Gas Analysis and Toxicity Assessment of Combustion Products of Aircraft Materials

Louise C. Speitel

Fire Safety Branch ATO-P, AJP-6320

FAA W.J. Hughes Technical Center

Atlantic City International Airport, NJ 08405

Materials Working Group Meeting

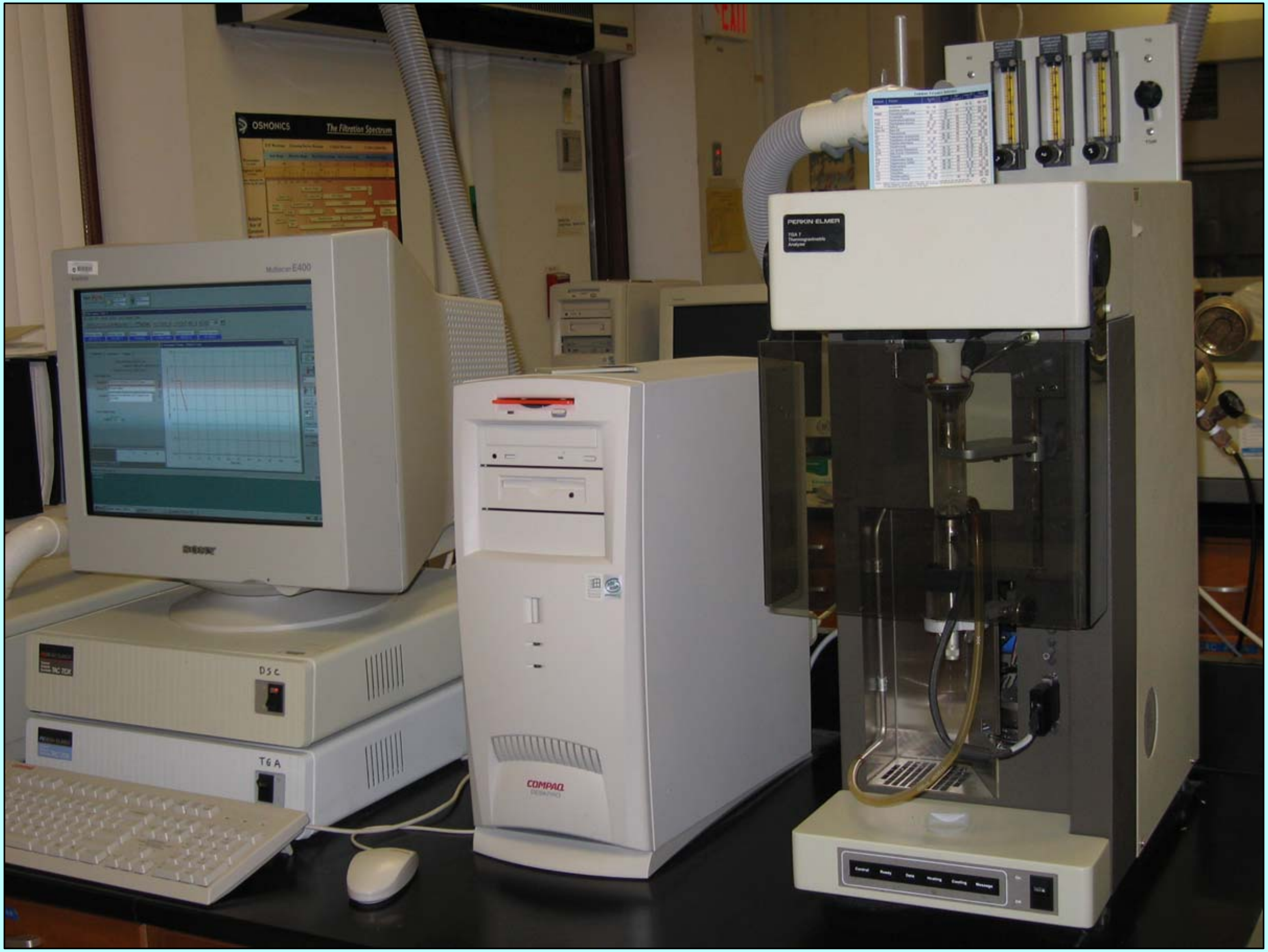
Atlantic City, NJ. March 20-21, 2006

OUTLINE OF TALK

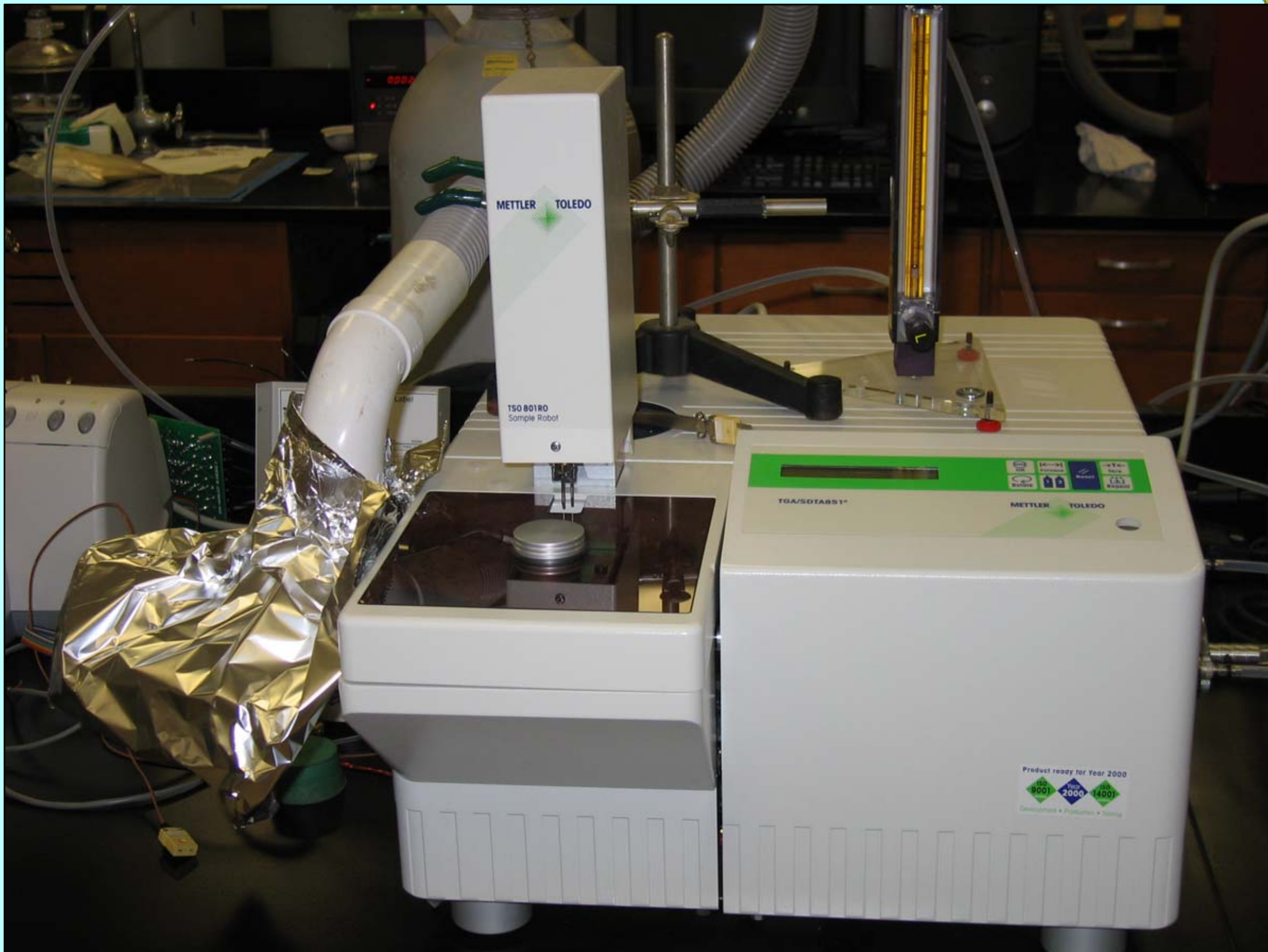
- FAA Gas Analysis Instrumentation
- Requirements for Toxicity Assessment of Combustion Gases
- The FAA Toxicity Model
- FTIR Method
- FTIR Results: Response Times, Gas Histories, Toxicity

CHEMISTRY & MATERIAL SCIENCE LABORATORY

TGA WITH EVOLVED GAS MONITORING



TGA-DTA WITH EVOLVED GAS MONITORING



GAS CHROMATOGRAPH WITH MASS SPECTOMETER (GC-MS) WITH PYROPROBE

FOURIER TRANSFORM INFRARED SPECTROMETER (FTIR) WITH PYROPROBE

ION CHROMATOGRAPH WITH ELECTROCHEMICAL & AMPEROMETRIC DETECTORS

GASES:

HCN

HF

HCl

HBr

HI

I_2

H_2S

SO_x

NO_x

PROCESS ANALYZERS:

<u>GASES:</u>

CO

CO2

O2

Halo-carbons

THC

Water

FTIR PROCESS ANALYTICAL SYSTEM

GASES:

CO
CO_2
HCN
NH_3
NO
NO_2
SO_2
HF
HCl
HBr
COF_2
H_2S
… etc.

REQUIREMENTS FOR TOXICITY ASSESSMENT OF COMBUSTION GASES

- Combustion conditions of test must match fire to be modeled
- Quick time to full response for gas measurements
- Operational simplicity: fire test, gas analysis and toxicity calculations
- Estimate of the reliability of each gas measurement as a function of time
- Valid toxicity model

FAA TOXICITY MODEL: FED_I & FED_L

For a constant concentration of a toxic gas:

The effect is predicted to occur when $FED_{Effect} = 1$

Incapacitation& Lethality Models

$$FED_{effect} = \frac{dose\ received\ at\ time\ t}{effective\ Ct\ dose\ to\ cause\ effect} = \frac{Ct}{Ct_{effect}} = \frac{t}{t_{effect}}$$

If the concentration varies with time:

$$FED_{Effect} = \int_o^t \frac{dt}{t_{Effect}}$$

FAA TOXICITY MODEL

$$FED_I = FED_{I\ Gases} + FED_{I\ Heat}$$

$$= FED_{I\ CO} + FED_{I\ HCN} + FED_{I\ HCl} + FED_{I\ HF} + FED_{I\ HBr} + FED_{I\ Acrolein} + FED_{I\ CO_2} + FED_{i\ NO_2} + FED_{I\ Low\,O_2} + FED_{I\ Heat}$$

$$V_{CO_2} = \frac{\exp(0.2496 \times C_{CO_2} + 1.9086)}{6.8}$$

where C_{CO_2} **= % CO_2**

FAA TOXICITY MODEL

$$FED_I = \frac{1}{3.4250}\int (V_{CO_2} \times C_{CO})\, dt \qquad \text{when } V_{CO_2} \times C_{CO} > 0.01\%$$

$$+ \int \frac{(V_{CO_2} \times C_{HCN} - 63)\, dt}{564} \qquad \text{when } V_{CO_2} \times C_{HCN} > 63 \text{ ppm}$$

$$+ \int \frac{dt}{3 + [(3.36 \times 10^{+5})/(V_{CO_2} \times C_{HCl} - 300)]} \qquad \text{when } V_{CO_2} \times C_{HCl} > 300 \text{ ppm}$$

$$+ \int \frac{dt}{3.0 + [(1.53 \times 10^{+5})/(V_{CO_2} \times C_{HF} - 136)]} \qquad \text{when } V_{CO_2} \times C_{HF} > 136 \text{ ppm}$$

$$+ \int \frac{dt}{3 + [(3.36 \times 10^{+5})/(V_{CO_2} \times C_{HBr} - 300)]} \qquad \text{when } V_{CO_2} \times C_{HBr} > 300 \text{ ppm}$$

$$+ \int \frac{dt}{1.50 + [(4.0 \times 10^{+4})/(V_{CO_2} \times C_{Acrolein} + 500)]} \qquad \text{when } V_{CO_2} \times C_{Acrolein} > 300 \text{ ppm}$$

$$+ \int \frac{(V_{CO_2} \times C_{NO_2} - 290)\, dt}{1.14 \times 10^{+4}} \qquad \text{when } V_{CO_2} \times C_{NO_2} > 290 \text{ ppm}$$

$$+ \int \frac{dt}{\exp(6.1623 - 0.5189 \times C_{CO_2})} \qquad \text{when } C_{CO_2} > 7.0\%$$

$$+ \int \frac{dt}{2193.8 - 311.6 \times C_{CO_2}} \qquad \text{when } 5.5 \le C_{CO_2} \le 7.0\%$$

$$+ \int \frac{dt}{\exp(8.55 - 0.511(20.9 - \%O_2))} \qquad \text{when } \%\, O2 < 11\%$$

$$+ \frac{1}{4.1 \times 10^{+8}} \int T^{3.61}\, dt \qquad \text{when } T > 50°C$$

REFERENCE

L. Speitel ,"Toxicity Assessment of Combustion Gases and Development of a Survival Model", Federal Aviation Administration, W.J.H. Technical Center, Report No. DOT/FAA/AR-95-5, July 1995

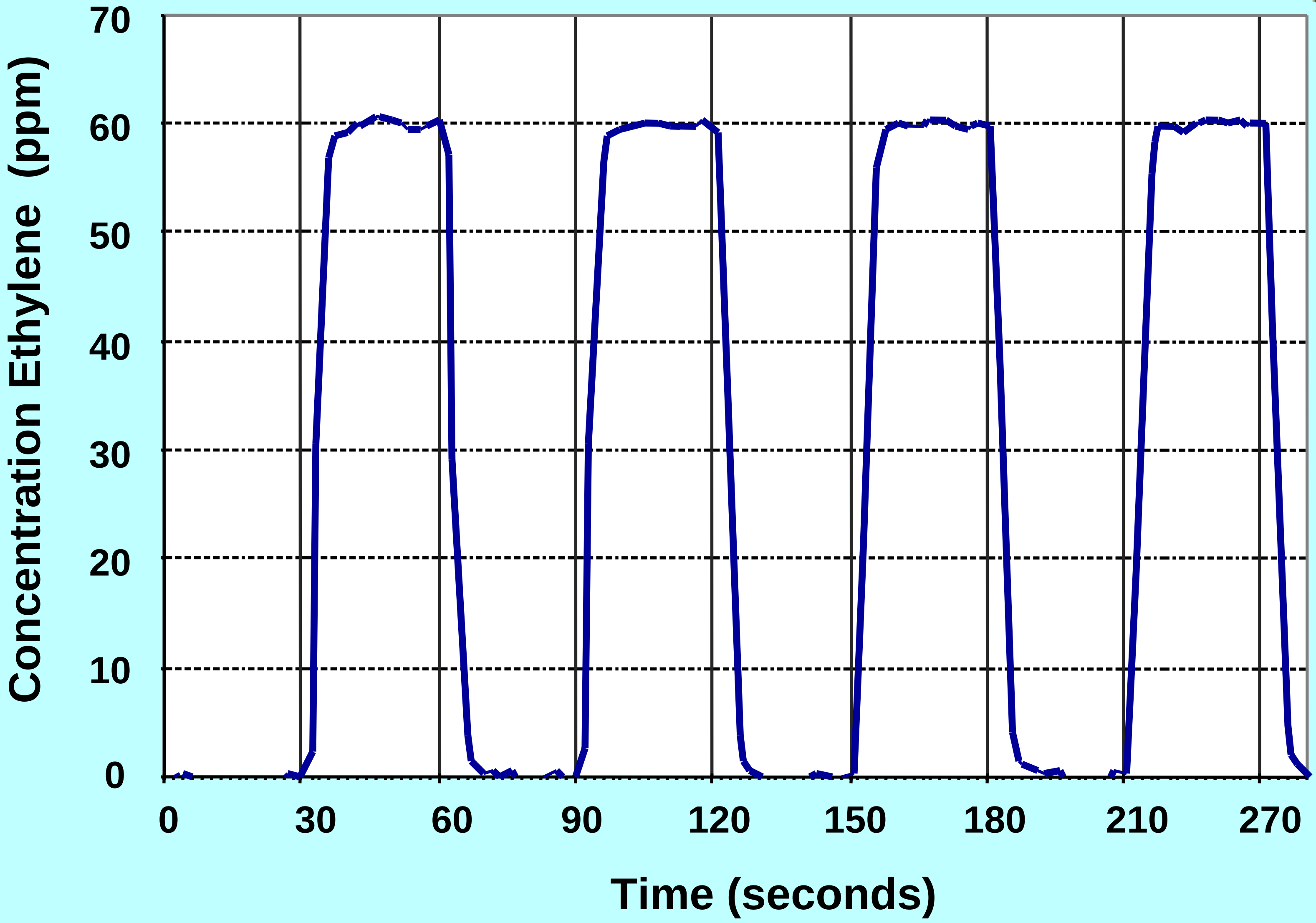
See http:/www.fire.tc.faa.gov

L. Speitel, "Fractional Effective Dose Model for Post-crash Aircraft Survivability", Toxicology, Volume 115, pp.167-177, 1996, Copyright 1996 by Elsevier Science Ireland Ltd.

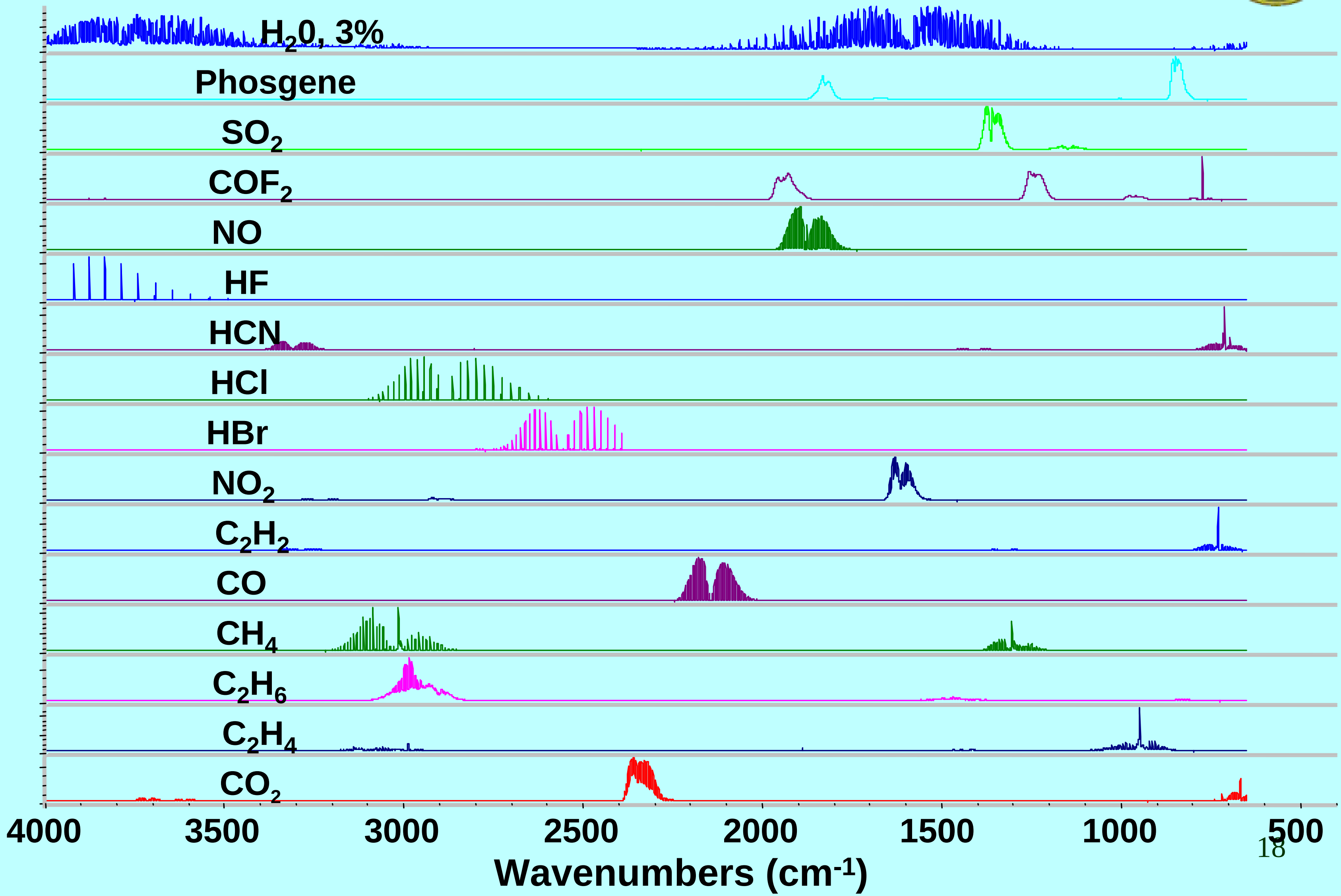
FAA FTIR SYSTEM AND METHOD

- Extractive FTIR analytical system to analyze rapidly changing moist fire gas concentrations as a function of time for 20 gases
- Short system response times
- Quantitative evaluation over wide dynamic range
- Estimate of reliability of each gas measurement over time
- 20+ gas method with low residuals

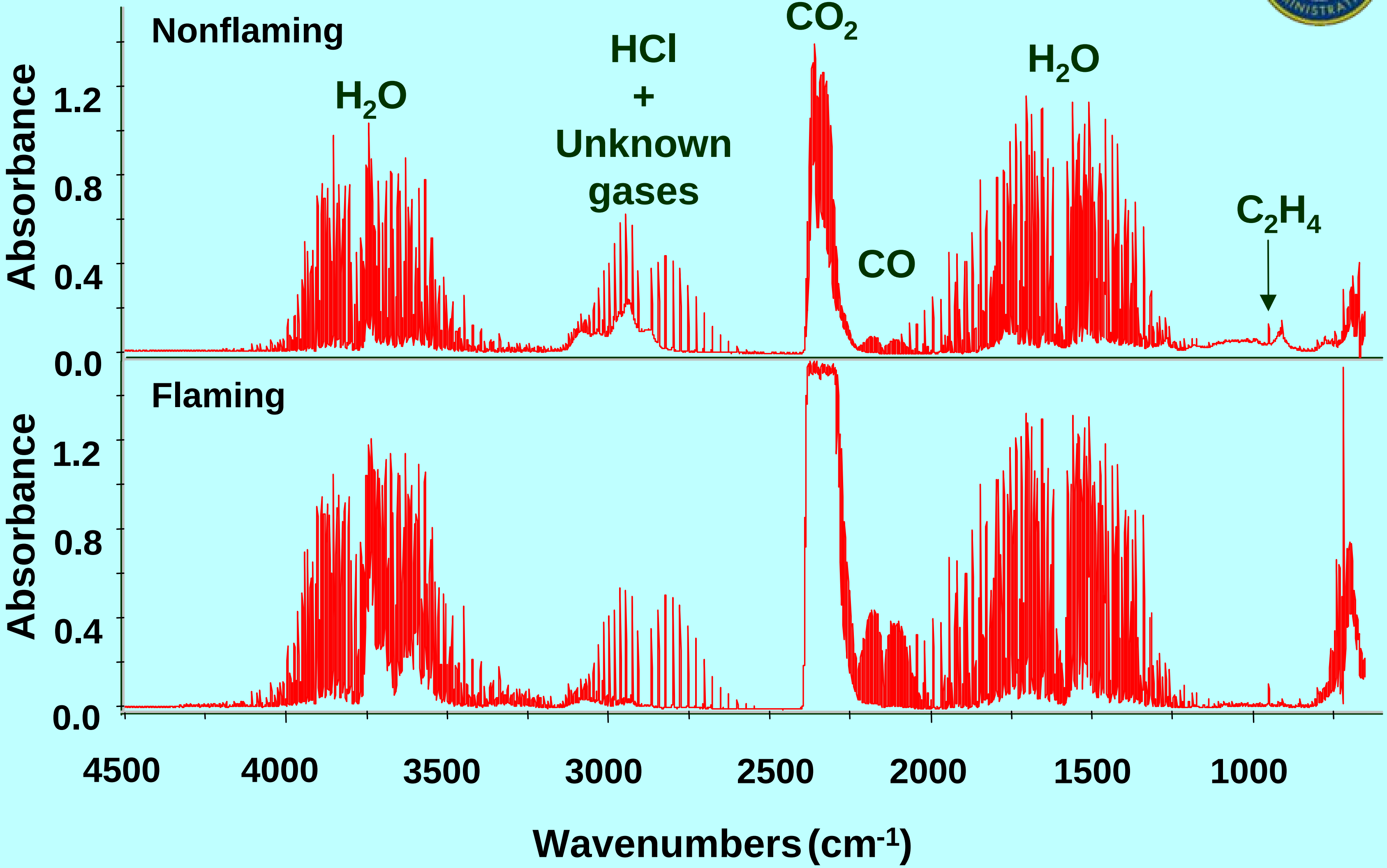
DYNAMIC FTIR SYSTEM RESPONSE WITH GAS INTRODUCED AT HEATED SAMPLE LINE INLET



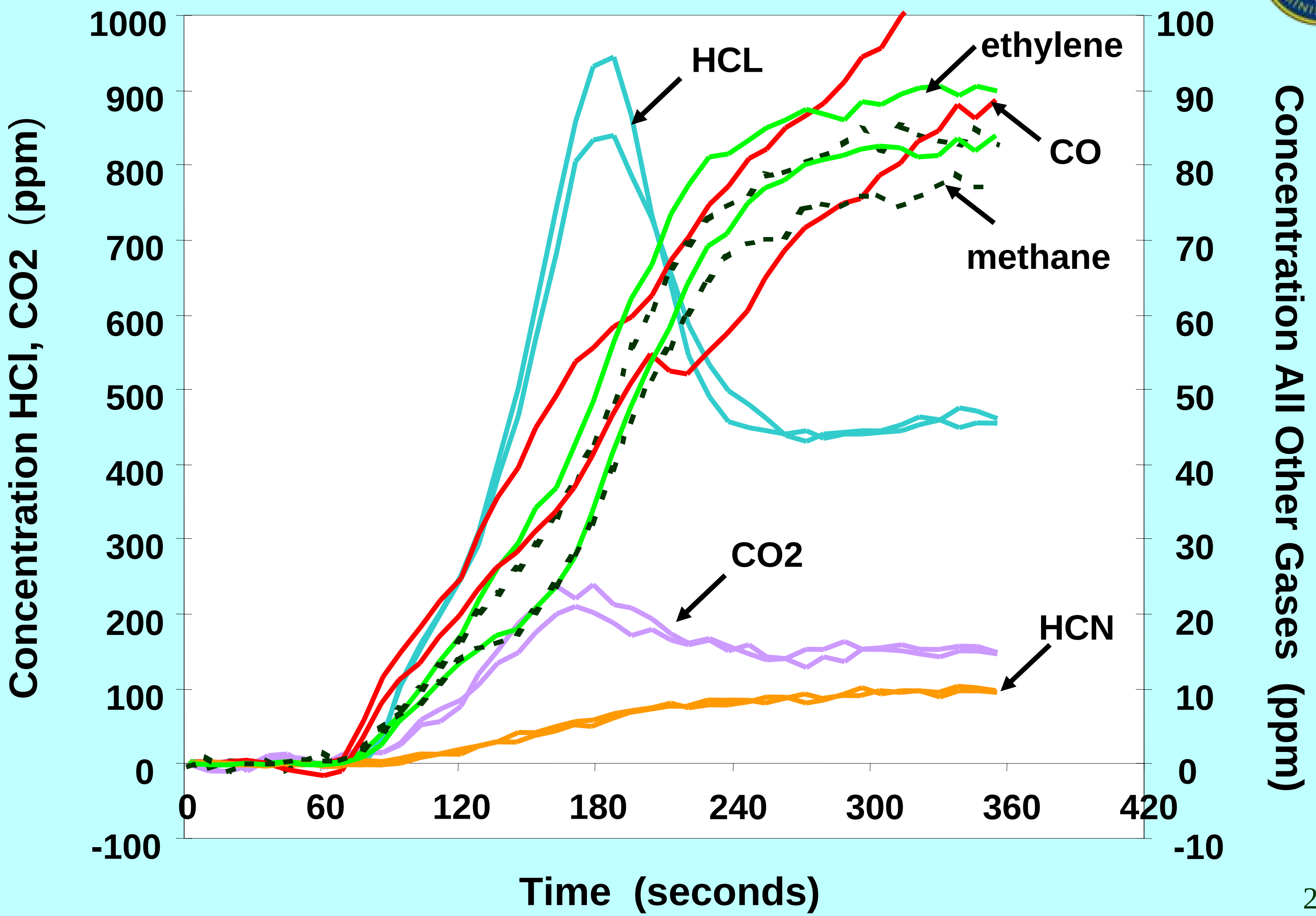
FTIR CALIBRATION SPECTRA OF SIXTEEN GASES AT 170 DEGREES C: FULL-SCALE



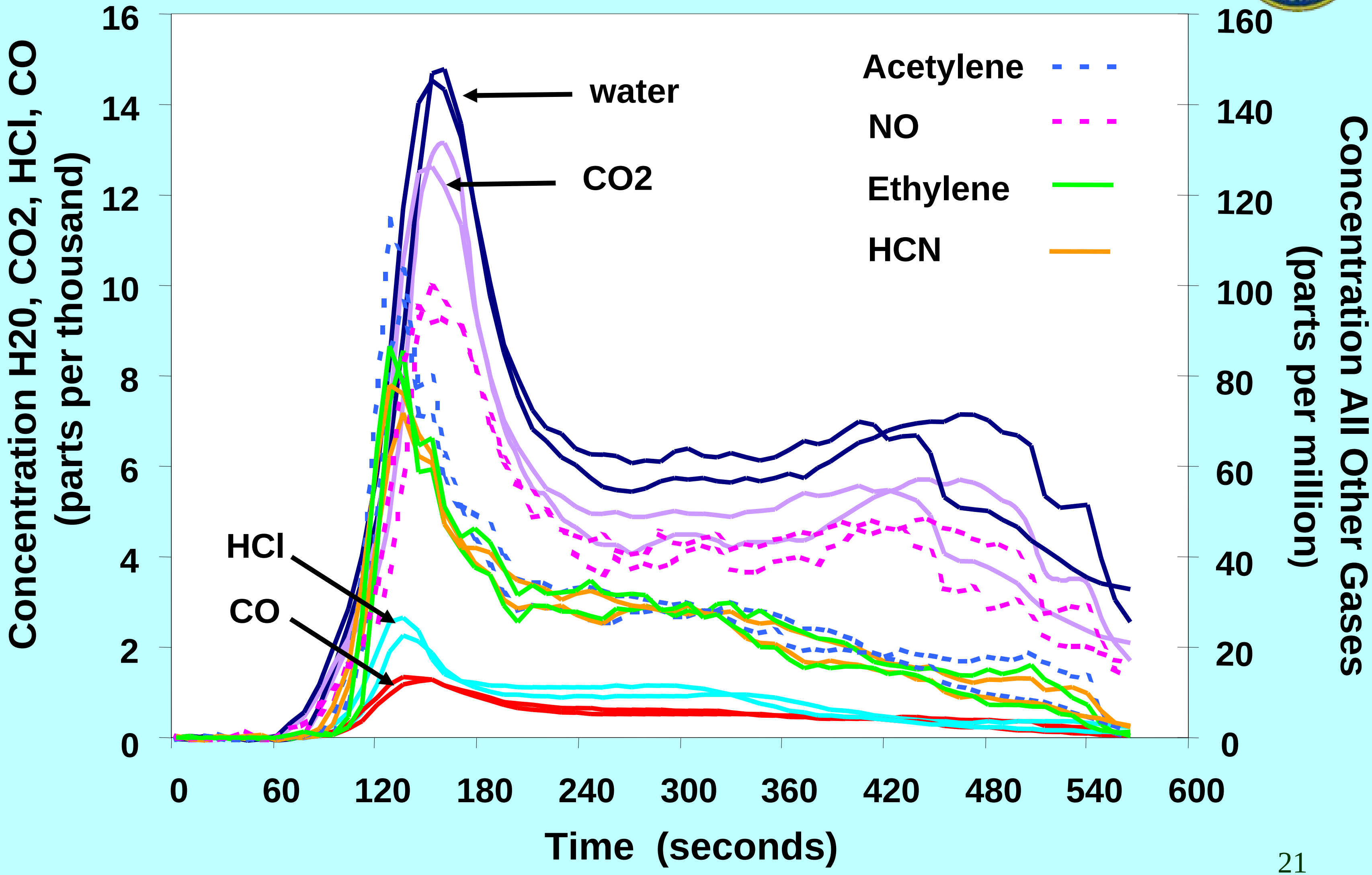
FTIR SPECTRA OF MIXED PLASTIC SPECIMENS



FIRE GAS HISTORIES FOR DUPLICATE NONFLAMING TESTS OF MIXED PLASTIC SPECIMEN



FIRE GAS HISTORIES FOR DUPLICATE FLAMING TESTS OF MIXED PLASTIC SPECIMEN

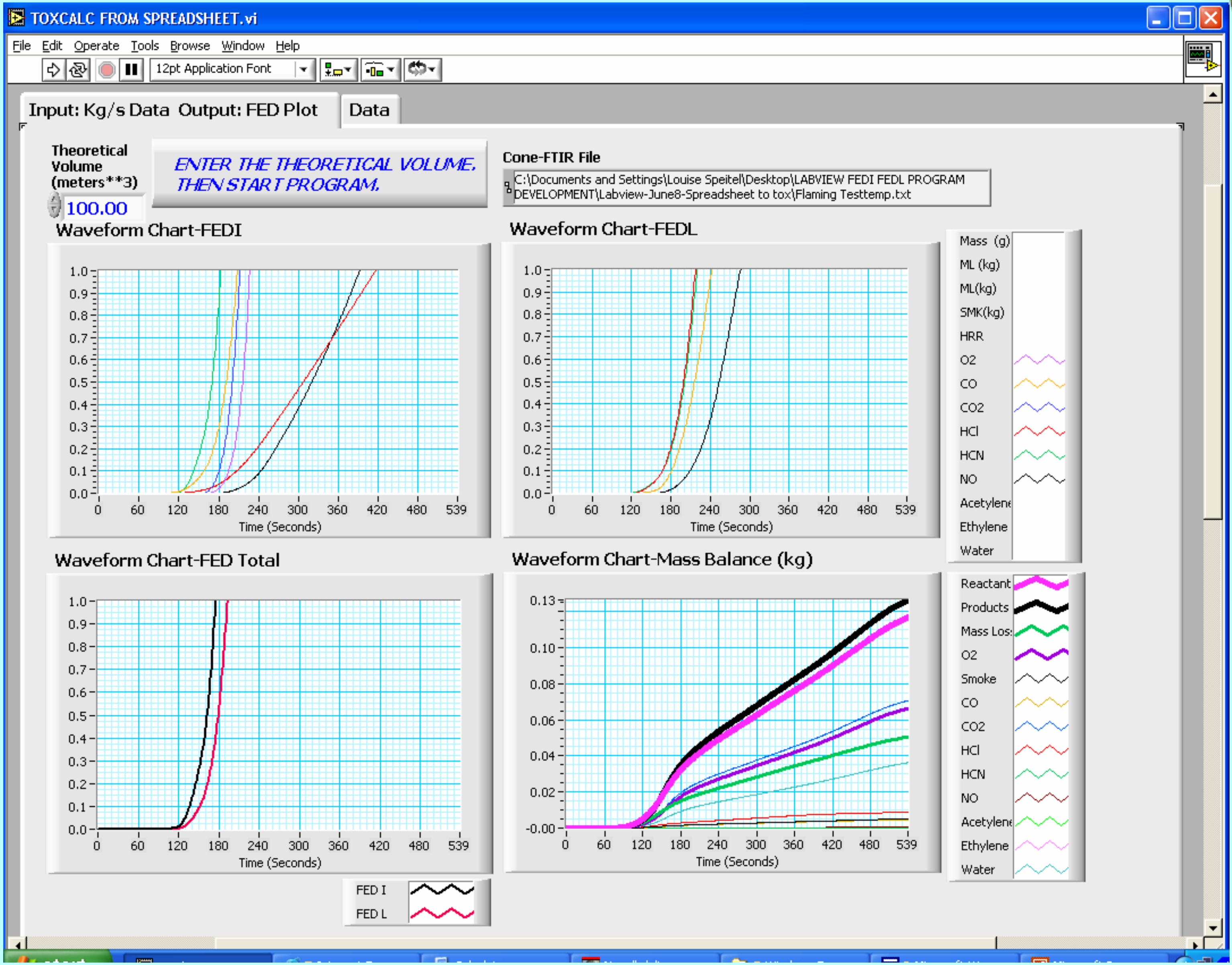


OBJECTIVES

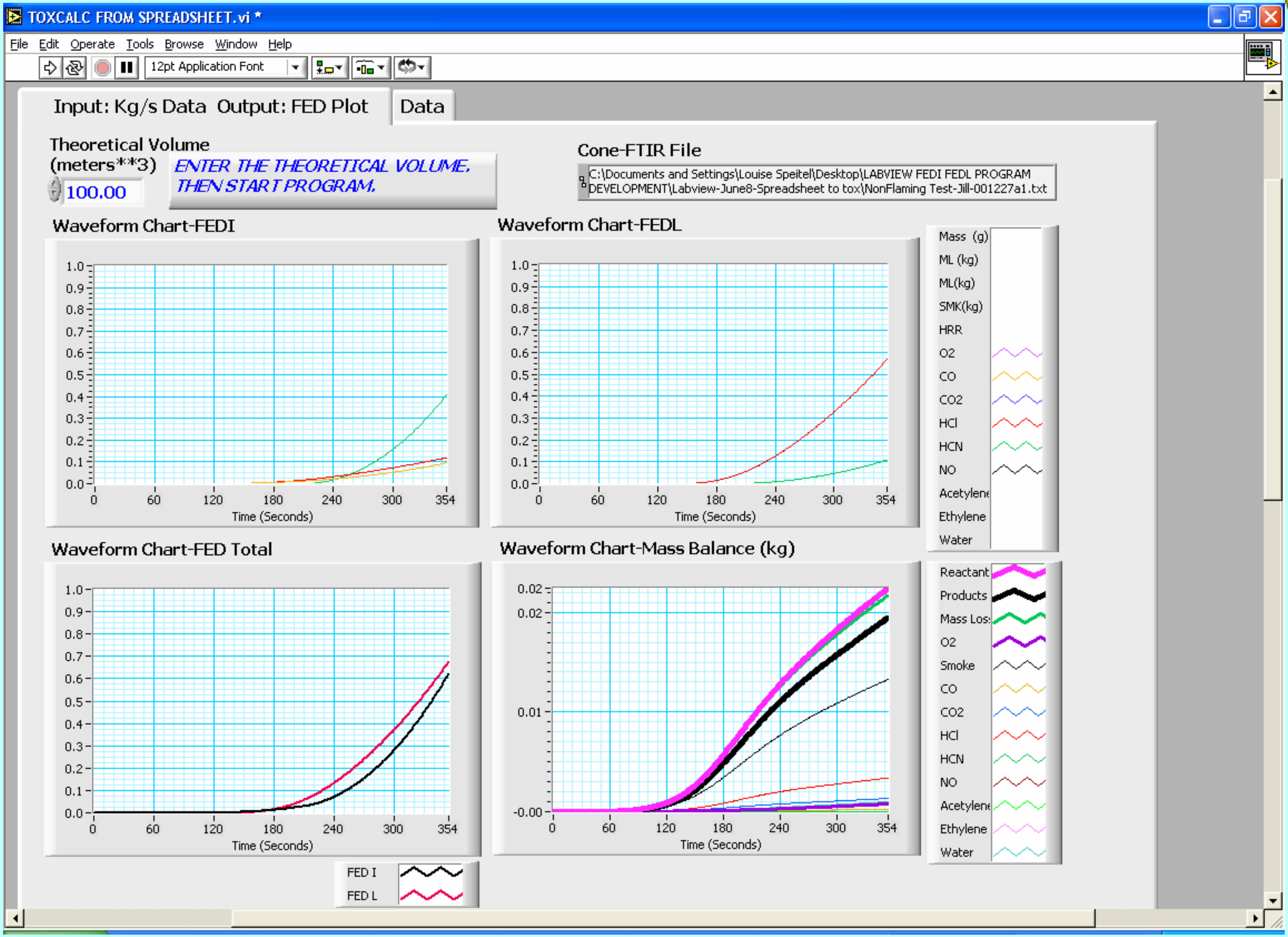
TOXICITY ASSESSMENT OF MATERIALS IN FIRE

- Develop software that calculates toxicity histories and mass balance histories for a cone calorimeter-FTIR test.
- The FAA models for incapacitation and lethality form the basis for the calculations. (FAA Report DOT/FAA/AR-95-5).

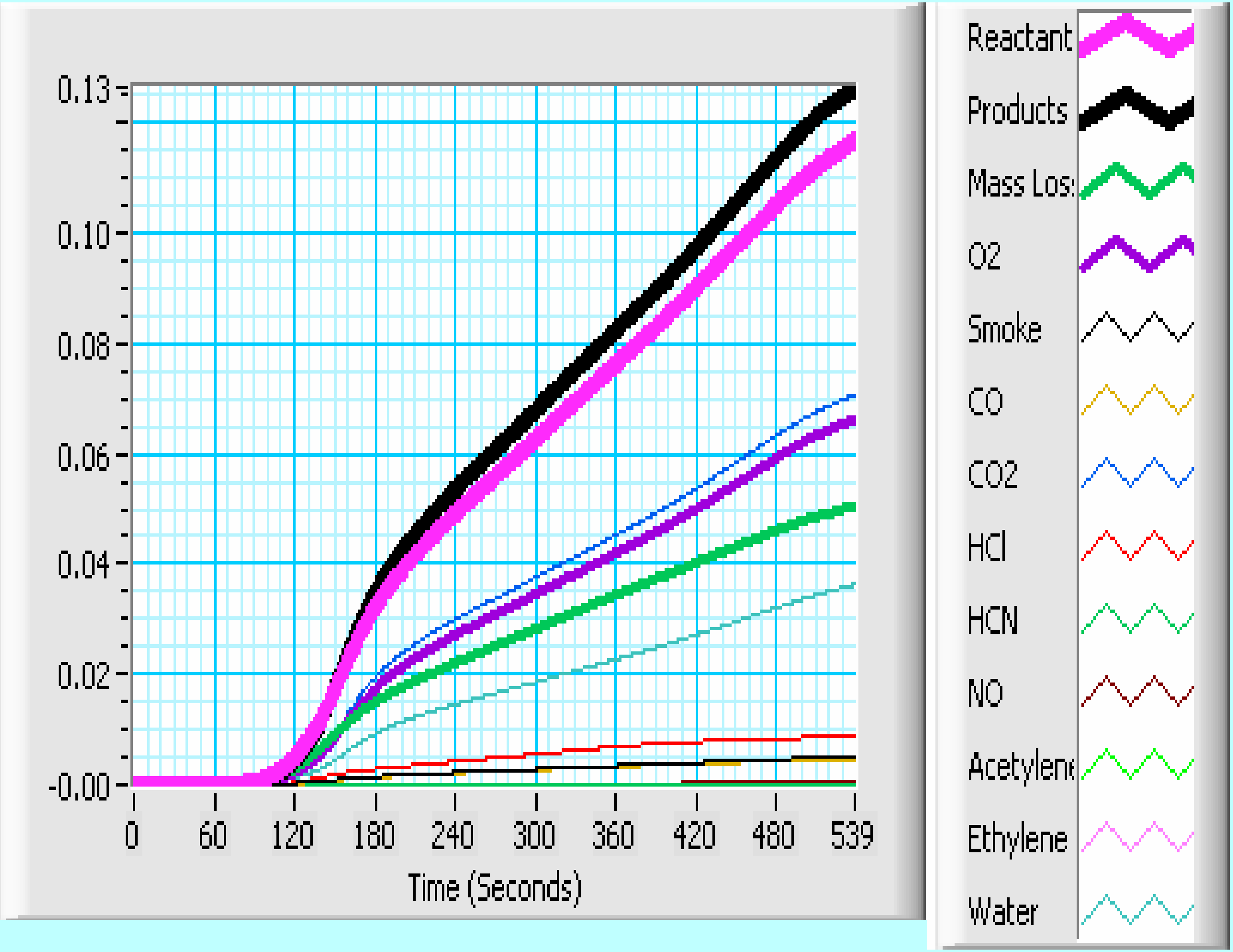
TOXICITY HISTORIES OF FLAMING MIXED PLASTIC SPECIMEN



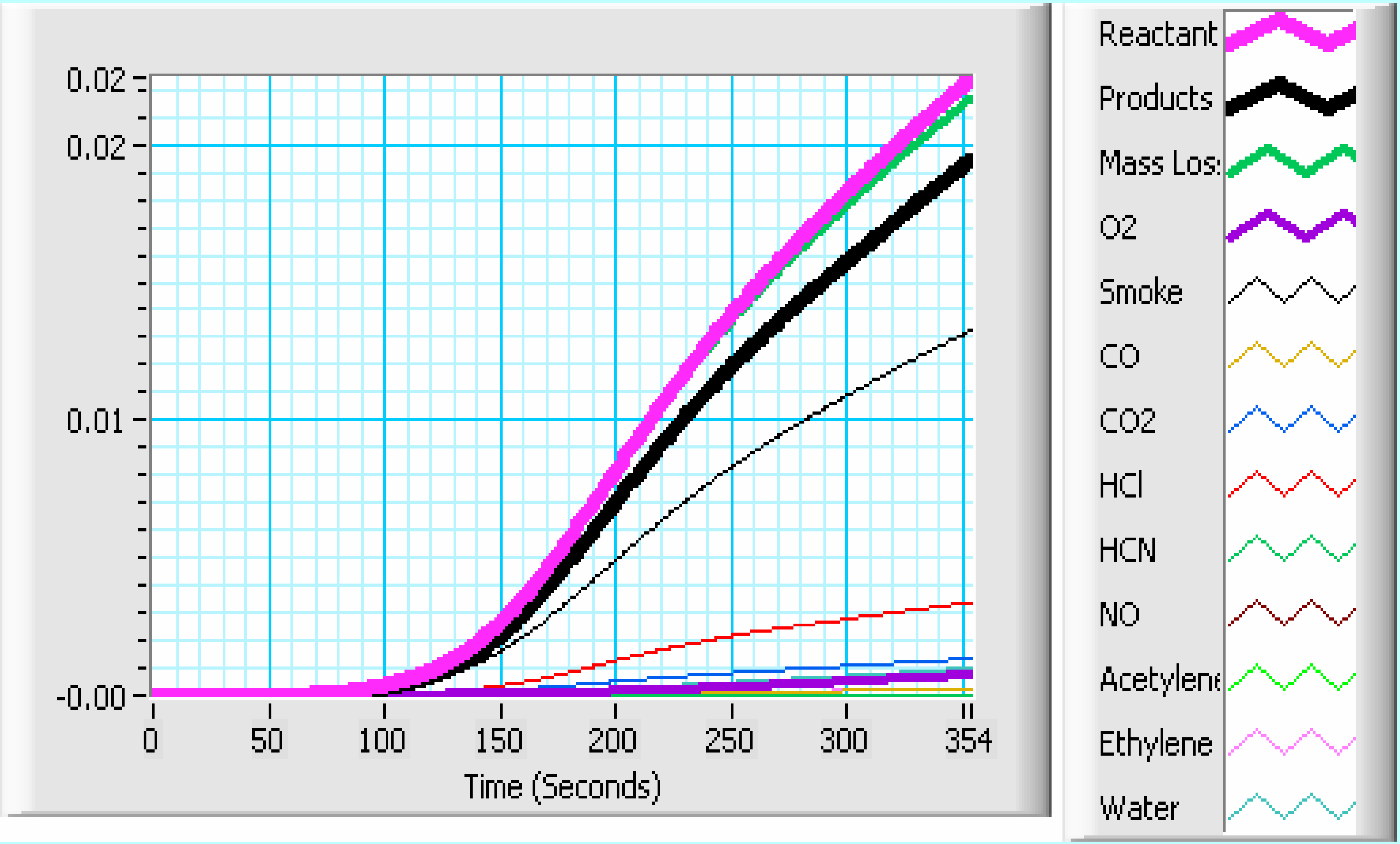
TOXICITY HISTORIES OF NONFLAMING MIXED PLASTIC SPECIMEN



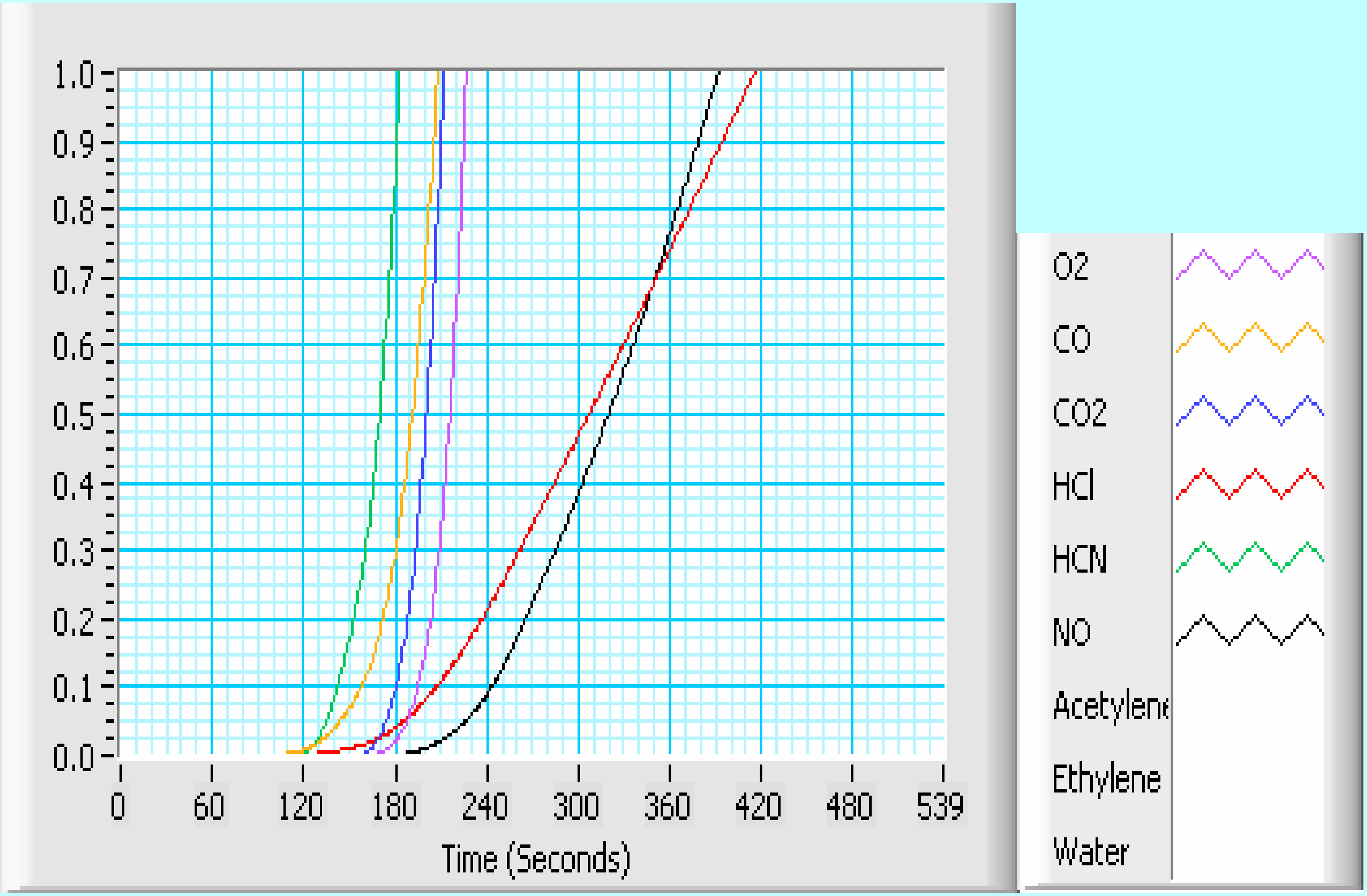
MASS BALANCE (KG) OF FLAMING MIXED PLASTIC SPECIMEN



MASS BALANCE (KG) OF NONFLAMING MIXED PLASTIC SPECIMEN

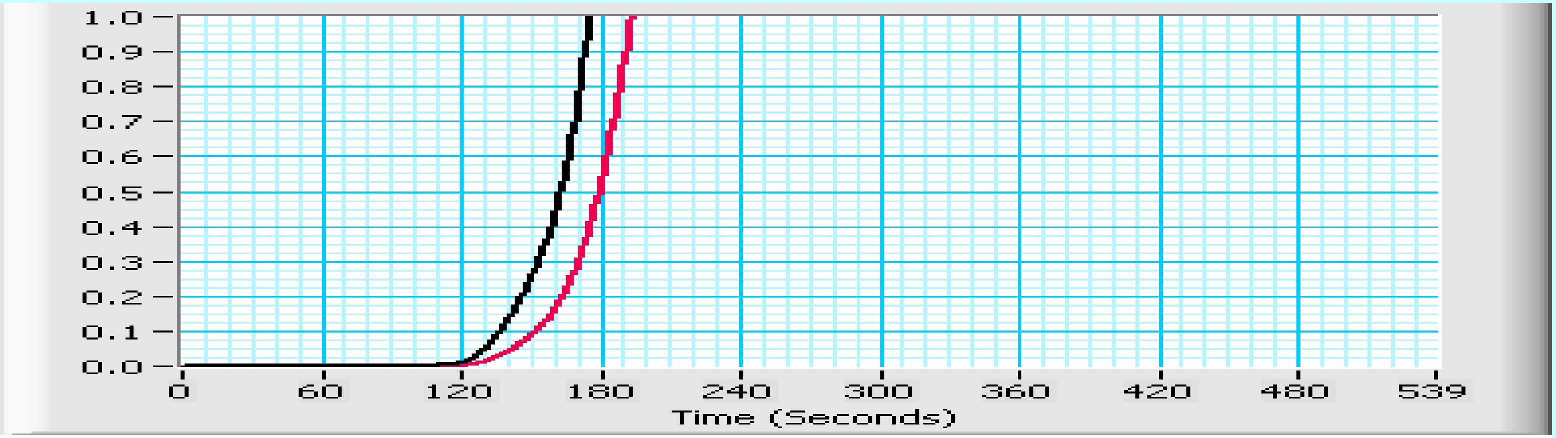


FED$_I$ OF FLAMING MIXED PLASTIC SPECIMEN



FED_{TOTAL} OF FLAMING AND NONFLAMING MIXED PLASTIC SPECIMEN

FLAMING



NONFLAMING