The Effects of Increased Ignition Energy on Cold Start Hydrocarbon Emissions

by

Raymond L. Slaughter, Jr.

Thesis Submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE in

Mechanical Engineering

Alan A. Kornhauser Co-Chairmen
Uri Vandsburger Co-Chairmen
Douglas J. Nelson

September 1998
Blacksburg, Virginia
A study on the effects of increased ignition energy on cold start hydrocarbon emissions was conducted. The tests were conducted on a single cylinder ASTM-CFR engine. The engine was outfitted with EFI, exhaust analyzers, and temperature probes. The engine was also modified to produce cold start conditions rapidly after each run. For the experiment, the engine was started from 18° C using three increasing ignition energy levels. The first level of ignition energy was the ignition energy produced by the stock CFR engine’s ignition system. The second and third increased ignition energy levels were obtained by adding 0.387 joules and 1.187 joules to the stock output through a supplementary ignition system. Startup emissions and the number of cycles until the first successful fire were measured.

The results of the tests show a 14% decrease in the average peak hydrocarbon (HC) concentration levels at the highest ignition energy. Overall reduction in HC was less. The variance in the peak HC levels was reduced at the highest ignition energy setting. CO production was increased in response to the increase in HC consumption. The spread in measured number of cycles until first fire was decreased at the highest ignition energy level.

Although positive results were obtained, the test apparatus had some problem areas that may have reduced the effectiveness of the high energy ignition system. Based on what was learned recommendations on apparatus refinements and further tests were included.
Acknowledgments

First I want to thank my co-advisors, Dr. Alan A. Kornhauser and Dr. Uri Vandsburger for all the guidance I received. Thank you for exposing me to new things. I want thank Dr. Douglas Nelson for serving on my committee and for the use of Hybrid Electric Vehicle equipment. Dr. Gregg Harrell, thank you for helping sort out the A/C system and bringing a laugh to the lab.

I would also like to thank the students on ’98 Mini-Baja team for helping me build parts and for supplying me with parts. Thanks is also in order for the students in the Reacting Flows Laboratory for their help throughout the project.

Of course I have to give thanks to my parents Raymond and June Slaughter for supporting me and keeping my spirits high. Thanks for giving me the opportunity to be free.
# Table Of Contents

Abstract .......................................................................................................................... ii

Acknowledgments ........................................................................................................... iii

List of Figures .................................................................................................................... vi

List of Tables ..................................................................................................................... viii

1. Motivation and Scope ................................................................................................. 1

2. Experimental Systems ............................................................................................... 9
   2.1 Introduction ............................................................................................................ 9
   2.2 Test Apparatus .................................................................................................... 12
      2.2.1 Test Engine .................................................................................................... 12
   2.3 Engine Modifications ......................................................................................... 13
      2.3.1 Engine Cooling ............................................................................................ 13
      2.3.2 Air Supply System ....................................................................................... 15
      2.3.3 Ignition System ........................................................................................... 18
      2.3.4 Electronic Fuel Injection .............................................................................. 24
   2.4 Temperature Measurements ............................................................................... 29
   2.5 Exhaust Gas Analyzers ...................................................................................... 31
      2.5.1 OTC 5 Gas Analyzer ..................................................................................... 31
      2.5.2 Hydrocarbon Analyzers .............................................................................. 32
      2.5.3 Exhaust Gas Flow to Analyzers .................................................................. 33

3. Experimental Procedures ......................................................................................... 36
   3.1 Initial Setup ........................................................................................................... 36
      3.1.1 Engine Coolant and Air Supply .................................................................. 36
      3.1.2 Ignition System ............................................................................................ 38
      3.1.3 Fuel Injection System .................................................................................. 38
      3.1.4 Gas Analyzer Calibration ............................................................................. 39
   3.2 Test Procedure ...................................................................................................... 41

4. Result and Discussion ............................................................................................... 44
   4.1 Results .................................................................................................................. 44
      4.1.1 Introduction ................................................................................................... 44
      4.1.2 Hydrocarbon Emissions .............................................................................. 45
      4.1.3 Carbon Monoxide Emissions ...................................................................... 48
      4.1.4 Number of Cycles Until the First Successful Fire ....................................... 49
List Of Figures

1.1 Federal Test Procedure, Emissions Test 72 and 75 ........................................... 2
1.2 Emissions Trace Over FTP - 72 Test .............................................................. 3
2.1 Picture #1 of Apparatus .................................................................................... 10
2.2 Picture #2 of Apparatus .................................................................................... 10
2.3 Picture #3 of Apparatus .................................................................................... 11
2.4 Picture #4 of Apparatus .................................................................................... 11
2.5 Water Cooling Circuit Diagram ....................................................................... 14
2.6 Air Conditioning and Supply System ............................................................... 17
2.7 Ignition Point Operation Diagram .................................................................... 20
2.8 High Energy Ignition System .......................................................................... 21
2.9 High Energy Power Supply ............................................................................ 22
2.10 Fuel Injector Trigger Circuit .......................................................................... 27
2.11 Fuel injector Driver Circuit ............................................................................ 28
2.12 Cylinder Head Temperature Plug ..................................................................... 30
2.13 Exhaust Sample Route #1 ............................................................................... 34
2.14 Exhaust Sample Route #2 ............................................................................... 35
4.1 HC Emissions For Stock Ignition System ........................................................ 50
4.2 Normalized HC Emissions For Stock Ignition System ....................................... 51
4.3 HC Emissions For 0.387 Joules of Additional Energy Over Stock .................. 52
4.4 Normalized HC Emissions For 0.387 Joules of Additional Energy Over Stock .... 53
4.5 HC Emissions For 1.187 Joules of Additional Energy Over Stock ................... 54
4.6 Normalized HC Emissions For 0.387 Joules of Additional Energy Over Stock .... 55
4.7 % Increase in Contribution to Total HCs Produced by Cold Start Vs. Additional Ignition Energy Over Stock ................................................................. 56
4.8 % Increase in Contribution to Total HC’s Produced by Cold Start
   Vs. Cycles to Start ..........................................................................................57
4.9 Number of Cycles Until Start For The Three Energy Levels .....................58
4.10 CO Emissions for Stock Ignition System ..................................................59
4.11 CO Emissions For 0.387 Joules of Additional Energy Over Stock .............60
4.12 HC Emissions For 1.187 Joules of Additional Energy Over Stock .............61
4.13 Example Graph of All Measured Emissions and Calculated A/F
   Versus Time ....................................................................................................68
4.14 Cylinder Temperature and Calculated A/F Ratio versus Time ....................69
4.15 Comparison of Estimated CO Concentration Changes and Measured
   CO Concentration Changes For A/F Ratio Fluctuations ...............................70
4.16 A/F Ratio Comparison Graph ...................................................................71
A1 Typical Distillation Curve For SI Fuel .........................................................79
B1 Calibration Curve for EFI ............................................................................85
D1 OTC 5 Gas Analyzer Response To Step Input at T = 42 Seconds .............88
D2 FID HC Analyzer Calibration Curve .............................................................89
D3 HC Analyzer Comparison, FID to Infrared Absorption (Hexane) ..............93
E1 CO₂ Emissions for Stock Ignition Energy ....................................................95
E2 O₂ Emissions for Stock Ignition Energy .......................................................96
E3 NOₓ Emissions for Stock Ignition Energy .....................................................97
E4 CO₂ Emissions for 0.387 Joules of Additional Energy Over Stock Ignition....98
E5 O₂ Emissions for 0.387 Joules of Additional Energy Over Stock Ignition.....99
E6 NOₓ Emissions for 0.387 Joules of Additional Energy Over Stock Ignition....100
E7 CO₂ Emissions for 1.187 Joules of Additional Energy Over Stock Ignition....101
E8 O₂ Emissions for 1.187 Joules of Additional Energy Over Stock Ignition.....102
E9 NOₓ Emissions for 1.187 Joules of Additional Energy Over Stock Ignition....103
List Of Tables

3.1 Sample Gas Concentrations .................................................................40

4.1 Cold Start Hydrocarbon Emissions Peak Level Comparison for Runs
   With Stock Ignition Energy.................................................................45

4.2 Cold Start Hydrocarbon Emissions Peak Level Comparison for Runs
   With 0.387 Joules of Additional Ignition Energy .................................46

4.3 Cold Start Hydrocarbon Emissions Peak Level Comparison for Runs
   With 1.187 Joules of Additional Ignition Energy .................................47

D1 Response Characteristics Of Exhaust Analyzers ...............................87

D2 Uncertainties of Exhaust Gas Composition .......................................91