	607	764	-0.688	9.57	-0.392	240.36
228.25	110511	11057	121567	1113	607	764	-0.688	10.37	-0.548	237.70
228.35	110546	10999	121545	1113	607	764	-0.687	11.23	-0.725	236.09
228.45	111194	10304	121498	1113	607	764	-0.685	12.12	-0.923	235.01
228.55	111533	9867	121400	1113	607	763	-0.683	13.20	-1.178	234.15
228.65	112309	8932	121241	1114	607	763	-0.680	14.44	-1.492	233.49
228.75	112644	8346	120990	1114	607	763	-0.678	15.96	-1.896	232.96
228.85	112678	7979	120657	1114	607	763	-0.678	17.77	-2.392	232.56
228.95	112748	7511	120258	1114	607	762	-0.677	19.77	-2.973	232.27
229.05	112818	6955	119773	1113	607	762	-0.676	22.02	-3.659	232.06
229.15	112940	6269	119210	1113	607	762	-0.677	24.60	-4.468	231.90
229.25	113193	5461	118654	1113	607	763	-0.679	27.32	-5.362	231.80
229.35	114810	3404	118214	1112	607	763	-0.683	30.15	-6.321	231.73
229.45	115050	2938	117988	1112	607	764	-0.684	32.74	-7.262	231.70
229.55	115549	2410	117959	1112	606	764	-0.686	35.27	-8.226	231.69
229.65	115595	2503	118098	1112	606	764	-0.686	37.58	-9.177	231.70
229.75	115755	2661	118416	1112	606	764	-0.687	39.92	-10.179	231.71
229.85	115803	3139	118942	1112	606	764	-0.686	41.98	-11.140	231.73
229.95	115823	3833	119656	1111	606	764	-0.686	43.91	-12.098	231.76
230.05	115872	4719	120591	1111	606	764	-0.685	45.56	-12.995	231.80
230.15	116575	5083	121657	1111	606	763	-0.683	46.87	-13.814	231.85
230.25	117412	5371	122783	1112	606	763	-0.680	48.09	-14.635	231.89
230.35	119746	4102	123847	1112	607	762	-0.675	49.28	-15.515	231.94
230.45	120880	3974	124854	1112	607	762	-0.672	50.83	-16.595	231.98
230.55	122565	3243	125808	1112	607	761	-0.668	52.54	-17.828	232.02
230.65	123239	3525	126763	1112	607	760	-0.666	54.52	-19.262	232.07
230.75	124526	3203	127729	1113	607	760	-0.663	56.49	-20.799	232.11
230.85	125804	2850	128654	1113	607	759	-0.659	58.75	-22.601	232.15

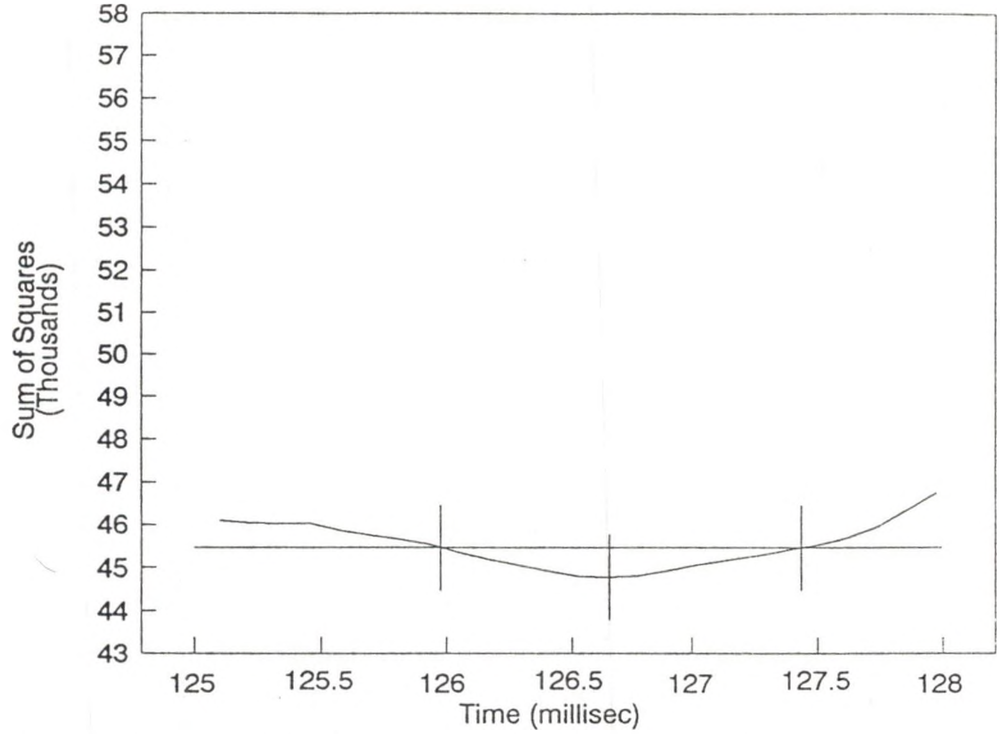

Figure 59. Velva Lignite Slurry Test CB2VL74 Ignition Time Confidence Interval

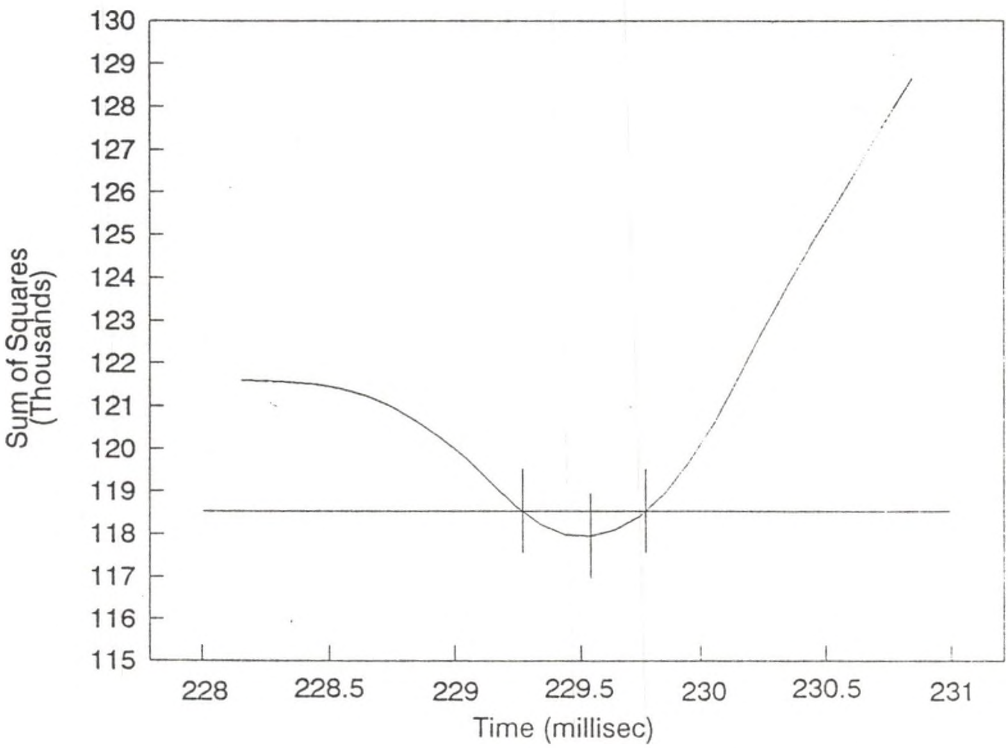

Figure 60. Velva Lignite Slurry Test CB2VL112 Ignition Time Confidence Interval

Appendix C - Statistical Analysis of the Ignition Delays, Combustion Durations and Heats of Combustion

The ignition delay, combustion duration, and heat of combustion results were analyzed to determine the statistical significance of the effects of fuel type, injection temperature, injection pressure, and slurry percent solids. The significance of interactions and curvature were also examined. This was done using the regression analysis capabilities of Lotus 1-2-3. The data was split into two major sets with the diesel fuel data comprising one set and the slurry fuel data comprising the other. The dependent variables considered individually for each of these two data sets were the ignition delay, the combustion duration and the heat of combustion. Thus, this procedure was performed six different times.

In the data set for slurry fuels there were two Otisca slurry runs at low bomb injection temperature where ignition of the fuel did not occur. For those two runs, the ignition delay was set to 10 milliseconds and the combustion duration was set to 20 milliseconds. This was done because the information from these two runs was an important part of this study and needed to be a part of the statistical analysis.

In performing the analysis, the bomb injection temperature, bomb injection pressure, and the slurry percent solids were normalized using the following equations:

Normalized temperature, x_1 = (1100 - temperature)/200

Normalized pressure, x_2 = (600 - pressure)/200

Normalized percent solids, x_3 = (50 - percent solids)/5

The normalization was done using actual test conditions. If the actual test condition equaled the design test condition, the normalized condition would equal +1, 0, or -1. In investigating the effect of slurry type, the Otisca slurry was arbitrarily given a value of +1 and the Velva lignite slurry was given a value of -1.

In each of the six analyses performed, the significance was first tested on the main independent variables, plus all interactions and curvature terms. The interaction and curvature terms that were insignificant were then removed and the data regression was performed again on the remaining terms. This was repeated until only the significant independent variables and interactions remained. The curvature was not found to be significant in any of the statistical analyses.

Table 47. Diesel Fuel Ignition Delay Significance Testing.

Trial	Fuel Injection Bomb Conditions Moles (gmol)	Temp (°K)	Pressure (psia)	Ignition Delay (millisec)	Combustion Duration (millisec)	Match With Design Run #
CB2DF53	0.129	1321	596	1.38	9.23	No Match
CB2DF61	0.149	1091	570	1.86	5.29	5
CB2DF62	0.089	1149	360	1.14	9.26	No Match
CB2DF63	0.156	1070	584	1.44	9.55	5
CB2DF65	0.128	927	416	1.26	9.97	1
CB2DF67	0.177	1284	793	1.38	10.17	4
CB2DF68	0.255	1030	918	1.98	9.23	No Match
CB2DF69	0.156	1139	620	1.44	8.4	5
CB3DF75	0.088	1209	374	1.02	8.23	2
CB3DF85	0.244	935	797	1.98	11.86	3
CB3DF86	0.156	1168	636	1.26	10.49	5
CB2DF114	0.088	1267	390	1.45	7.96	2

Significance Test

Trial	Ignition Delay (millisec) y	Norm. Temp x1	Norm. Pressure x2	x1x2	x2^2	x1^2
CB2DF53	1.38	1.105	-0.02	-0.022	0.000	1.221
CB2DF61	1.86	-0.045	-0.15	0.007	0.023	0.002
CB2DF62	1.14	0.245	-1.2	-0.294	1.440	0.060
CB2DF63	1.44	-0.15	-0.08	0.012	0.006	0.023
CB2DF65	1.26	-0.865	-0.92	0.796	0.846	0.748
CB2DF67	1.38	0.92	0.965	0.888	0.931	0.846
CB2DF68	1.98	-0.35	1.59	-0.557	2.528	0.122
CB2DF69	1.44	0.195	0.1	0.020	0.010	0.038
CB3DF75	1.02	0.545	-1.13	-0.616	1.277	0.297
CB3DF85	1.98	-0.825	0.985	-0.813	0.970	0.681
CB3DF86	1.26	0.34	0.18	0.061	0.032	0.116
CB2DF114	1.45	0.835	-1.05	-0.877	1.103	0.697

y = Combustion Duration
Regression Output:

Constant		1.505			
Std Err of Y Est		0.216			
R Squared		0.742			
No. of Observations		12			
Degrees of Freedom		6			
X Coefficient(s)	-0.182	0.237	-0.223	-0.061	0.063
Std Err of Coef.	0.111	0.075	0.129	0.093	0.170
t value	-1.635	3.175	-1.726	-0.655	0.372

Table 47. Diesel Fuel Ignition Delay Significance Testing (cont.).

Significance Test

Trial	Ignition Delay (millisec) y	Norm. Temp. x1	Norm. Pressure x2	(x1)(x2)
CB2DF53	1.38	1.105	-0.02	-0.022
CB2DF61	1.86	-0.045	-0.15	0.007
CB2DF62	1.14	0.245	-1.2	-0.294
CB2DF63	1.44	-0.15	-0.08	0.012
CB2DF65	1.26	-0.865	-0.92	0.796
CB2DF67	1.38	0.92	0.965	0.888
CB2DF68	1.98	-0.35	1.59	-0.557
CB2DF69	1.44	0.195	0.1	0.020
CB3DF75	1.02	0.545	-1.13	-0.616
CB3DF85	1.98	-0.825	0.985	-0.813
CB3DF86	1.26	0.34	0.18	0.061
CB2DF114	1.45	0.835	-1.05	-0.877

Regression Output:

Constant		1.484	
Std Err of Y Est		0.195	
R Squared		0.720	
No. of Observations		12	
Degrees of Freedom		8	
X Coefficient(s)	-0.158	0.231	-0.183
Std Err of Coef.	0.094	0.066	0.105
t value	-1.685	3.491	-1.737

With 8 degrees of freedom, term is significant at 95% confidence level if t value is greater than 2.306

Table 47. Diesel Fuel Ignition Delay Significance Testing (cont.).

Significance Test

Trial	Ignition Delay (millisec) y	Norm. Temp. x1	Norm. Pressure x2
CB2DF53	1.38	1.105	-0.02
CB2DF61	1.86	-0.045	-0.15
CB2DF62	1.14	0.245	-1.2
CB2DF63	1.44	-0.15	-0.08
CB2DF65	1.26	-0.865	-0.92
CB2DF67	1.38	0.92	0.965
CB2DF68	1.98	-0.35	1.59
CB2DF69	1.44	0.195	0.1
CB3DF75	1.02	0.545	-1.13
CB3DF85	1.98	-0.825	0.985
CB3DF86	1.26	0.34	0.18
CB2DF114	1.45	0.835	-1.05

Regression Output:

Constant		1.506
Std Err of Y Est		0.216
R Squared		0.614
No. of Observations		12
Degrees of Freedom		9
X Coefficient(s)	-0.163	0.223
Std Err of Coef.	0.104	0.073
t value	-1.574	3.060

With 9 degrees of freedom, term is significant
at 95% confidence level if t value is greater than 2.262

Table 47. Diesel Fuel Ignition Delay Significance Testing (cont.).

Significance Test

Trial	Ignition Delay (millisec) y	Norm. Pressure x2
CB2DF53	1.38	-0.02
CB2DF61	1.86	-0.15
CB2DF62	1.14	-1.2
CB2DF63	1.44	-0.08
CB2DF65	1.26	-0.92
CB2DF67	1.38	0.965
CB2DF68	1.98	1.59
CB2DF69	1.44	0.1
CB3DF75	1.02	-1.13
CB3DF85	1.98	0.985
CB3DF86	1.26	0.18
CB2DF114	1.45	-1.05

Regression Output:

Constant		1.481
Std Err of Y Est		0.232
R Squared		0.508
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	0.246	
Std Err of Coef.	0.077	
t value	3.211	

With 10 degrees of freedom, term is significant
at 95% confidence level if t value is greater than 2.228

Table 48. Diesel Fuel Combustion Duration Significance Testing.

Trial	Fuel Injection Bomb Conditions Moles (gmol)	Temp (°K)	Pressure (psia)	Ignition Delay (millisec)	Combustion Duration (millisec)	Match With Design Run #
CB2DF53	0.129	1321	596	1.38	9.23	No Match
CB2DF61	0.149	1091	570	1.86	5.29	5
CB2DF62	0.089	1149	360	1.14	9.26	No Match
CB2DF63	0.156	1070	584	1.44	9.55	5
CB2DF65	0.128	927	416	1.26	9.97	1
CB2DF67	0.177	1284	793	1.38	10.17	4
CB2DF68	0.255	1030	918	1.98	9.23	No Match
CB2DF69	0.156	1139	620	1.44	8.4	5
CB3DF75	0.088	1209	374	1.02	8.23	2
CB3DF85	0.244	935	797	1.98	11.86	3
CB3DF86	0.156	1168	636	1.26	10.49	5
CB2DF114	0.088	1267	390	1.45	7.96	2

Significance Test

Trial	Combustion Duration (msec) y	Normal. Temp. x1	Normal. Pressure x2	(x1)(x2)	(x2)^2	(x1)^2
CB2DF53	9.23	1.105	-0.02	-0.022	0.000	1.221
CB2DF61	5.29	-0.045	-0.15	0.007	0.023	0.002
CB2DF62	9.26	0.245	-1.2	-0.294	1.440	0.060
CB2DF63	9.55	-0.15	-0.08	0.012	0.006	0.023
CB2DF65	9.97	-0.865	-0.92	0.796	0.846	0.748
CB2DF67	10.17	0.92	0.965	0.888	0.931	0.846
CB2DF68	9.23	-0.35	1.59	-0.557	2.528	0.122
CB2DF69	8.4	0.195	0.1	0.020	0.010	0.038
CB3DF75	8.23	0.545	-1.13	-0.616	1.277	0.297
CB3DF85	11.86	-0.825	0.985	-0.813	0.970	0.681
CB3DF86	10.49	0.34	0.18	0.061	0.032	0.116
CB2DF114	7.96	0.835	-1.05	-0.877	1.103	0.697

Regression Output:

Constant		8.519			
Std Err of Y Est		1.774			
R Squared		0.344			
No. of Observations		12			
Degrees of Freedom		6			
X Coefficient(s)	-0.815	0.479	0.090	0.147	1.678
Std Err of Coef.	0.913	0.611	1.057	0.761	1.396
t value	-0.893	0.784	0.085	0.193	1.201

With 6 degrees of freedom, term is significant
at 95% confidence level if t value is greater than 2.447

Table 48. Diesel Fuel Combustion Duration Significance Testing (cont.).

Significance Test

Trial	Combustion Duration (msec) y	Normal. Temp. x1	Normal. Pressure x2	(x1)^2
CB2DF53	9.23	1.105	-0.02	1.221
CB2DF61	5.29	-0.045	-0.15	0.002
CB2DF62	9.26	0.245	-1.2	0.060
CB2DF63	9.55	-0.15	-0.08	0.023
CB2DF65	9.97	-0.865	-0.92	0.748
CB2DF67	10.17	0.92	0.965	0.846
CB2DF68	9.23	-0.35	1.59	0.122
CB2DF69	8.4	0.195	0.1	0.038
CB3DF75	8.23	0.545	-1.13	0.297
CB3DF85	11.86	-0.825	0.985	0.681
CB3DF86	10.49	0.34	0.18	0.116
CB2DF114	7.96	0.835	-1.05	0.697

Regression Output:

Constant		8.614	
Std Err of Y Est		1.541	
R Squared		0.340	
No. of Observations		12	
Degrees of Freedom		8	
X Coefficient(s)	-0.849	0.499	1.708
Std Err of Coef.	0.779	0.523	1.187
t value	-1.090	0.953	1.439

With 8 degrees of freedom, term is significant
at 95% confidence level if t value is greater than 2.306

Table 48. Diesel Fuel Combustion Duration Significance Testing (cont.).

Significance Test

Trial	Combustion Duration (msec) y	Normal. Temp. x1	Normal. Pressure x2
CB2DF53	9.23	1.105	-0.02
CB2DF61	5.29	-0.045	-0.15
CB2DF62	9.26	0.245	-1.2
CB2DF63	9.55	-0.15	-0.08
CB2DF65	9.97	-0.865	-0.92
CB2DF67	10.17	0.92	0.965
CB2DF68	9.23	-0.35	1.59
CB2DF69	8.4	0.195	0.1
CB3DF75	8.23	0.545	-1.13
CB3DF85	11.86	-0.825	0.985
CB3DF86	10.49	0.34	0.18
CB2DF114	7.96	0.835	-1.05

Regression Output:

Constant		9.252
Std Err of Y Est		1.630
R Squared		0.169
No. of Observations		12
Degrees of Freedom		9
X Coefficient(s)	-0.492	0.576
Std Err of Coef.	0.781	0.551
t value	-0.630	1.047

With 9 degrees of freedom, term is significant
at 95% confidence level if t value is greater than 2.262

Table 49. Slurry Fuel Ignition Delay Significance Testing.

Trial	Slurry % Solids (%)	Fuel Inj. Moles (gmol)	Bomb Conditions Temp (°K)	Bomb Conditions Pressure (psia)	Ignition Delay (msec)	Comb. Duration (msec)	Design Run Match
CB2OT89	53.4	0.129	901	406	5.85	17.57	5
CB2OT90	53.4	0.177	1254	776	1.75	7.69	8
CB2OT91	53.4	0.089	1201	373	1.45	13.20	6
CB2OT93	53.4	0.254	868	772	6.90	14.75	7
CB2OT94	53.4	0.089	1336	415	1.95	14.48	6
CB2OT97	49.4	0.158	1137	631	2.75	12.03	9
CB2OT99	49.4	0.156	1106	603	1.55	7.43	9
CB2OT102	44.0	0.087	1270	386	1.15	7.16	2
CB2OT103	44.0	0.177	1252	775	1.50	7.91	4
CB2OT104	44.0	0.085	1205	358	1.75	10.52	2
CB2OT105	44.0	0.177	1243	769	3.35	12.13	4
CB2VL71	45.4	0.088	1241	383	1.08	9.55	2
CB2VL72	45.4	0.255	1021	908	2.22	7.93	3
CB2VL73	45.4	0.128	949	423	2.34	8.49	1
CB2VL74	45.4	0.176	1232	761	1.26	5.90	4
CB2VL112	49.3	0.156	1115	608	2.65	4.79	5
CB2OT106	44.0	0.255	909	808	10	20	3
CB2OT107	44.0	0.126	924	407	10	20	1

Table 49. Slurry Fuel Ignition Delay Significance Testing (cont.).

Significance Test

Trial	Ignition Delay y	Norm. Slurry x0	Norm. Temp. x1	Norm. Pressure x2	Norm. %solids x3	(x1)(x2)	(x1)(x3)	(x2)(x3)	(x0)(x1)	(x0)(x2)	(x0)(x3)	(x2)^2
CB2OT89	5.85	1	-0.995	-0.97	0.68	0.965	-0.677	-0.660	-0.995	-0.970	0.680	0.941
CB2OT90	1.75	1	0.77	0.88	0.68	0.678	0.524	0.598	0.770	0.880	0.680	0.774
CB2OT91	1.45	1	0.505	-1.135	0.68	-0.573	0.343	-0.772	0.505	-1.135	0.680	1.288
CB2OT93	6.90	1	-1.16	0.86	0.68	-0.998	-0.789	0.585	-1.160	0.860	0.680	0.740
CB2OT94	1.95	1	1.18	-0.925	0.68	-1.092	0.802	-0.629	1.180	-0.925	0.680	0.856
CB2OT97	2.75	1	0.185	0.155	-0.12	0.029	-0.022	-0.019	0.185	0.155	-0.120	0.024
CB2OT99	1.55	1	0.03	0.015	-0.12	0.000	-0.004	-0.002	0.030	0.015	-0.120	0.000
CB2OT102	1.15	1	0.85	-1.07	-1.2	-0.910	-1.020	1.284	0.850	-1.070	-1.200	1.145
CB2OT103	1.50	1	0.76	0.875	-1.2	0.665	-0.912	-1.050	0.760	0.875	-1.200	0.766
CB2OT104	1.75	1	0.525	-1.21	-1.2	-0.635	-0.630	1.452	0.525	-1.210	-1.200	1.464
CB2OT105	3.35	1	0.715	0.845	-1.2	0.604	-0.858	-1.014	0.715	0.845	-1.200	0.714
CB2VL71	1.08	-1	0.705	-1.085	-0.92	-0.765	-0.649	0.998	-0.705	1.085	0.920	1.177
CB2VL72	2.22	-1	-0.395	1.54	-0.92	-0.608	0.363	-1.417	0.395	-1.540	0.920	2.372
CB2VL73	2.34	-1	-0.755	-0.885	-0.92	0.668	0.695	0.814	0.755	0.885	0.920	0.783
CB2VL74	1.26	-1	0.66	0.805	-0.92	0.531	-0.607	-0.741	-0.660	-0.805	0.920	0.648
CB2VL112	2.65	-1	0.075	0.04	-0.14	0.003	-0.011	-0.006	-0.075	-0.040	0.140	0.002
CB2OT106	10	1	-0.955	1.04	-1.2	-0.993	1.146	-1.248	-0.955	1.040	-1.200	1.082
CB2OT107	10	1	-0.88	-0.965	-1.2	0.849	1.056	1.158	-0.880	-0.965	-1.200	0.931

Regression Output:

Constant	3.161
Std Err of Y Est	1.359
R Squared	0.922
No. of Observations	18
Degrees of Freedom	6

	x0	x1	x2	x3	(x1)(x2)	(x1)(x3)	(x2)(x3)	(x0)(x1)	(x0)(x2)	(x0)(x3)	(x2)^2
X Coefficient(s)	0.183	-1.224	0.003	0.838	0.223	1.363	-0.108	-1.952	0.329	-1.722	0.932
Std Err of Coef.	0.937	0.684	0.489	1.262	0.519	0.518	0.465	0.638	0.450	1.194	0.921
t value	0.195	-1.789	0.005	0.664	0.429	2.628	-0.233	-3.062	0.732	-1.442	1.012

Table 49. Slurry Fuel Ignition Delay Significance Testing (cont.).

Significance Test

Trial	Ignition Delay y	Norm. Slurry x0	Norm. Temp. x1	Norm. Pressure x2	Norm. %solids x3	(x1)(x3)	(x0)(x1)	(x0)(x3)	(x2)^2
CB2OT89	5.85	1	-0.995	-0.97	0.68	-0.677	-0.995	0.680	0.941
CB2OT90	1.75	1	0.77	0.88	0.68	0.524	0.770	0.680	0.774
CB2OT91	1.45	1	0.505	-1.135	0.68	0.343	0.505	0.680	1.288
CB2OT93	6.90	1	-1.16	0.86	0.68	-0.789	-1.160	0.680	0.740
CB2OT94	1.95	1	1.18	-0.925	0.68	0.802	1.180	0.680	0.856
CB2OT97	2.75	1	0.185	0.155	-0.12	-0.022	0.185	-0.120	0.024
CB2OT99	1.55	1	0.03	0.015	-0.12	-0.004	0.030	-0.120	0.000
CB2OT102	1.15	1	0.85	-1.07	-1.2	-1.020	0.850	-1.200	1.145
CB2OT103	1.50	1	0.76	0.875	-1.2	-0.912	0.760	-1.200	0.766
CB2OT104	1.75	1	0.525	-1.21	-1.2	-0.630	0.525	-1.200	1.464
CB2OT105	3.35	1	0.715	0.845	-1.2	-0.858	0.715	-1.200	0.714
CB2VL71	1.08	-1	0.705	-1.085	-0.92	-0.649	-0.705	0.920	1.177
CB2VL72	2.22	-1	-0.395	1.54	-0.92	0.363	0.395	0.920	2.372
CB2VL73	2.34	-1	-0.755	-0.885	-0.92	0.695	0.755	0.920	0.783
CB2VL74	1.26	-1	0.66	0.805	-0.92	-0.607	-0.660	0.920	0.648
CB2VL112	2.65	-1	0.075	0.04	-0.14	-0.011	-0.075	0.140	0.002
CB2OT106	10	1	-0.955	1.04	-1.2	1.146	-0.955	-1.200	1.082
CB2OT107	10	1	-0.88	-0.965	-1.2	1.056	-0.880	-1.200	0.931

Regression Output:

Constant			3.266						
Std Err of Y Est			1.169						
R Squared			0.913						
No. of Observations			18						
Degrees of Freedom			9						
X Coefficient(s)		0.386	-1.322	0.182	0.486	1.353	-1.887	-1.420	0.495
Std Err of Coef.		0.775	0.561	0.301	0.999	0.439	0.536	0.971	0.605
t value		0.498	-2.355	0.606	0.486	3.083	-3.517	-1.463	0.820

Table 49. Slurry Fuel Ignition Delay Significance Testing (cont.).

Significance Test

Trial	Ignition Delay y	Norm. Slurry x0	Norm. Temp. x1	Norm. Pressure x2	Norm. %solids x3	(x1)(x3)	(x0)(x1)
CB2OT89	5.85	1	-0.995	-0.97	0.68	-0.677	-0.995
CB2OT90	1.75	1	0.77	0.88	0.68	0.524	0.770
CB2OT91	1.45	1	0.505	-1.135	0.68	0.343	0.505
CB2OT93	6.90	1	-1.16	0.86	0.68	-0.789	-1.160
CB2OT94	1.95	1	1.18	-0.925	0.68	0.802	1.180
CB2OT97	2.75	1	0.185	0.155	-0.12	-0.022	0.185
CB2OT99	1.55	1	0.03	0.015	-0.12	-0.004	0.030
CB2OT102	1.15	1	0.85	-1.07	-1.2	-1.020	0.850
CB2OT103	1.50	1	0.76	0.875	-1.2	-0.912	0.760
CB2OT104	1.75	1	0.525	-1.21	-1.2	-0.630	0.525
CB2OT105	3.35	1	0.715	0.845	-1.2	-0.858	0.715
CB2VL71	1.08	-1	0.705	-1.085	-0.92	-0.649	-0.705
CB2VL72	2.22	-1	-0.395	1.54	-0.92	0.363	0.395
CB2VL73	2.34	-1	-0.755	-0.885	-0.92	0.695	0.755
CB2VL74	1.26	-1	0.66	0.805	-0.92	-0.607	-0.660
CB2VL112	2.65	-1	0.075	0.04	-0.14	-0.011	-0.075
CB2OT106	10	1	-0.955	1.04	-1.2	1.146	-0.955
CB2OT107	10	1	-0.88	-0.965	-1.2	1.056	-0.880

Regression Output:

Constant		2.666				
Std Err of Y Est		1.178				
R Squared		0.893				
No. of Observations		18				
Degrees of Freedom		11				
X Coefficient(s)	1.409	-1.388	0.171	-0.879	1.354	-1.807
Std Err of Coef.	0.326	0.558	0.303	0.374	0.442	0.531
t value	4.327	-2.487	0.565	-2.350	3.065	-3.403

Table 49. Slurry Fuel Ignition Delay Significance Testing (cont.).

Significance Test

Trial	Ignition Delay y	Norm. Slurry x0	Norm. Temp. x1	Norm. %solids x3	(x1)(x3)	(x0)(x1)
CB2OT89	5.85	1	-0.995	0.68	-0.677	-0.995
CB2OT90	1.75	1	0.77	0.68	0.524	0.770
CB2OT91	1.45	1	0.505	0.68	0.343	0.505
CB2OT93	6.90	1	-1.16	0.68	-0.789	-1.160
CB2OT94	1.95	1	1.18	0.68	0.802	1.180
CB2OT97	2.75	1	0.185	-0.12	-0.022	0.185
CB2OT99	1.55	1	0.03	-0.12	-0.004	0.030
CB2OT102	1.15	1	0.85	-1.2	-1.020	0.850
CB2OT103	1.50	1	0.76	-1.2	-0.912	0.760
CB2OT104	1.75	1	0.525	-1.2	-0.630	0.525
CB2OT105	3.35	1	0.715	-1.2	-0.858	0.715
CB2VL71	1.08	-1	0.705	-0.92	-0.649	-0.705
CB2VL72	2.22	-1	-0.395	-0.92	0.363	0.395
CB2VL73	2.34	-1	-0.755	-0.92	0.695	0.755
CB2VL74	1.26	-1	0.66	-0.92	-0.607	-0.660
CB2VL112	2.65	-1	0.075	-0.14	-0.011	-0.075
CB2OT106	10	1	-0.955	-1.2	1.146	-0.955
CB2OT107	10	1	-0.88	-1.2	1.056	-0.880

Regression Output:

Constant		2.656			
Std Err of Y Est		1.144			
R Squared		0.889			
No. of Observations		18			
Degrees of Freedom		12			
X Coefficient(s)	1.395	-1.416	-0.893	1.345	-1.807
Std Err of Coef.	0.315	0.540	0.362	0.429	0.516
t value	4.424	-2.624	-2.465	3.135	-3.503

Table 50. Slurry Fuel Combustion Duration Significance Testing.

Trial	Slurry % Solids (%)	Fuel Inj. Moles (gmol)	Bomb Conditions Temp (°K)	Bomb Conditions Pressure (psia)	Ignition Delay (msec)	Combustion Duration (msec)	Design Run Match
CB2OT89	53.4	0.129	901	406	5.85	17.57	5
CB2OT90	53.4	0.177	1254	776	1.75	7.69	8
CB2OT91	53.4	0.089	1201	373	1.45	13.20	6
CB2OT93	53.4	0.254	868	772	6.90	14.75	7
CB2OT94	53.4	0.089	1336	415	1.95	14.48	6
CB2OT97	49.4	0.158	1137	631	2.75	12.03	9
CB2OT99	49.4	0.156	1106	603	1.55	7.43	9
CB2OT102	44.0	0.087	1270	386	1.15	7.16	2
CB2OT103	44.0	0.177	1252	775	1.50	7.91	4
CB2OT104	44.0	0.085	1205	358	1.75	10.52	2
CB2OT105	44.0	0.177	1243	769	3.35	12.13	4
CB2VL71	45.4	0.088	1241	383	1.08	9.55	2
CB2VL72	45.4	0.255	1021	908	2.22	7.93	3
CB2VL73	45.4	0.128	949	423	2.34	8.49	1
CB2VL74	45.4	0.176	1232	761	1.26	5.90	4
CB2VL112	49.3	0.156	1115	608	2.65	4.79	5
CB2OT106	44.0	0.255	909	808	10	20	3
CB2OT107	44.0	0.126	924	407	10	20	1

Table 50. Slurry Fuel Combustion Duration Significance Testing (cont.).

Significance Test

Trial	Combustio] Duration y	Norm. Slurry x0	Norm. Temp. x1	Norm. Pressure x2	Norm. % solids x3	(x1)(x2)	(x1)(x3)	(x2)(x3)	(x0)(x1)	(x0)(x2)	(x0)(x3)	(x2)^2
CB2OT89	17.57	1	-0.995	-0.97	0.68	0.965	-0.677	-0.660	-0.995	-0.970	0.680	0.941
CB2OT90	7.69	1	0.77	0.88	0.68	0.678	0.524	0.598	0.770	0.880	0.680	0.774
CB2OT91	13.20	1	0.505	-1.135	0.68	-0.573	0.343	-0.772	0.505	-1.135	0.680	1.288
CB2OT93	14.75	1	-1.16	0.86	0.68	-0.998	-0.789	0.585	-1.160	0.860	0.680	0.740
CB2OT94	14.48	1	1.18	-0.925	0.68	-1.092	0.802	-0.629	1.180	-0.925	0.680	0.856
CB2OT97	12.03	1	0.185	0.155	-0.12	0.029	-0.022	-0.019	0.185	0.155	-0.120	0.024
CB2OT99	7.43	1	0.03	0.015	-0.12	0.000	-0.004	-0.002	0.030	0.015	-0.120	0.000
CB2OT102	7.16	1	0.85	-1.07	-1.2	-0.910	-1.020	1.284	0.850	-1.070	-1.200	1.145
CB2OT103	7.91	1	0.76	0.875	-1.2	0.665	-0.912	-1.050	0.760	0.875	-1.200	0.766
CB2OT104	10.52	1	0.525	-1.21	-1.2	-0.635	-0.630	1.452	0.525	-1.210	-1.200	1.464
CB2OT105	12.13	1	0.715	0.845	-1.2	0.604	-0.858	-1.014	0.715	0.845	-1.200	0.714
CB2VL71	9.55	-1	0.705	-1.085	-0.92	-0.765	-0.649	0.998	-0.705	1.085	0.920	1.177
CB2VL72	7.93	-1	-0.395	1.54	-0.92	-0.608	0.363	-1.417	0.395	-1.540	0.920	2.372
CB2VL73	8.49	-1	-0.755	-0.885	-0.92	0.668	0.695	0.814	0.755	0.885	0.920	0.783
CB2VL74	5.90	-1	0.66	0.805	-0.92	0.531	-0.607	-0.741	-0.660	-0.805	0.920	0.648
CB2VL112	4.79	-1	0.075	0.04	-0.14	0.003	-0.011	-0.006	-0.075	-0.040	0.140	0.002
CB2OT106	20	1	-0.955	1.04	-1.2	-0.993	1.146	-1.248	-0.955	1.040	-1.200	1.082
CB2OT107	20	1	-0.88	-0.965	-1.2	0.849	1.056	1.158	-0.880	-0.965	-1.200	0.931

Regression Output:

Constant			7.929									
Std Err of Y Est			2.638									
R Squared			0.887									
No. of Observations			18									
Degrees of Freedom			6									
X Coefficient(s)		3.284	-0.913	-2.086	-0.657	0.047	2.075	-1.597	-2.974	0.918	0.198	2.147
Std Err of Coef.		1.818	1.328	0.949	2.449	1.008	1.006	0.903	1.237	0.873	2.318	1.788
t value		1.806	-0.688	-2.199	-0.268	0.047	2.062	-1.769	-2.403	1.052	0.085	1.201

Table 50. Slurry Fuel Combustion Duration Significance Testing (cont.).

Significance Test

Trial	Combustio Duration y	Norm. Slurry x0	Norm. Temp. x1	Norm. Pressure x2	Norm. % solids x3	(x1)(x3)	(x2)(x3)	(x0)(x1)	(x0)(x2)	(x2)^2
CB2OT89	17.57	1	-0.995	-0.97	0.68	-0.677	-0.660	-0.995	-0.970	0.941
CB2OT90	7.69	1	0.77	0.88	0.68	0.524	0.598	0.770	0.880	0.774
CB2OT91	13.20	1	0.505	-1.135	0.68	0.343	-0.772	0.505	-1.135	1.288
CB2OT93	14.75	1	-1.16	0.86	0.68	-0.789	0.585	-1.160	0.860	0.740
CB2OT94	14.48	1	1.18	-0.925	0.68	0.802	-0.629	1.180	-0.925	0.856
CB2OT97	12.03	1	0.185	0.155	-0.12	-0.022	-0.019	0.185	0.155	0.024
CB2OT99	7.43	1	0.03	0.015	-0.12	-0.004	-0.002	0.030	0.015	0.000
CB2OT102	7.16	1	0.85	-1.07	-1.2	-1.020	1.284	0.850	-1.070	1.145
CB2OT103	7.91	1	0.76	0.875	-1.2	-0.912	-1.050	0.760	0.875	0.766
CB2OT104	10.52	1	0.525	-1.21	-1.2	-0.630	1.452	0.525	-1.210	1.464
CB2OT105	12.13	1	0.715	0.845	-1.2	-0.858	-1.014	0.715	0.845	0.714
CB2VL71	9.55	-1	0.705	-1.085	-0.92	-0.649	0.998	-0.705	1.085	1.177
CB2VL72	7.93	-1	-0.395	1.54	-0.92	0.363	-1.417	0.395	-1.540	2.372
CB2VL73	8.49	-1	-0.755	-0.885	-0.92	0.695	0.814	0.755	0.885	0.783
CB2VL74	5.90	-1	0.66	0.805	-0.92	-0.607	-0.741	-0.660	-0.805	0.648
CB2VL112	4.79	-1	0.075	0.04	-0.14	-0.011	-0.006	-0.075	-0.040	0.002
CB2OT106	20	1	-0.955	1.04	-1.2	1.146	-1.248	-0.955	1.040	1.082
CB2OT107	20	1	-0.88	-0.965	-1.2	1.056	1.158	-0.880	-0.965	0.931

Regression Output:

Constant	8.033
Std Err of Y Est	2.287
R Squared	0.886
No. of Observations	18
Degrees of Freedom	8

	x0	x1	x2	x3	(x1)(x3)	(x2)(x3)	(x0)(x1)	(x0)(x2)	(x2)^2
X Coefficient(s)	3.138	-0.920	-2.092	-0.474	2.070	-1.603	-2.973	0.933	2.188
Std Err of Coef.	0.635	1.104	0.820	0.768	0.867	0.778	1.046	0.728	1.183
t value	4.939	-0.833	-2.551	-0.618	2.387	-2.060	-2.843	1.281	1.849

Table 50. Slurry Fuel Combustion Duration Significance Testing (cont.).

Significance Test

Trial	Combustio Duration y	Norm. Slurry x0	Norm. Temp. x1	Norm. Pressure x2	Norm. % solids x3	(x1)(x3)	(x2)(x3)	(x0)(x1)
CB2OT89	17.57	1	-0.995	-0.97	0.68	-0.677	-0.660	-0.995
CB2OT90	7.69	1	0.77	0.88	0.68	0.524	0.598	0.770
CB2OT91	13.20	1	0.505	-1.135	0.68	0.343	-0.772	0.505
CB2OT93	14.75	1	-1.16	0.86	0.68	-0.789	0.585	-1.160
CB2OT94	14.48	1	1.18	-0.925	0.68	0.802	-0.629	1.180
CB2OT97	12.03	1	0.185	0.155	-0.12	-0.022	-0.019	0.185
CB2OT99	7.43	1	0.03	0.015	-0.12	-0.004	-0.002	0.030
CB2OT102	7.16	1	0.85	-1.07	-1.2	-1.020	1.284	0.850
CB2OT103	7.91	1	0.76	0.875	-1.2	-0.912	-1.050	0.760
CB2OT104	10.52	1	0.525	-1.21	-1.2	-0.630	1.452	0.525
CB2OT105	12.13	1	0.715	0.845	-1.2	-0.858	-1.014	0.715
CB2VL71	9.55	-1	0.705	-1.085	-0.92	-0.649	0.998	-0.705
CB2VL72	7.93	-1	-0.395	1.54	-0.92	0.363	-1.417	0.395
CB2VL73	8.49	-1	-0.755	-0.885	-0.92	0.695	0.814	0.755
CB2VL74	5.90	-1	0.66	0.805	-0.92	-0.607	-0.741	-0.660
CB2VL112	4.79	-1	0.075	0.04	-0.14	-0.011	-0.006	-0.075
CB2OT106	20	1	-0.955	1.04	-1.2	1.146	-1.248	-0.955
CB2OT107	20	1	-0.88	-0.965	-1.2	1.056	1.158	-0.880

Regression Output:

Constant			9.744					
Std Err of Y Est			2.473					
R Squared			0.834					
No. of Observations			18					
Degrees of Freedom			10					
X Coefficient(s)		3.039	-1.247	-1.805	-0.875	2.087	-1.572	-2.716
Std Err of Coef.		0.684	1.176	0.794	0.797	0.938	0.804	1.115
t value		4.445	-1.060	-2.274	-1.098	2.225	-1.955	-2.436

Table 50. Slurry Fuel Combustion Duration Significance Testing (cont.).

Significance Test

Trial	Combustion Duration y	Norm. Slurry x0	Norm. Temp. x1	Norm. Pressure x2	Norm. % solids x3	(x1)(x3)	(x0)(x1)
CB2OT89	17.57	1	-0.995	-0.97	0.68	-0.677	-0.995
CB2OT90	7.69	1	0.77	0.88	0.68	0.524	0.770
CB2OT91	13.20	1	0.505	-1.135	0.68	0.343	0.505
CB2OT93	14.75	1	-1.16	0.86	0.68	-0.789	-1.160
CB2OT94	14.48	1	1.18	-0.925	0.68	0.802	1.180
CB2OT97	12.03	1	0.185	0.155	-0.12	-0.022	0.185
CB2OT99	7.43	1	0.03	0.015	-0.12	-0.004	0.030
CB2OT102	7.16	1	0.85	-1.07	-1.2	-1.020	0.850
CB2OT103	7.91	1	0.76	0.875	-1.2	-0.912	0.760
CB2OT104	10.52	1	0.525	-1.21	-1.2	-0.630	0.525
CB2OT105	12.13	1	0.715	0.845	-1.2	-0.858	0.715
CB2VL71	9.55	-1	0.705	-1.085	-0.92	-0.649	-0.705
CB2VL72	7.93	-1	-0.395	1.54	-0.92	0.363	0.395
CB2VL73	8.49	-1	-0.755	-0.885	-0.92	0.695	0.755
CB2VL74	5.90	-1	0.66	0.805	-0.92	-0.607	-0.660
CB2VL112	4.79	-1	0.075	0.04	-0.14	-0.011	-0.075
CB2OT106	20	1	-0.955	1.04	-1.2	1.146	-0.955
CB2OT107	20	1	-0.88	-0.965	-1.2	1.056	-0.880

Regression Output:

Constant		9.975				
Std Err of Y Est		2.772				
R Squared		0.771				
No. of Observations		18				
Degrees of Freedom		11				
X Coefficient(s)	3.036	-1.043	-0.875	-0.613	2.351	-2.692
Std Err of Coef.	0.766	1.313	0.712	0.880	1.040	1.250
t value	3.962	-0.794	-1.229	-0.696	2.261	-2.154

Table 50. Slurry Fuel Combustion Duration Significance Testing (cont.).

Significance Test

Trial	Combustio Duration y	Norm. Slurry x0	Norm. Temp. x1	Norm. Pressure x2	Norm. % solids x3	(x1)(x3)
CB2OT89	17.57	1	-0.995	-0.97	0.68	-0.677
CB2OT90	7.69	1	0.77	0.88	0.68	0.524
CB2OT91	13.20	1	0.505	-1.135	0.68	0.343
CB2OT93	14.75	1	-1.16	0.86	0.68	-0.789
CB2OT94	14.48	1	1.18	-0.925	0.68	0.802
CB2OT97	12.03	1	0.185	0.155	-0.12	-0.022
CB2OT99	7.43	1	0.03	0.015	-0.12	-0.004
CB2OT102	7.16	1	0.85	-1.07	-1.2	-1.020
CB2OT103	7.91	1	0.76	0.875	-1.2	-0.912
CB2OT104	10.52	1	0.525	-1.21	-1.2	-0.630
CB2OT105	12.13	1	0.715	0.845	-1.2	-0.858
CB2VL71	9.55	-1	0.705	-1.085	-0.92	-0.649
CB2VL72	7.93	-1	-0.395	1.54	-0.92	0.363
CB2VL73	8.49	-1	-0.755	-0.885	-0.92	0.695
CB2VL74	5.90	-1	0.66	0.805	-0.92	-0.607
CB2VL112	4.79	-1	0.075	0.04	-0.14	-0.011
CB2OT106	20	1	-0.955	1.04	-1.2	1.146
CB2OT107	20	1	-0.88	-0.965	-1.2	1.056

Regression Output:

Constant		10.099			
Std Err of Y Est		3.165			
R Squared		0.674			
No. of Observations		18			
Degrees of Freedom		12			
X Coefficient(s)	2.814	-3.032	-0.878	-0.476	1.634
Std Err of Coef.	0.867	1.066	0.813	1.002	1.125
t value	3.246	-2.845	-1.080	-0.475	1.453

Table 50. Slurry Fuel Combustion Duration Significance Testing (cont.).

Significance Test

Trial	Combustion Duration y	Norm. Slurry x0	Norm. Temp. x1	Norm. Pressure x2	Norm. % solids x3
CB2OT89	17.57	1	-0.995	-0.97	0.68
CB2OT90	7.69	1	0.77	0.88	0.68
CB2OT91	13.20	1	0.505	-1.135	0.68
CB2OT93	14.75	1	-1.16	0.86	0.68
CB2OT94	14.48	1	1.18	-0.925	0.68
CB2OT97	12.03	1	0.185	0.155	-0.12
CB2OT99	7.43	1	0.03	0.015	-0.12
CB2OT102	7.16	1	0.85	-1.07	-1.2
CB2OT103	7.91	1	0.76	0.875	-1.2
CB2OT104	10.52	1	0.525	-1.21	-1.2
CB2OT105	12.13	1	0.715	0.845	-1.2
CB2VL71	9.55	-1	0.705	-1.085	-0.92
CB2VL72	7.93	-1	-0.395	1.54	-0.92
CB2VL73	8.49	-1	-0.755	-0.885	-0.92
CB2VL74	5.90	-1	0.66	0.805	-0.92
CB2VL112	4.79	-1	0.075	0.04	-0.14
CB2OT106	20	1	-0.955	1.04	-1.2
CB2OT107	20	1	-0.88	-0.965	-1.2

Regression Output:

Constant		10.136		
Std Err of Y Est		3.297		
R Squared		0.616		
No. of Observations		18		
Degrees of Freedom		13		
X Coefficient(s)	2.751	-3.495	-0.925	-0.296
Std Err of Coef.	0.902	1.060	0.846	1.036
t value	3.050	-3.299	-1.094	-0.286

Table 50. Slurry Fuel Combustion Duration Significance Testing (cont.).

Significance Test

Trial	Combustio Duration y	Norm. Slurry x0	Norm. Temp. x1
CB2OT89	17.57	1	-0.995
CB2OT90	7.69	1	0.77
CB2OT91	13.20	1	0.505
CB2OT93	14.75	1	-1.16
CB2OT94	14.48	1	1.18
CB2OT97	12.03	1	0.185
CB2OT99	7.43	1	0.03
CB2OT102	7.16	1	0.85
CB2OT103	7.91	1	0.76
CB2OT104	10.52	1	0.525
CB2OT105	12.13	1	0.715
CB2VL71	9.55	-1	0.705
CB2VL72	7.93	-1	-0.395
CB2VL73	8.49	-1	-0.755
CB2VL74	5.90	-1	0.66
CB2VL112	4.79	-1	0.075
CB2OT106	20	1	-0.955
CB2OT107	20	1	-0.88

Regression Output:

Constant		10.301
Std Err of Y Est		3.212
R Squared		0.580
No. of Observations		18
Degrees of Freedom		15
X Coefficient(s)	2.775	-3.346
Std Err of Coef.	0.846	1.023
t value	3.281	-3.269

Table 51. Diesel Fuel Heat of Combustion Significance Testing.

Trial	Fuel Injection Bomb Conditions Moles (gmol)	Temp (°K)	Pressure (psia)	Heat of Combustion (cal)	Match With Design Run #
CB2DF53	0.129	1322	596	1079	No Match
CB2DF62	0.089	1149	360	1143	No Match
CB2DF63	0.156	1070	584	1070	5
CB2DF65	0.128	927	416	1135	1
CB2DF67	0.177	1283	792	1121	4
CB2DF68	0.255	1030	918	721	No Match
CB2DF69	0.156	1139	620	1127	5
CB3DF75	0.088	1212	375	938	2
CB3DF85	0.244	935	797	789	3
CB3DF86	0.156	1169	636	1071	5
CB2DF114	0.088	1267	390	571	2

Significance Test

Trial	Heat of Combustion y	Norm. Temp. x1	Norm. Pressure x2	(x1)(x2)	(x1)^2	(x2)^2
CB2DF53	1079	1.11	-0.02	-0.022	1.232	0.000
CB2DF62	1143	0.245	-1.2	-0.294	0.060	1.440
CB2DF63	1070	-0.15	-0.08	0.012	0.023	0.006
CB2DF65	1135	-0.865	-0.92	0.796	0.748	0.846
CB2DF67	1121	0.915	0.96	0.878	0.837	0.922
CB2DF68	721	-0.35	1.59	-0.557	0.122	2.528
CB2DF69	1127	0.195	0.1	0.020	0.038	0.010
CB3DF75	938	0.56	-1.125	-0.630	0.314	1.266
CB3DF85	789	-0.825	0.985	-0.813	0.681	0.970
CB3DF86	1071	0.345	0.18	0.062	0.119	0.032
CB2DF114	571	0.835	-1.05	-0.877	0.697	1.103

Regression Output:

Constant		1119.936			
Std Err of Y Est		139.541			
R Squared		0.751			
No. of Observations		11			
Degrees of Freedom		5			
X Coefficient(s)	8.497	-31.409	246.767	-130.619	-65.973
Std Err of Coef.	72.062	48.159	83.280	114.527	62.970
t value	0.118	-0.652	2.963	-1.141	-1.048

Table 51. Diesel Fuel Heat of Combustion Significance Testing.

Significance Test

Trial	Heat of Combustion y	Norm. Temp. x1	Norm. Pressure x2	(x1)(x2)
CB2DF53	1079	1.11	-0.02	-0.022
CB2DF62	1143	0.245	-1.2	-0.294
CB2DF63	1070	-0.15	-0.08	0.012
CB2DF65	1135	-0.865	-0.92	0.796
CB2DF67	1121	0.915	0.96	0.878
CB2DF68	721	-0.35	1.59	-0.557
CB2DF69	1127	0.195	0.1	0.020
CB3DF75	938	0.56	-1.125	-0.630
CB3DF85	789	-0.825	0.985	-0.813
CB3DF86	1071	0.345	0.18	0.062
CB2DF114	571	0.835	-1.05	-0.877

y = heat of combustion
Regression Output:

Constant		1010.383	
Std Err of Y Est		143.620	
R Squared		0.631	
No. of Observations		11	
Degrees of Freedom		7	
X Coefficient(s)	-0.449	-43.571	262.291
Std Err of Coef.	69.214	48.783	77.546
t value	-0.006	-0.893	3.382

Table 52. Slurry Fuel Heat of Combustion Significance Testing.

Trial	Slurry %Solids (%)	Fuel Inj. Moles (gmol)	Bomb Cond. Temp (°K)	Bomb Cond. Pressure (psia)	Heat of Comb. (cal)	Design Run Match
CB2OT89	53.4	0.129	901	406	65	5
CB2OT90	53.4	0.177	1254	775	219	8
CB2OT91	53.4	0.089	1204	374	599	6
CB2OT94	53.4	0.089	1336	415	595	6
CB2OT97	49.4	0.158	1127	624	670	9
CB2OT99	49.4	0.156	1106	603	422	9
CB2OT102	44.0	0.087	1272	387	423	2
CB2OT103	44.0	0.177	1256	777	-17	4
CB2OT104	44.0	0.085	1213	360	712	2
CB2OT105	44.0	0.177	1243	770	545	4
CB2OT106	44.0	0.255	909	808	-12	3
CB2OT107	44.0	0.126	924	407	-90	1
CB2VL71	45.4	0.088	1240	383	514	2
CB2VL72	45.4	0.255	1022	910	51	3
CB2VL73	45.4	0.128	949	423	290	1
CB2VL74	45.4	0.176	1146	708	26	4
CB2VL112	49.3	0.156	1116	609	-28	5

Table 52. Slurry Fuel Heat of Combustion Significance Testing (cont.).

<u>Significance Test</u>

Trial	Heat of Comb. y	Slurry Type x0	Norm. Temp. x1	Norm. Pressure x2	Norm. %solids x3	(x1)(x2)	(x1)(x3)	(x2)(x3)	(x0)(x1)	(x0)(x2)	(x0)(x3)	(x1)^2	(x2)^2	(x3)^2
CB2OT89	65	1	-0.995	-0.97	0.68	0.965	-0.677	-0.660	-0.995	-0.970	0.680	0.990	0.941	0.462
CB2OT90	219	1	0.77	0.875	0.68	0.674	0.524	0.595	0.770	0.875	0.680	0.593	0.766	0.462
CB2OT91	599	1	0.52	-1.13	0.68	-0.588	0.354	-0.768	0.520	-1.130	0.680	0.270	1.277	0.462
CB2OT94	595	1	1.18	-0.925	0.68	-1.092	0.802	-0.629	1.180	-0.925	0.680	1.392	0.856	0.462
CB2OT97	670	1	0.135	0.12	-0.12	0.016	-0.016	-0.014	0.135	0.120	-0.120	0.018	0.014	0.014
CB2OT99	422	1	0.03	0.015	-0.12	0.000	-0.004	-0.002	0.030	0.015	-0.120	0.001	0.000	0.014
CB2OT102	423	1	0.86	-1.065	-1.2	-0.916	-1.032	1.278	0.860	-1.065	-1.200	0.740	1.134	1.440
CB2OT103	-17	1	0.78	0.885	-1.2	0.690	-0.936	-1.062	0.780	0.885	-1.200	0.608	0.783	1.440
CB2OT104	712	1	0.565	-1.2	-1.2	-0.678	-0.678	1.440	0.565	-1.200	-1.200	0.319	1.440	1.440
CB2OT105	545	1	0.715	0.85	-1.2	0.608	-0.858	-1.020	0.715	0.850	-1.200	0.511	0.722	1.440
CB2OT106	-12	1	-0.955	1.04	-1.2	-0.993	1.146	-1.248	-0.955	1.040	-1.200	0.912	1.082	1.440
CB2OT107	-90	1	-0.88	-0.965	-1.2	0.849	1.056	1.158	-0.880	-0.965	-1.200	0.774	0.931	1.440
CB2VL71	514	-1	0.7	-1.085	-0.92	-0.760	-0.644	0.998	-0.700	1.085	0.920	0.490	1.177	0.846
CB2VL72	51	-1	-0.39	1.55	-0.92	-0.605	0.359	-1.426	0.390	-1.550	0.920	0.152	2.403	0.846
CB2VL73	290	-1	-0.755	-0.885	-0.92	0.668	0.695	0.814	0.755	0.885	0.920	0.570	0.783	0.846
CB2VL74	26	-1	0.23	0.54	-0.92	0.124	-0.212	-0.497	-0.230	-0.540	0.920	0.053	0.292	0.846
CB2VL112	-28	-1	0.08	0.045	-0.14	0.004	-0.011	-0.006	-0.080	-0.045	0.140	0.006	0.002	0.020

Regression Output:

Constant	226
Std Err of Y Est	273
R Squared	0.825
No. of Observations	17
Degrees of Freedom	3

	x0	x1	x2	x3	(x1)(x2)	(x1)(x3)	(x2)(x3)	(x0)(x1)	(x0)(x2)	(x0)(x3)	(x1)^2	(x2)^2	(x3)^2
X Coefficient(s)	304	70	-188	-315	-109	-26	-34	121	96	211	-220	95	-278
Std Err of Coef.	194	230	140	373	169	147	122	154	100	231	312	241	504
t value	1.567	0.305	-1.345	-0.845	-0.644	-0.180	-0.281	0.789	0.955	0.916	-0.707	0.393	-0.552

Table 52. Slurry Fuel Heat of Combustion Significance Testing (cont.).

Significance Test

Trial	Heat of Comb. y	Slurry Type x0	Norm. Temp. x1	Norm. Pressure x2	Norm. %solids x3
CB2OT89	65	1	-0.995	-0.97	0.68
CB2OT90	219	1	0.77	0.875	0.68
CB2OT91	599	1	0.52	-1.13	0.68
CB2OT94	595	1	1.18	-0.925	0.68
CB2OT97	670	1	0.135	0.12	-0.12
CB2OT99	422	1	0.03	0.015	-0.12
CB2OT102	423	1	0.86	-1.065	-1.2
CB2OT103	-17	1	0.78	0.885	-1.2
CB2OT104	712	1	0.565	-1.2	-1.2
CB2OT105	545	1	0.715	0.85	-1.2
CB2OT106	-12	1	-0.955	1.04	-1.2
CB2OT107	-90	1	-0.88	-0.965	-1.2
CB2VL71	514	-1	0.7	-1.085	-0.92
CB2VL72	51	-1	-0.39	1.55	-0.92
CB2VL73	290	-1	-0.755	-0.885	-0.92
CB2VL74	26	-1	0.23	0.54	-0.92
CB2VL112	-28	-1	0.08	0.045	-0.14

Regression Output:

Constant		233		
Std Err of Y Est		229		
R Squared		0.505		
No. of Observations		17		
Degrees of Freedom		12		
X Coefficient(s)	46	206	-112	9
Std Err of Coef.	63	83	62	77
t value	0.717	2.494	-1.810	0.121

Table 52. Slurry Fuel Heat of Combustion Significance Testing (cont.).

Significance Test

Trial	Heat of Comb. y	Norm. Temp. x1	Norm. Pressure x2
CB2OT89	65	-0.995	-0.97
CB2OT90	219	0.77	0.875
CB2OT91	599	0.52	-1.13
CB2OT94	595	1.18	-0.925
CB2OT97	670	0.135	0.12
CB2OT99	422	0.03	0.015
CB2OT102	423	0.86	-1.065
CB2OT103	-17	0.78	0.885
CB2OT104	712	0.565	-1.2
CB2OT105	545	0.715	0.85
CB2OT106	-12	-0.955	1.04
CB2OT107	-90	-0.88	-0.965
CB2VL71	514	0.7	-1.085
CB2VL72	51	-0.39	1.55
CB2VL73	290	-0.755	-0.885
CB2VL74	26	0.23	0.54
CB2VL112	-28	0.08	0.045

Regression Output:

Constant		244
Std Err of Y Est		217
R Squared		0.481
No. of Observations		17
Degrees of Freedom		14
X Coefficient(s)	217	-118
Std Err of Coef.	77	58
t value	2.821	-2.057

Table 52. Slurry Fuel Heat of Combustion Significance Testing (cont.).

Significance Test

Trial	Heat of Comb. y	Norm. Temp. x1
CB2OT89	65	-0.995
CB2OT90	219	0.77
CB2OT91	599	0.52
CB2OT94	595	1.18
CB2OT97	670	0.135
CB2OT99	422	0.03
CB2OT102	423	0.86
CB2OT103	-17	0.78
CB2OT104	712	0.565
CB2OT105	545	0.715
CB2OT106	-12	-0.955
CB2OT107	-90	-0.88
CB2VL71	514	0.7
CB2VL72	51	-0.39
CB2VL73	290	-0.755
CB2VL74	26	0.23
CB2VL112	-28	0.08

Regression Output:

Constant	259
Std Err of Y Est	240
R Squared	0.324
No. of Observations	17
Degrees of Freedom	15

X Coefficient(s)	227
Std Err of Coef.	85
t value	2.683

Appendix D - Calorimeter Standardization

The bomb calorimeter was calibrated before beginning testing with the diesel fuel and slurries. The calibration was accomplished by burning a known amount of hydrogen with excess oxygen in the bomb and measuring the temperature change of the calorimeter water bath. The specific heat of the calorimeter was calculated from the change in the water bath temperature and the heat from combustion of H_2 assuming complete combustion of the H_2 (68.32 kcal/gmol). The results of the calibration tests are shown in Table 53. The water bath contained 2000 grams of water in each test. These results established the specific heat of the calorimeter as a whole and were then used to calculate the heat given off from a reaction using the temperature change of the water bath (with the bath containing 2000 grams of water). The calorimeter specific heat was calculated to be 2601 cal/^{o}C with a standard deviation of 118 cal/^{o}C.

Table 53. Calorimeter Calibration.

Initial Water Temp (°C)	Final Water Temp (°C)	Change in Water Temp (°C)	Final Bomb Moles (gmol)	Moles H2 Burned (gmol)	Calc. Heat of H2 Comb. (cal)	Calor. Specific Heat (cal/°C)
24.250	24.670	0.420	0.133	0.0172	1181	2813
19.196	19.888	0.692	0.194	0.0248	1702	2460
20.432	21.299	0.867	0.198	0.0344	2353	2714
20.911	21.500	0.589	0.131	0.0229	1570	2666
20.822	21.426	0.604	0.131	0.0229	1570	2599
22.330	23.143	0.813	0.154	0.0307	2100	2583
22.319	23.355	1.036	0.193	0.0381	2609	2518
21.285	22.817	1.532	0.255	0.0565	3866	2524
21.921	23.608	1.687	0.251	0.0557	3812	2260
26.501	27.514	1.013	0.173	0.0384	2627	2594
21.292	22.803	1.511	0.253	0.0561	3838	2540
22.818	23.862	1.044	0.174	0.0387	2647	2535
22.867	24.259	1.392	0.253	0.0562	3844	2761
23.692	24.418	0.726	0.128	0.0284	1944	2678
20.755	22.238	1.483	0.255	0.0566	3871	2610
21.786	22.382	0.596	0.132	0.0226	1552	2604
21.965	22.970	1.005	0.257	0.0387	2649	2636
22.278	22.805	0.527	0.133	0.0201	1377	2613
21.135	21.711	0.576	0.132	0.0228	1561	2711
21.040	21.469	0.429	0.094	0.0163	1116	2601
					Average =	2601
				Standard Deviation	=	118

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