

APPENDIX

APPENDIX A

Typical Distillations Curve of Fuel for Spark Ignition Engine

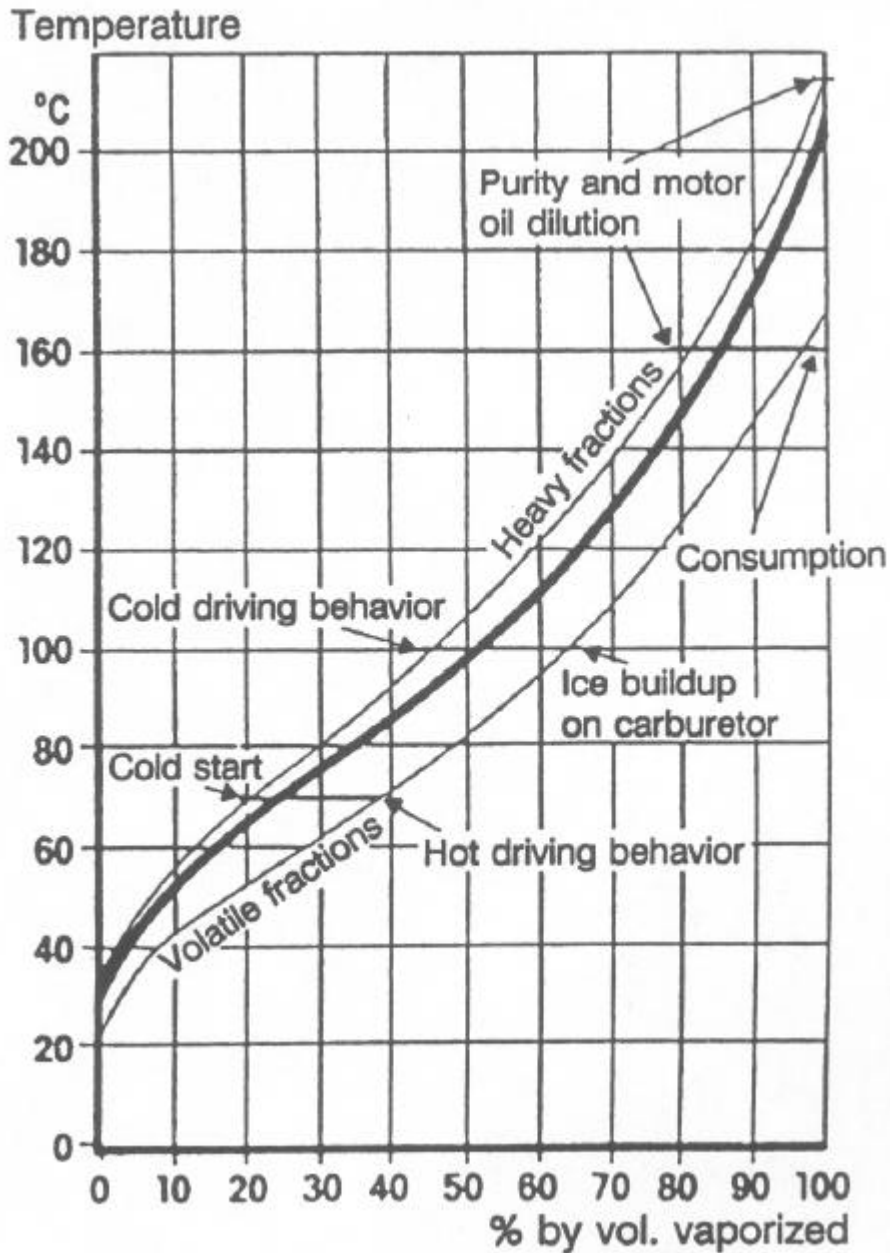


Figure A1 - Typical Distillation Curve For SI Fuel

APPENDIX B

Electronic Fuel Injection

a.) EFI PROGRAM

C This is the FORTRAN program to control the fuel injector.
C The Program controls a Data Translation 2601-A A/D board
C The motor is assumed to operating at 900 RPM and all calculations are
C based on that fact. If speed is increased the program should be updated.
C It will also need to be re-calibrated.
C The program allows in the current state uses 8 points to define a fuel map
C versus time. The program uses no feedback. It can be added with the 16
C single ended analog inputs.

C *****Defining all Variables
\$NOTRUNCATE

```
INTEGER*2 TERMINATE,INITIALIZE,DISABLE_SYSTEM_CLOCK
INTEGER*2 ENABLE_SYSTEM_CLOCK,DAC_VALUE,DAC0,DAC1
INTEGER*2 VHIINT(900),VLOWINT,RAMPINT,I,STEP,J,CHANNEL
INTEGER*2 DIVCOUNT,VON, OFF,OFF2, FIRE(7000),AVAL,GAIN1
INTEGER*2 VALUE, DAC_ON_TRIGGER,RAMPLOW,CYCLE,CALVHI
INTEGER*2 ADC_VALUE
CHARACTER *20 FILENAME
```

```
REAL VOLTLOW, VOLTHI, RUNTIME,TON(900)
REAL DELTAVOLT, PULSEWIDTH(900), SLOPE,TMIN(900)
```

C*****Prompt User For File Name and Length Of Run

```
PRINT *, 'ENTER FILE NAME FOR DATA TO BE STORED'
PRINT*, ' USING SINGLE QUOTES AROUND THE FILENAME'
READ *, FILENAME
PRINT *, 'Enter total run time in minute increments.'
READ *, Runtime
```

C*****This section defines the 8 operating points

```
PULSEWIDTH(1) = 30
PULSEWIDTH(2) = 30
PULSEWIDTH(3) = 21.2
PULSEWIDTH(4) = 21.2
```

```
PULSEWIDTH(5) = 21.2
PULSEWIDTH(6) = 21.2
PULSEWIDTH(7) = 21.2
PULSEWIDTH(8) = 21.2
```

```
TMIN(1)=3
TMIN(2)=3.05
TMIN(3)=3.10
TMIN(4)=4
TMIN(5)=5
TMIN(6)=6
TMIN(7)=6.5
TMIN(8)=8
```

C This section calculates the Hi voltage that will produce required PW
C The program was calculated for a 50 MHz 486. If a fast computer is used the
C Numbers the equation in line 333 can be altered until they give the correct
C Pulsewidth. An oscilloscope will help in the calibration.

```
DO 20 I = 1, 8
    TON(I) = TMIN(I)*450
333    DELTAVOLT = PULSEWIDTH(I)/1000/2.9/0.000122*0.002441
    VOLTHI = 4.00 + DELTAVOLT
    VHIINT(I) = VOLTHI/10*4096
20    CONTINUE
```

C*****This section Prints the Time and the Pulsewidth and the On voltage

```
DO 30 I = 1,8
    PRINT*, VHIINT(I),PULSEWIDTH(I), TON(I)
30    CONTINUE
```

C*****This Section assigns a variables a value to reserve memory space

```
VOLTLOW = 4.000
VOLTHI = 4.400
VLOWINT = VOLTLOW/10*4096
CALVHI = 0
STEP = 1
RAMPINT = VLOWINT
TIMECOUNT = RUNTIME*900/2
VALUE = 0
DIVCOUNT = 0
DAC0 = 0
DAC1 = 1
VON = 0
```

```

I = 1
AVAL = 0
J = 1
CHANNEL = 0
GAIN1 = 1
OFF2 = 2048
OFF = 0
RAMPLOW = VLOWINT - 4
CYCLE = 1
SLOPE = 0

```

C This section Clears buffers and turns off the Computers Clock
C If the clock is not turned off the an interrupt can break up the EFI timing

```

C = TERMINATE()
C = INITIALIZE()
C = DISABLE_SYSTEM_CLOCK()

```

```

I = 3

```

C This section waits for the trigger signal
C When triggered it calculates the PW and produces the necessary saw wave
C and reference voltage out of DAC0 and DAC1.
C The actual pulse is formed by the op-amp.

```

DO WHILE (I .LE. TIMECOUNT)

```

```

    C = DAC_VALUE(DAC1,VLOWINT)
    RAMPINT = VLOWINT
    VALUE = RAMPLOW
    C = DAC_ON_TRIGGER(DAC0,VALUE)

```

```

IF ((I .GE. TON(1)) .AND. (I .LT. TON(2))) THEN
    SLOPE = (VHIINT(2)-VHIINT(1))/(TON(2)-TON(1))
    CALVHI = SLOPE*(I-TON(1))+VHIINT(1)
    PRINT*, "1"
ELSEIF ((I .GE. TON(2)).AND. (I .LT. TON(3))) THEN
    SLOPE = (VHIINT(3)-VHIINT(2))/(TON(3)-TON(2))
    CALVHI = SLOPE*(I-TON(2))+VHIINT(2)
    PRINT*, "2"
ELSEIF ((I .GE. TON(3)).AND. (I .LT. TON(4))) THEN
    SLOPE = (VHIINT(4)-VHIINT(3))/(TON(4)-TON(3))
    CALVHI = SLOPE*(I - TON(3))+VHIINT(3)
    PRINT*, "3"

```

```

ELSEIF ((I .GE. TON(4)).AND. (I .LT. TON(5))) THEN
    SLOPE = (VHIINT(5)-VHIINT(4))/(TON(5)-TON(4))
    CALVHI = SLOPE*(I - TON(4))+VHIINT(4)
    PRINT*, "4"
ELSEIF ((I .GE. TON(5)).AND. (I .LT. TON(6))) THEN
    SLOPE = (VHIINT(6)-VHIINT(5))/(TON(6)-TON(5))
    CALVHI = SLOPE*(I - TON(5))+VHIINT(5)
    PRINT*, "5"
ELSEIF ((I .GE. TON(6)).AND. (I .LT. TON(7))) THEN
    SLOPE = (VHIINT(7)-VHIINT(6))/(TON(7)-TON(6))
    CALVHI = SLOPE*(I - TON(6))+VHIINT(6)
    PRINT*, "6"
ELSEIF ((I .GE. TON(7)).AND. (I .LT. TON(8))) THEN
    SLOPE = (VHIINT(8)-VHIINT(7))/(TON(8)-TON(7))
    CALVHI = SLOPE*(I - TON(7))+VHIINT(7)
    PRINT*, "7"
ELSEIF (I .GE. TON(8)) THEN
    CALVHI = VHIINT(8)

ELSE
    CALVHI = RAMPLOW
END IF
PRINT *, CALVHI

```

C This section creates the saw wave. The wave goes from voltage low to V HI
C When The saw wave voltage is greater than the reference the op-amp turns on .
C When the saw voltage fall below the reference voltage the op-amp outputs a
C negative voltage.

```

DO WHILE ( RAMPINT .LE. CALVHI)
    C = DAC_VALUE(DAC0,RAMPINT)
    RAMPINT = RAMPINT + STEP
C
PRINT *, RAMPINT
END DO
RAMPINT = VLOWINT - 3
C = DAC_VALUE(DAC0,RAMPINT)
C = ADC_VALUE(CHANNEL,GAIN1, AVAL)
FIRE(I-3)= AVAL
I =I +1
CALVHI = 0
END DO

C = DAC_VALUE(DAC0,OFF)
C = DAC_VALUE(DAC1,OFF2)
PRINT *, 'PROGRAM TERMINATED'
C = ENABLE_SYSTEM_CLOCK()

```

C THIS SECTION WRITES THE DATA TO THE INPUTTED FILE NAME

```
OPEN (UNIT =1, FILE = FILENAME, STATUS='NEW')
WRITE(1,*) 'THIS IS THE DATA FILE FOR HEI PROJECT'
WRITE(1,*) 'RAYMOND L. SLAUGHTER'
WRITE(1,*)
WRITE(1,*) 'THIS IS A LOG OF THE TIME DELAY BETWEEN THE FIRST'

WRITE(1,*) 'AND THE FIRST COMBUSTION PROCESS'
WRITE(1,*) '      '

WRITE(1,*) '    '

DO 130 J = 0,TIMECOUNT
    WRITE(1,*) FIRE(J)
130 CONTINUE
CLOSE(UNIT=1)

STOP
END
```

b.) Calibration Curve for PW Vs. A/F Ratio

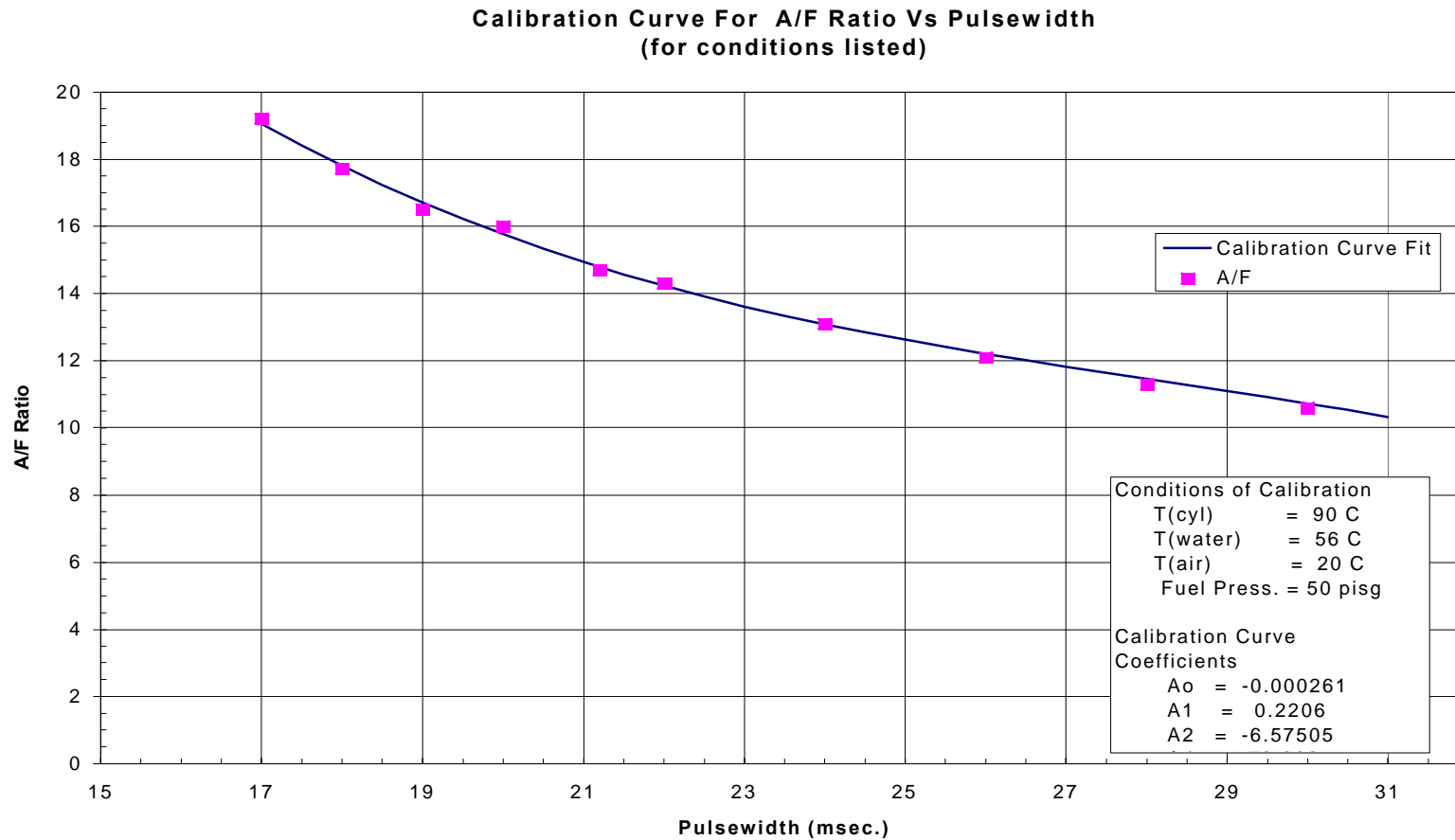


Figure B1 - Calibration Curve for EFI

APPENDIX C

Recharge Time Calculation for Capacitor In H.E.I. System

The engine operates at 900 RPM . It is a four stroke engine which means the ignition fires at a frequency of 7.5 Hz. The time between firings is about 133.3 ms less the duration of the spark.

The current flowing through the storage capacitor was calculated using the equation shown below.

$$i = \frac{E}{R} * e^{-t/R*C}$$

where

$$R = 20 \text{ k}\Omega$$

$$C = 1\mu\text{F}$$

$$E = 2200\text{VDC max.}$$

$$t = 0.1333 \text{ sec}$$

Evaluating the equation above for the current flowing through the capacitor after 133.3 ms gives a current of $1.40 * 10^{-4}$ amps. Given the initial current flow at time $t = 0$ of .11 amps, the capacitor is 99.9% charged in 133.3 ms.

APPENDIX D

Exhaust Analyzer Information

a.) Sample Time Lag and Individual Analyzer Time Constants

The table below list the time constant for each of the exhaust analyzers used inside the OTC unit. The time lag caused by the length of the sample line is also supplied. To determine the values in the table, calibration gas was supplied through the exhaust pipe. The response of the analyzers were recorded and graphed. On the graph, time zero for the application of the calibration gas is at 41 seconds. The response of the HC analyzer was assumed to be the same as CO and CO₂. The three use the same infrared absorption unit and the same internal sample lines. NO_x has the highest time constant and sample delay followed by O₂.

Table D1 -Response Characteristics Of Exhaust Analyzers

Analyzer	Time Constant	Sample Delay
CO, CO₂, HC	10.03 sec	14 second
O₂	12	12 second
NO_x	15.03	18

Gas Analyzer Response Plot

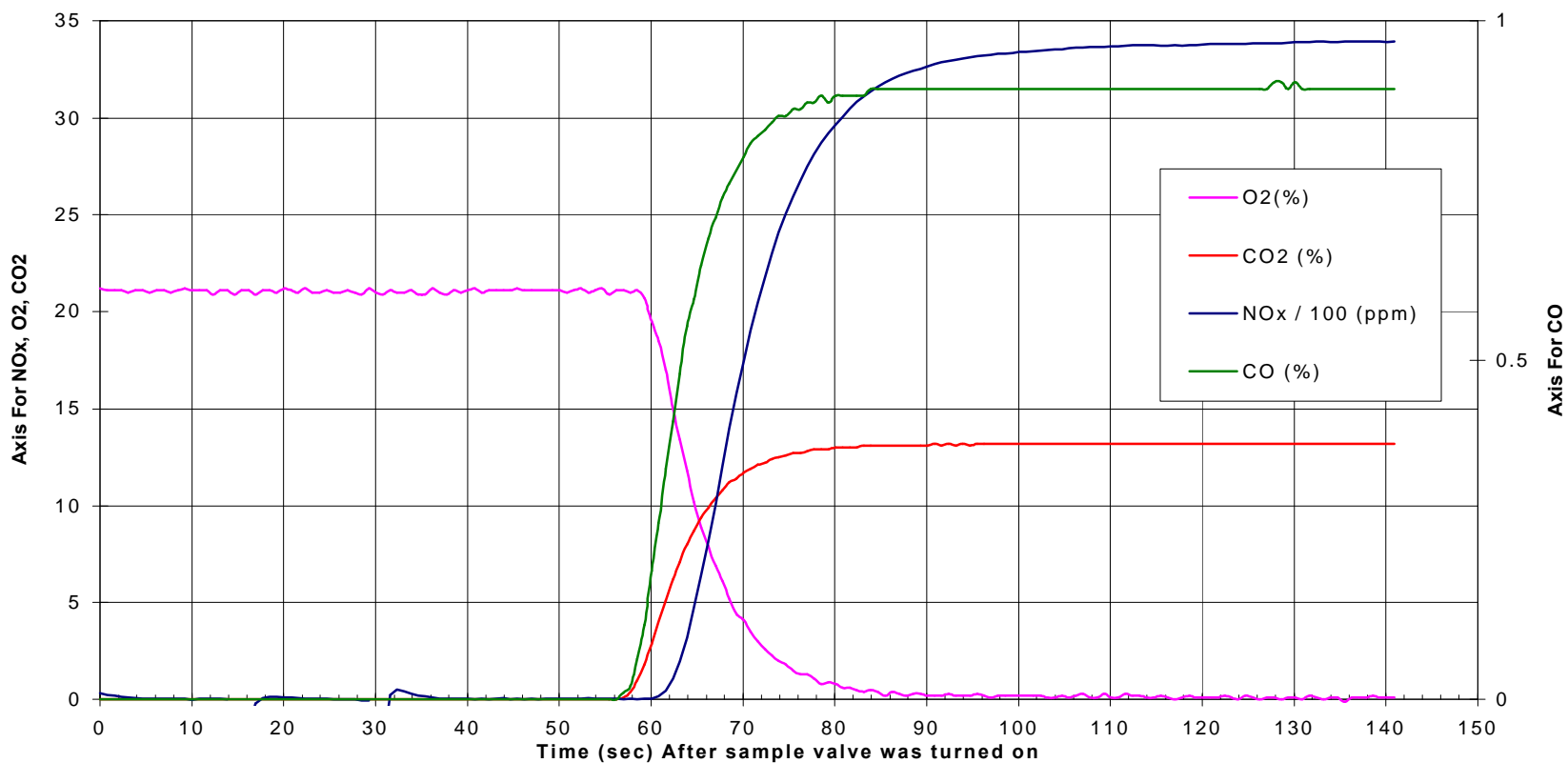


Figure D1 - OTC 5 Gas Analyzer Response To Step Input

b.) Calibration Curve for FID HC Analyzer

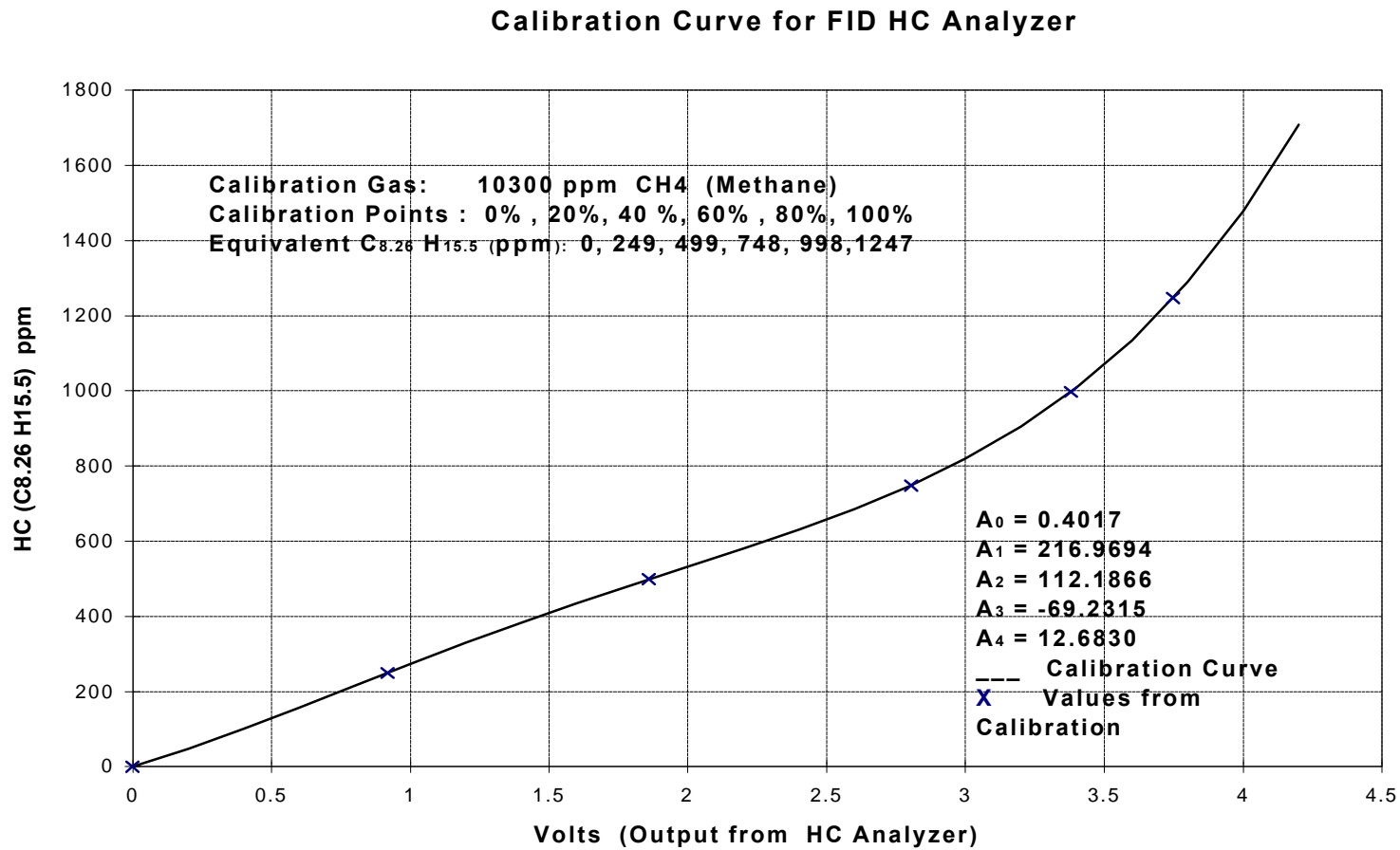


Figure D2 - FID HC Analyzer Calibration Curve

c.) Air/Fuel Ratio Calculation

The air/fuel ratio was calculated from the concentration analysis of the exhaust gas. All major products in the exhaust were measured except for nitrogen. Given the concentrations of the major combustion products in the exhaust, the equation below derived from balancing oxygen molecules was used. The equation below was taken from Heywood[30].

$$\frac{A}{F} = 4.773 \left(\frac{M_{air}}{M_{fuel}} \right) \frac{(CO_2) + (CO) / 2 + (H_2O) / 2 + (NO) / 2 + (NO_2) + (O_2)}{(HC) + (CO) + (CO_2)}$$

28.96 was used for M_{air} (The molecular weight of air). The molecular weight of gasoline varies because of it is made of many types of hydrocarbon molecules. For the experiment gasoline was assumed to be $C_{8.26}H_{15.5}$ giving it a molecular weight of 114.80 g/mole[31]. In the air/fuel equation above the exhaust products are in molar concentrations. During the experiment the concentration NO_x was measured in the exhaust. The concentration of NO_x is a combination of NO and NO_2 . However, the NO_x concentration was entered into the equation for NO and NO_2 was set to zero because in an automobile engine NO is a couple of orders large in magnitude than NO_2 . The analyzer was not capable of measuring H_2O Concentration in the exhaust. But given that the background moisture content of all the exhaust gases were the same, the concentration of H_2O was calculated using the equation provided below. It was derived from Heywood[30].

$$(H_2O) = 938 \frac{(CO_2) + (CO)}{(CO) / [K(CO_2)] + 1}$$

The values for K used in the equation was 3.6. The commonly used values for K range from 3.5 to 3.8, The difference in the calculated A/F ratio through this range of K is negligible.

d.) Accuracy Assessment of Air/Fuel Calculations Based on Uncertainties of Exhaust Analyzer

The uncertainty of the air/fuel ratio calculations was based on the uncertainty in concentration measurements of the exhaust analyzer. The uncertainty of each exhaust gas concentration was provided in the specification manual of the OTC 5-gas analyzer. The percent uncertainty of each gas is listed in Table A-1.

Table D2 - Uncertainties of Exhaust Gas Composition

Exhaust Gas	Measurement Uncertainty	
	Range	uncertainty
HC	0-240 ppm	11 ppm
	240-400 ppm	12 ppm
	400-2000 ppm	3%
	> 2000 ppm	5.0 %
CO	0.0-2.0%	0.05%
	1.0-2.0%	0.06%
	2.0-3.0%	5.0 %
	3.0-5.0%	0.15%
	5.0-7.0%	0.20%
	7.0-10.0%	0.3%
CO ₂	0-16%	0.4%
	16-20%	1.0%
NO _x	0-1000 ppm	32 ppm
	1001-2000 ppm	60 ppm
	2001-4000 ppm	120 ppm
O ₂	full range	0.2%

Given the table of uncertainty, the summation of the uncertainty of CO, CO₂, O₂, and NO_x ranges from 6.2% to 0.65%. The uncertainty of HC was neglected from the summation total because of its low concentrations in the exhaust. Even at there maximum level of uncertainty its effects on the air/fuel ratio is negligible.

e.) FID and Infrared Hydrocarbon Analyzer Comparison

Figure D3 on the following page shows the concentration of HC read by the Rosemount FID HC analyzer and the OTC infrared HC (hexane) analyzer and the A/F ratio corresponding to the HC levels. The Rosemount HC analyzer was calibrated to read the carbon atom count in $C_{8.26} H_{15.5}$. The graph shows that Hexane is large percentage of the total HC's emitted. Based on a carbon atom count 40% by volume of the carbon atoms are in Hexane molecules. The percentage of the total HC emission contributed by Hexane is fairly constant. The changes in hexane concentration due to the increased ignition energy should closely reflect the changes in overall HC emissions.

Measured HC Concentration of the FID HC Analyzer and the Infrared HC Analyzer For the Same Exhaust Sample and A/F Ratio

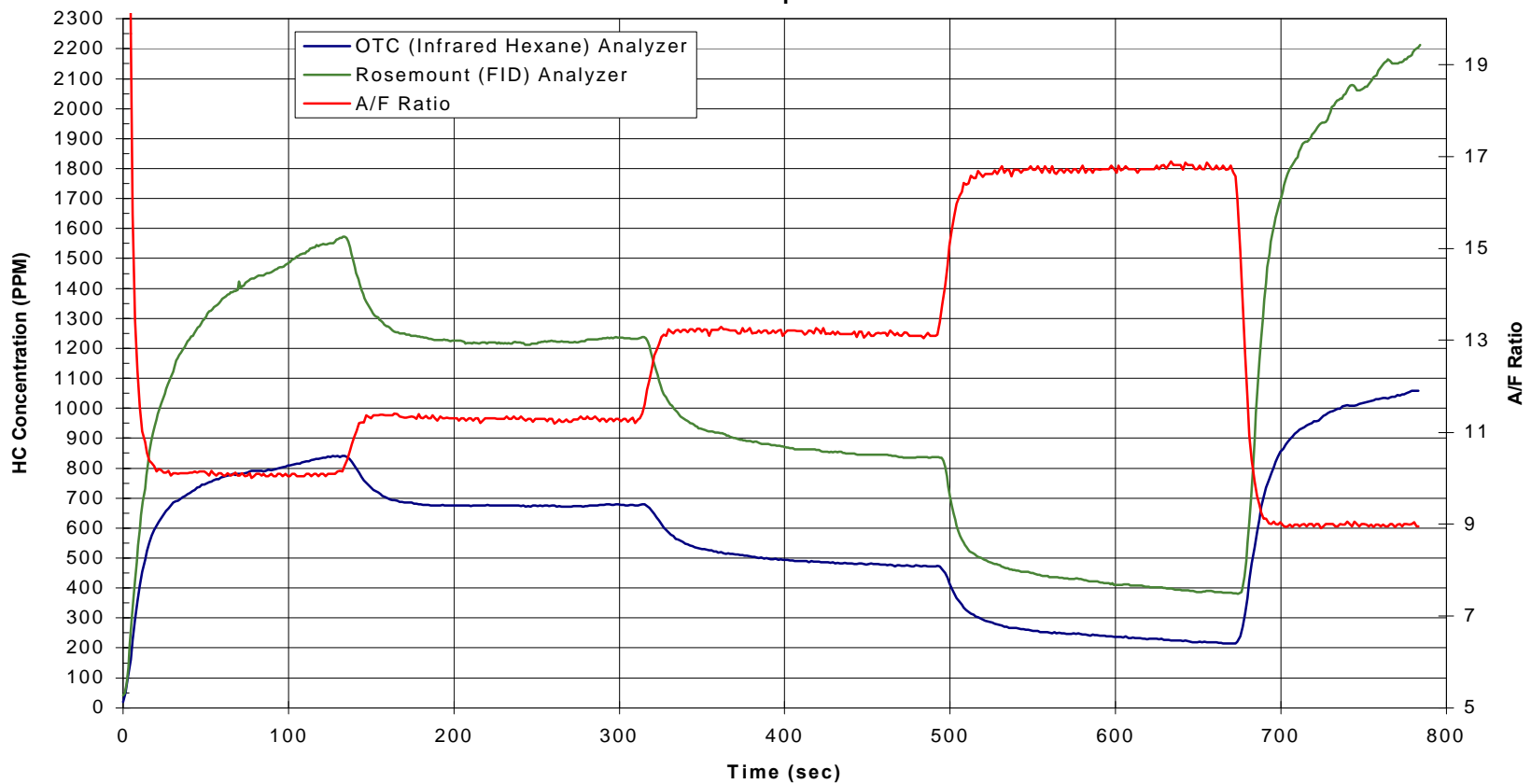


Figure D3 - HC Analyzer Comparison, FID to Infrared Absorption (Hexane)

APPENDIX E
Emission Data for CO₂, NO_x, O₂

CO2 Emission Versus Time For Stock Ignition System

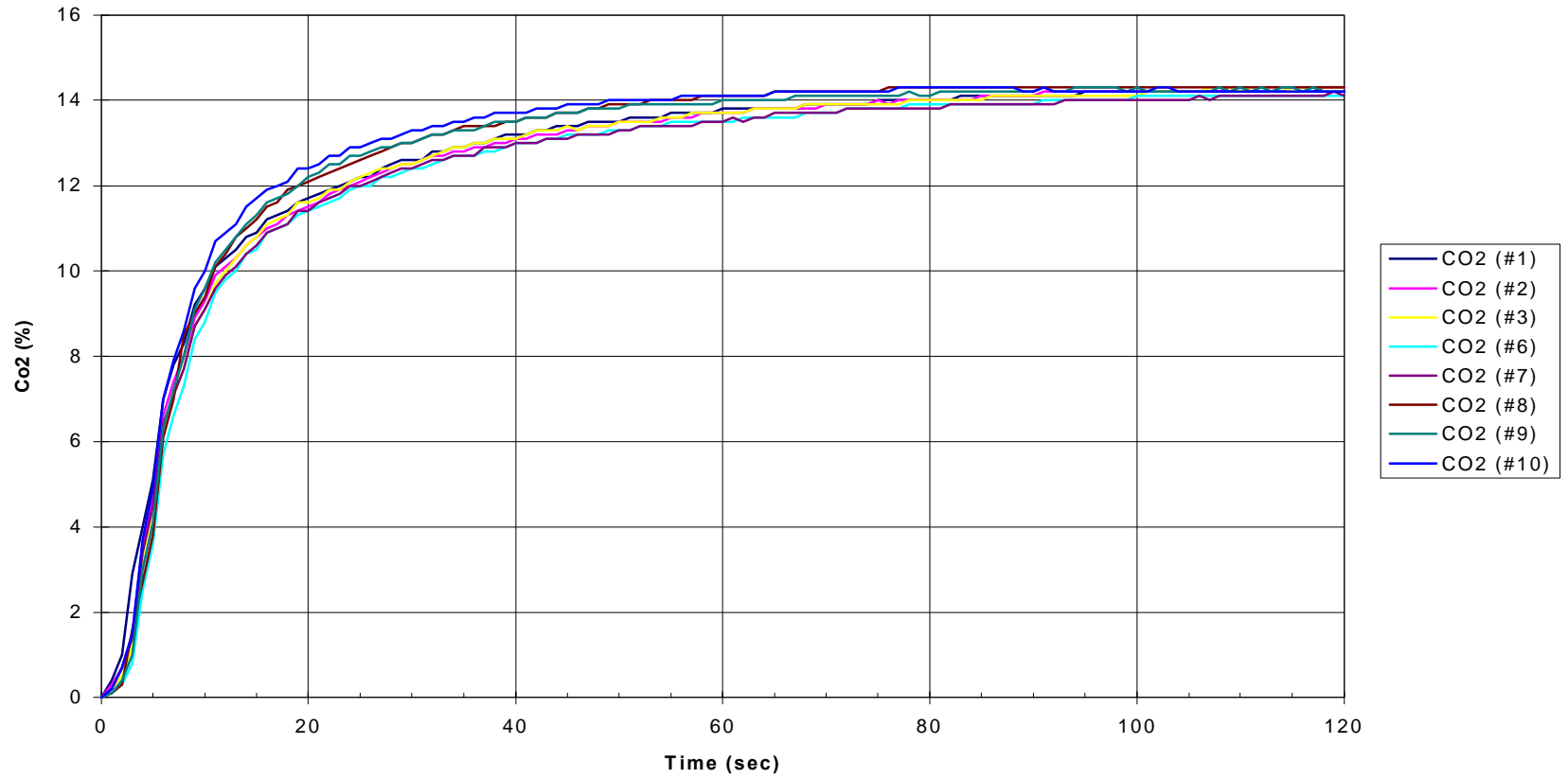


FIGURE E1 - CO₂ Emissions for Stock Ignition Energy

O2 Emission Versus Time For Stock Ignition System

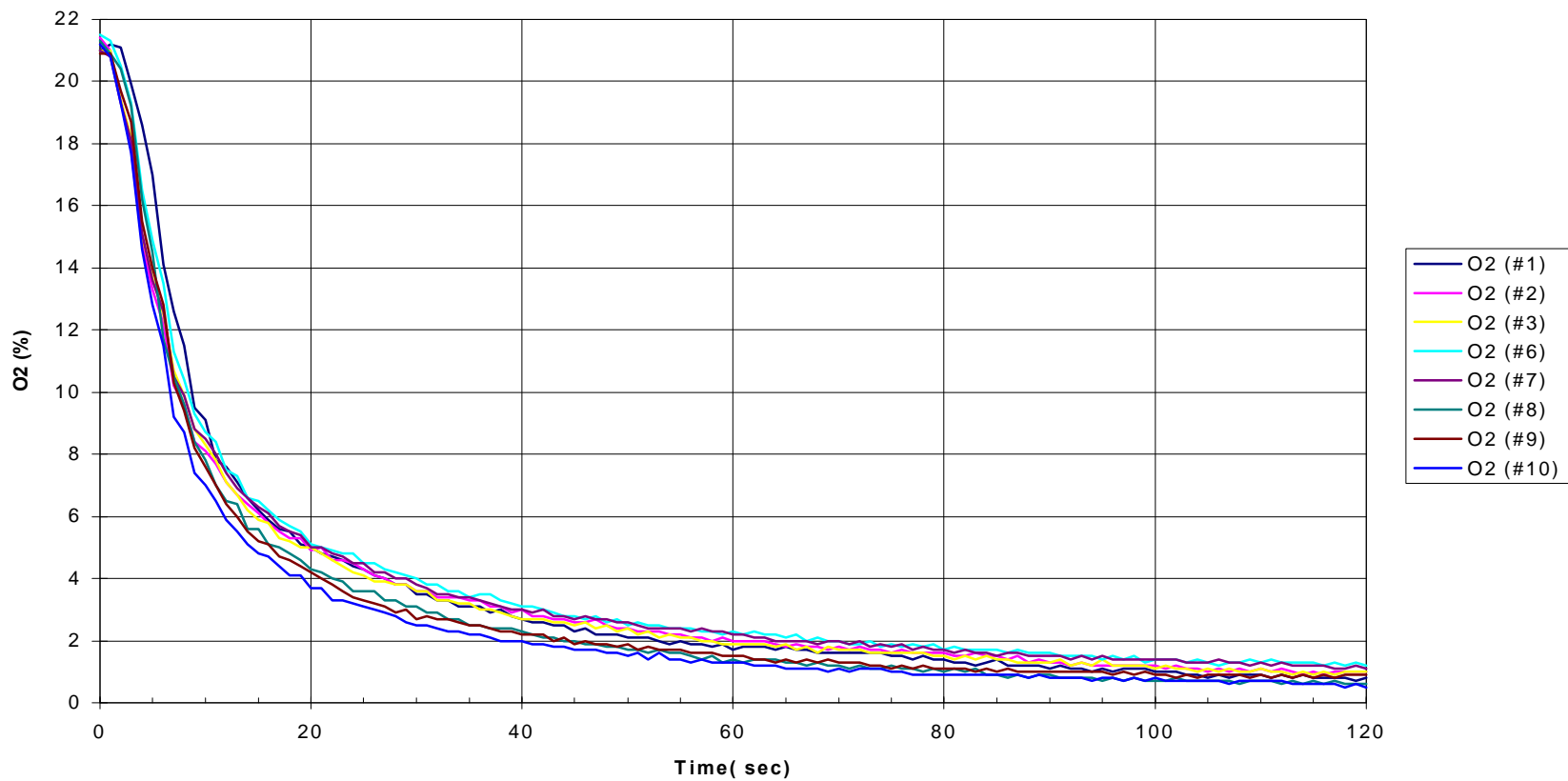


FIGURE E2- O₂ Emissions for Stock Ignition Energy

NOx Emission Versus Time For Stock Ignition System

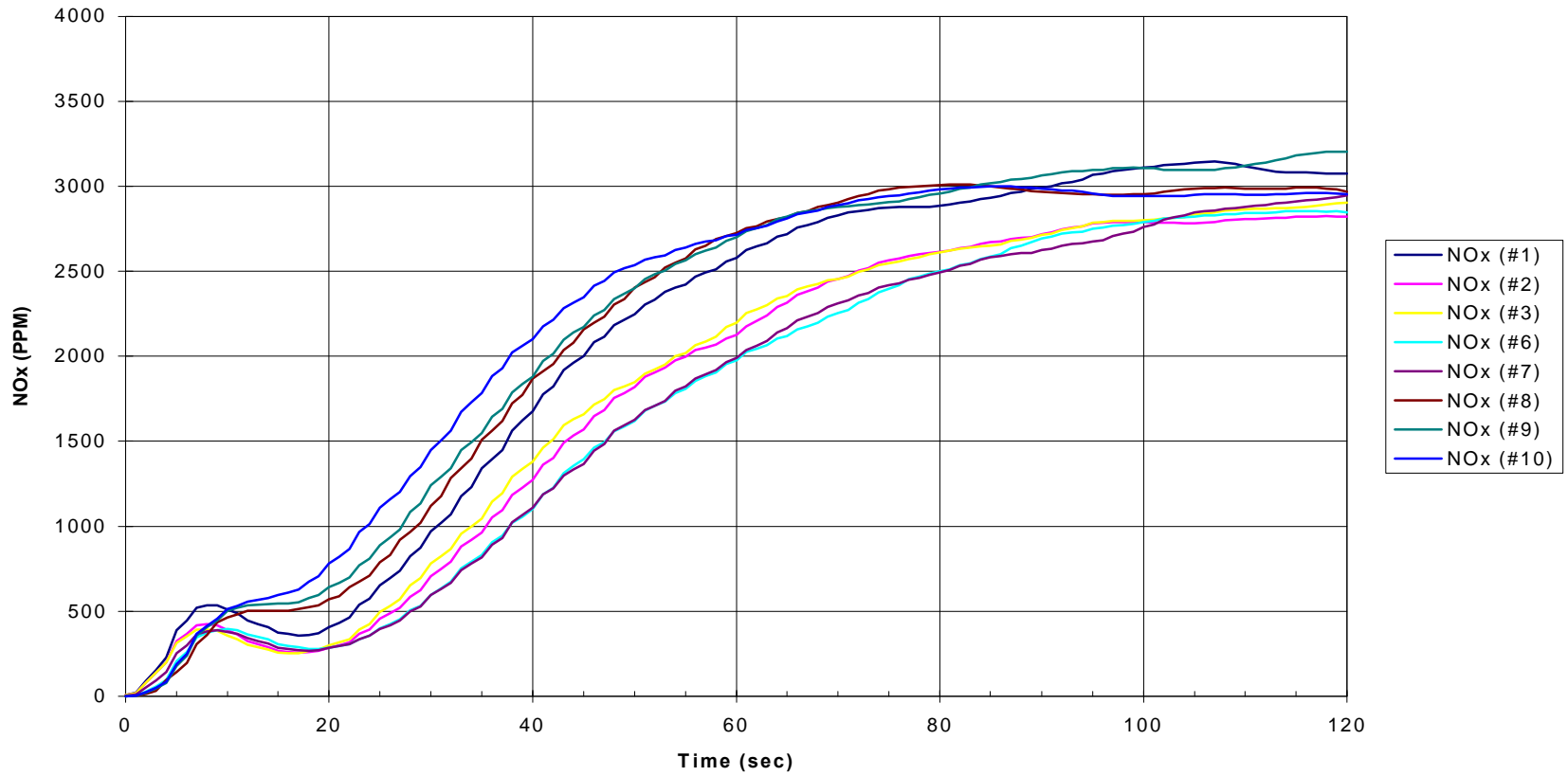


FIGURE E3- NO_x Emissions for Stock Ignition Energy

CO2 Emission Versus Time For 0.387 Joules of Additional Ignition Energy Over Stock

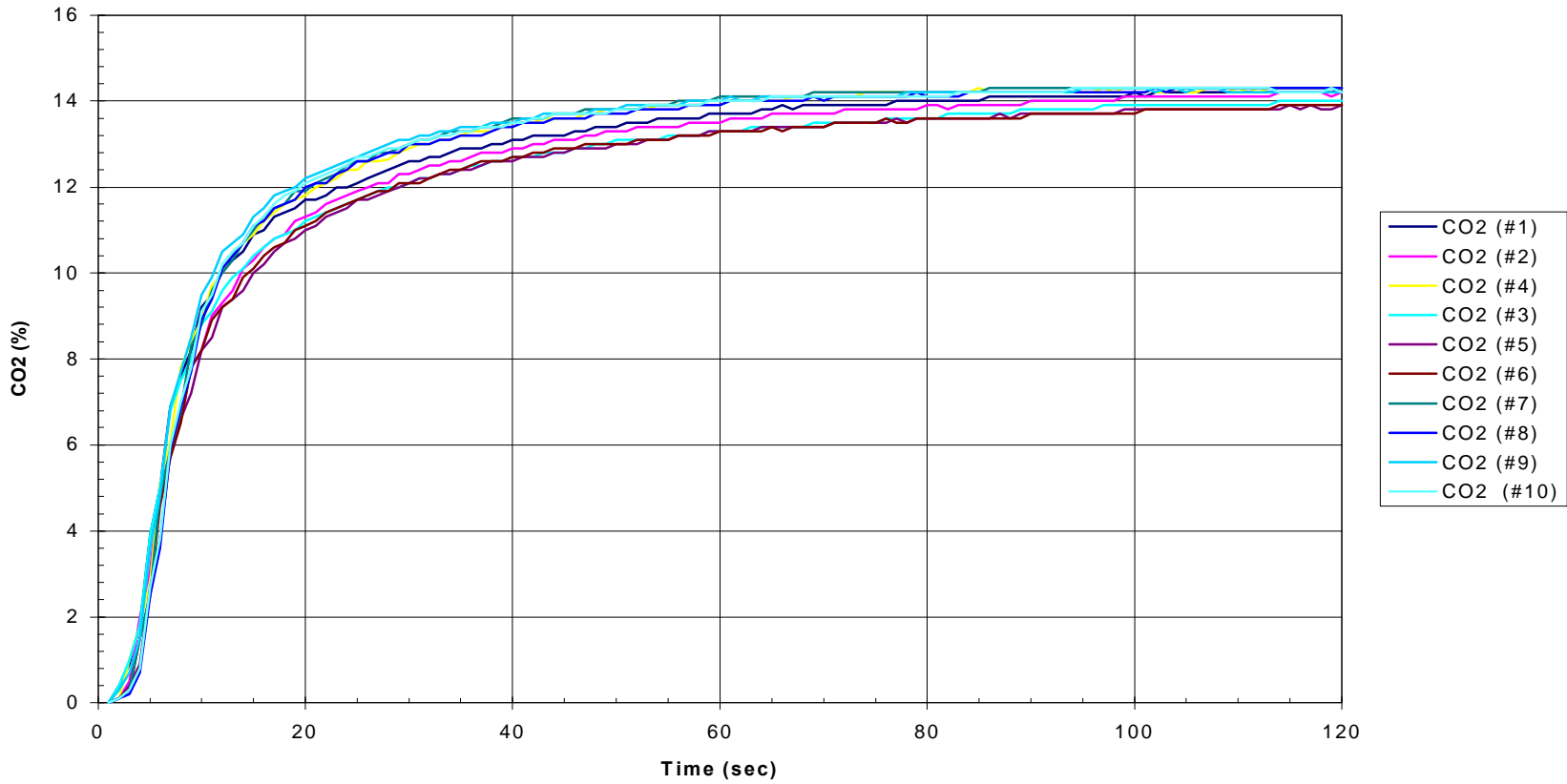


FIGURE E4- CO₂ Emissions for 0.387 Joules of Additional Energy Over Stock Ignition

O₂ Emission Versus Time For 0.387 Joules of Additional Ignition Energy Over Stock

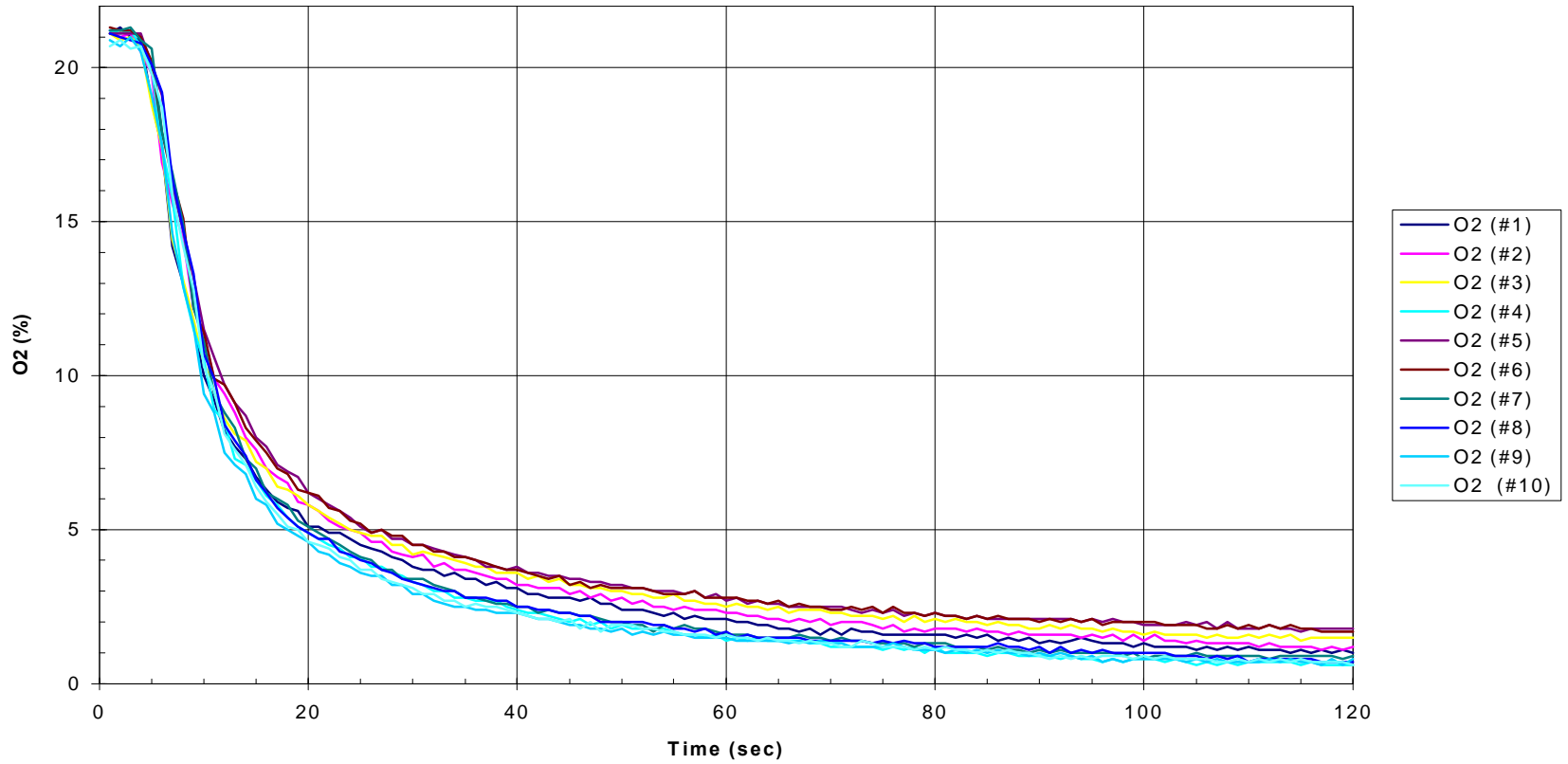


FIGURE E5- O₂ Emissions for 0.387 Joules of Additional Energy Over Stock Ignition

NOx Emission Versus Time For 0.387 Joules of Additional Ignition Energy Over Stock

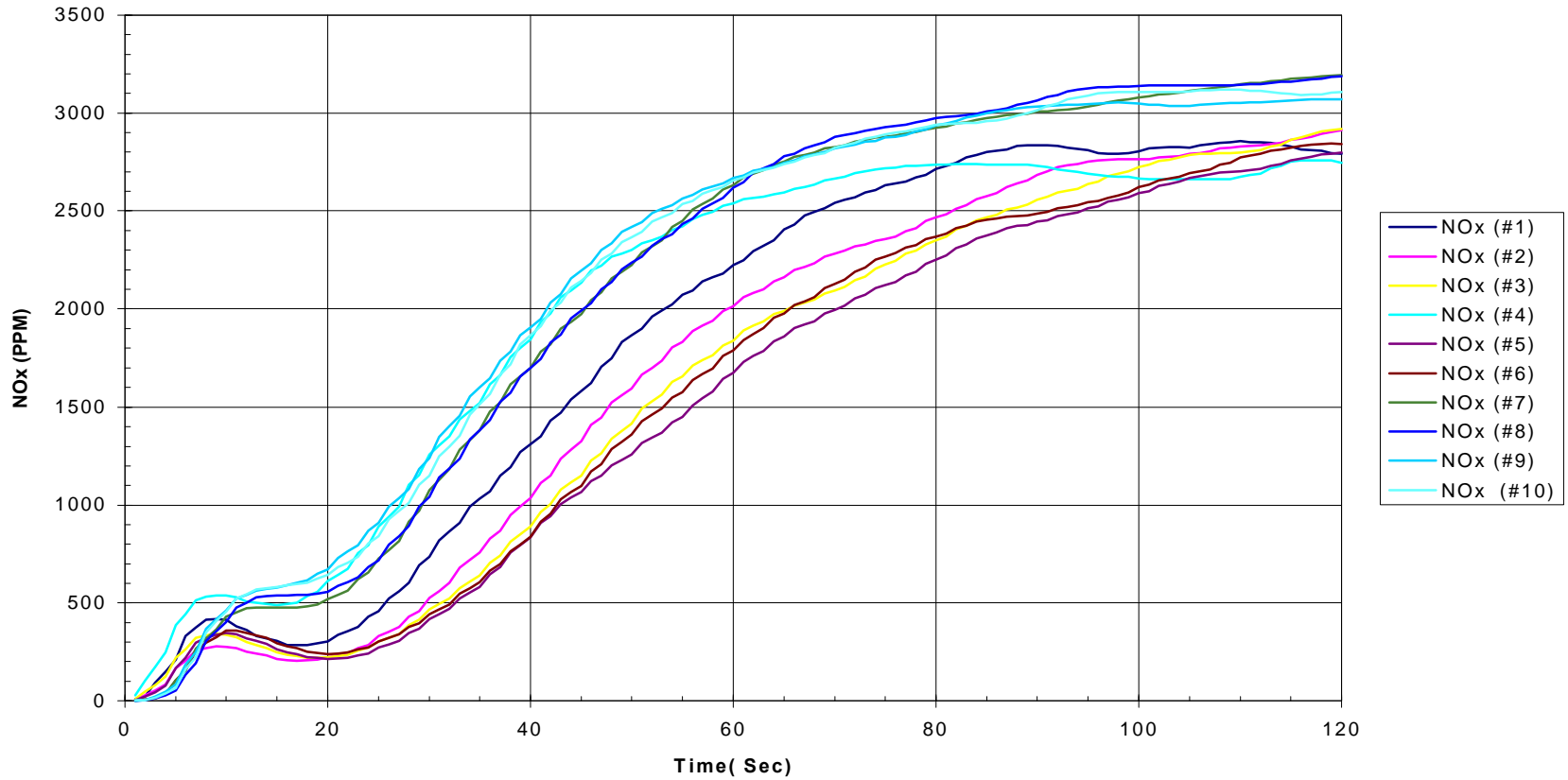


FIGURE E6- No_x Emissions for 0.387 Joules of Additional Energy Over Stock Ignition

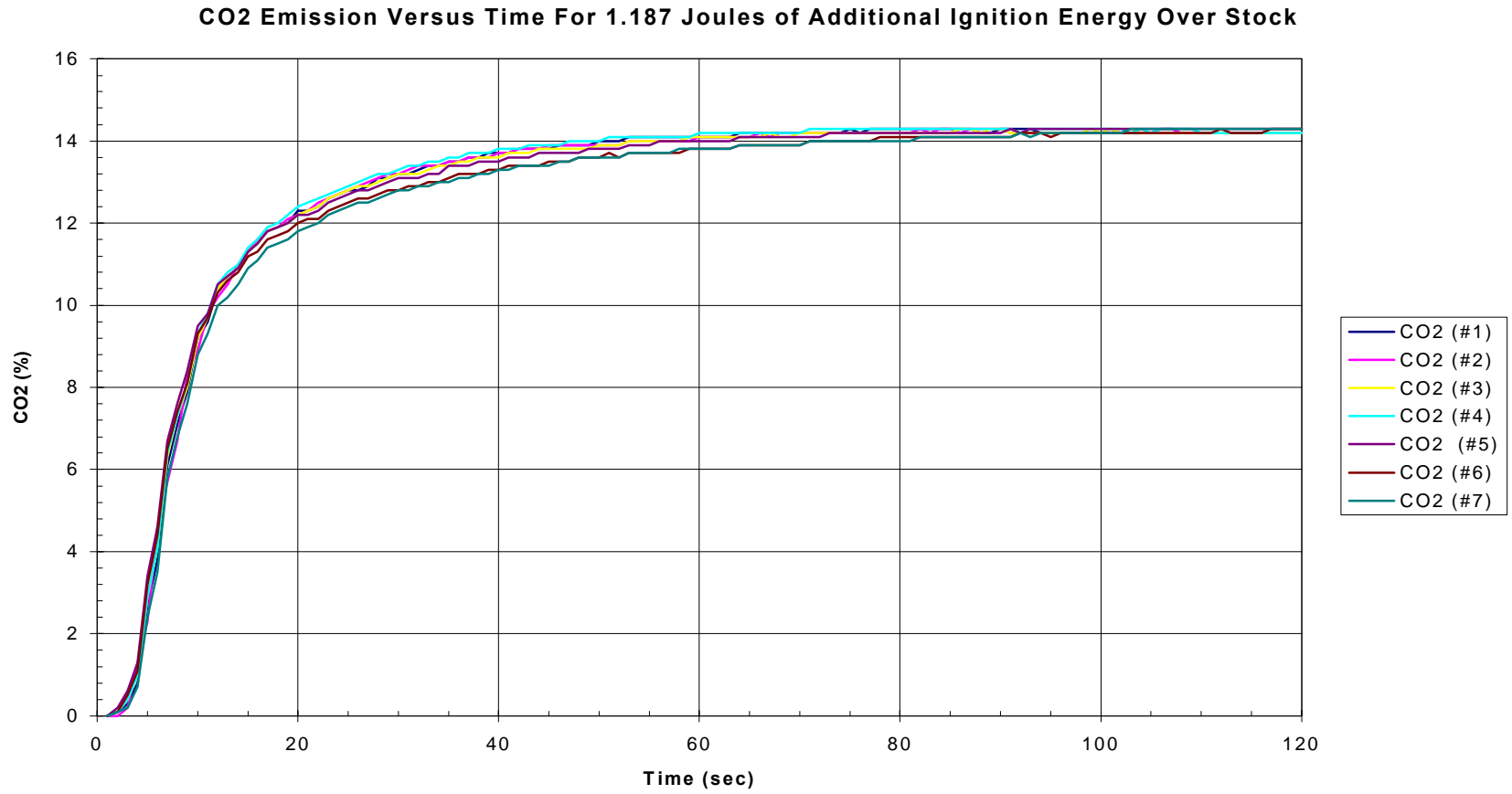


FIGURE E7- CO₂ Emissions for 1.187 Joules of Additional Energy Over Stock Ignition

O2 Emission Versus Time For 1.187 Joules of Additional Ignition Energy Over Stock

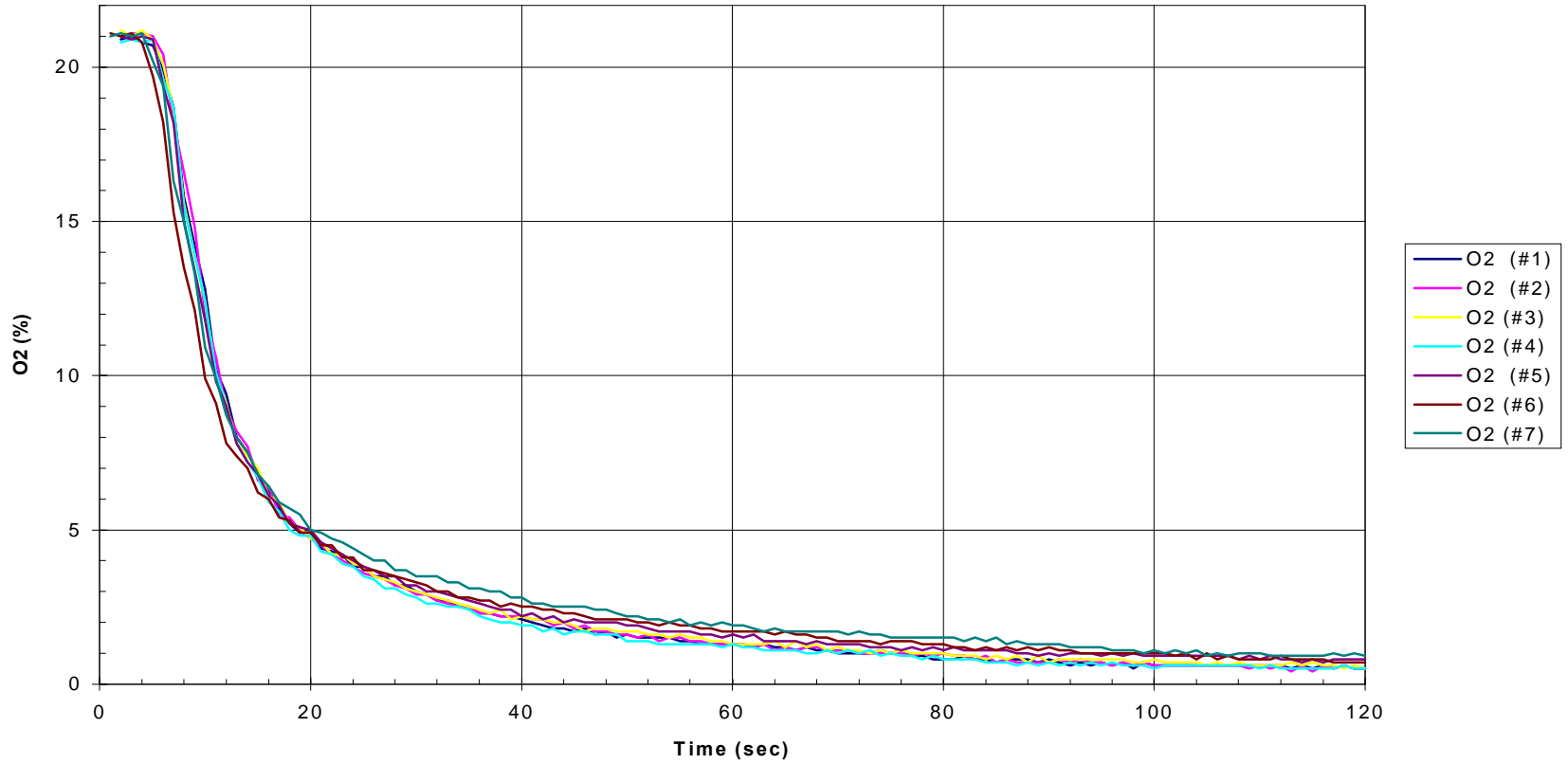


FIGURE E8- O₂ Emissions for 1.187 Joules of Additional Energy Over Stock Ignition

NOx Emission Versus Time For 1.187 Joules of Additional Ignition Energy Over Stock

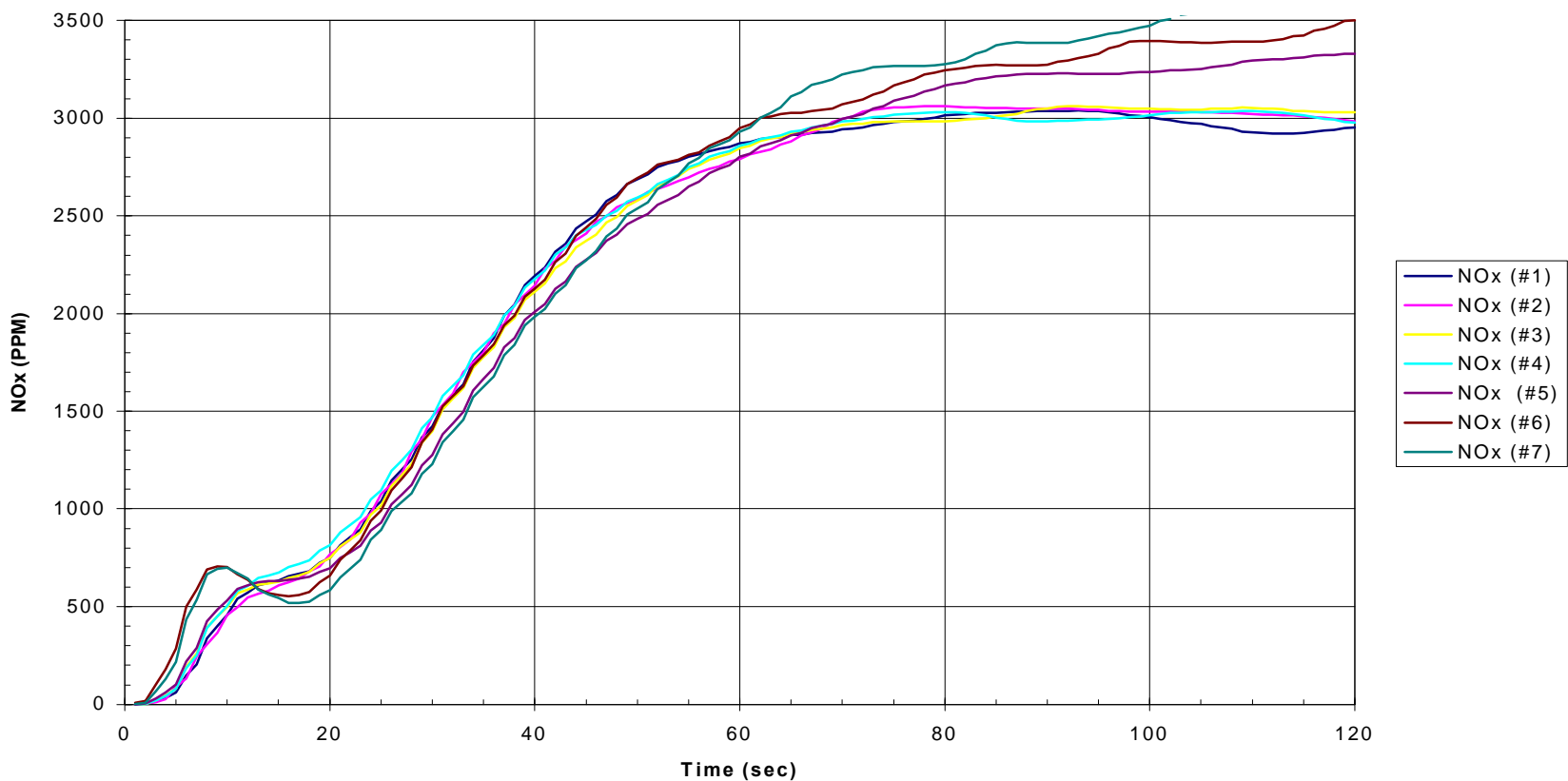


FIGURE E9- NO_x Emissions for 1.187 Joules of Additional Energy Over Stock Ignition