

S&A FY03 ANNUAL REVIEW MEETING

DIAGNOSTICS AND CONTROL OF NATURAL GAS FIRED FURNACES VIA FLAME IMAGE ANALYSIS

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Project Overview

- **Project description**

- *Image analysis via machine vision and artificial intelligence techniques are used to obtain information from flame video images for diagnostics & control of gas fired furnaces. This includes guidance for balancing oxygen/fuel ratios between individual burners on multi-burner furnaces.*

- **Objectives**

- *Macroscopic & Microscopic time varying Flame Image Analysis*
- *Establish correlation between flame imagery & furnace control parameters for multi-burner application*
- *Verification of the technique for multi-burner commercial glass furnaces (both oxy fuel and air fuel)*
- *Improve individual burner performance*
- *Develop virtual temperature sensing capability*

Project Overview

- **Overall goal**

- *The goal is to provide guidance for balancing oxygen/fuel or air/fuel ratios between individual burners on multi-burner furnaces. Identifying and correcting fuel rich burners should result in improved fuel efficiency. It is anticipated that this system will offer great potential for improving furnace thermal efficiency and lowering NOx emissions.*

Technical Merit

- **Relevance to the S/A Priorities of the IOFs**
 - Combustion Optimization for Improved Control
 - Imaging/Machine Vision for Monitoring & Inspection
 - Real-time Temperature Sensing

Technical Merit

- **Contribution to the S/A Community**

- Substantially Supplementing Machine Vision Knowledge for:
 - Control
 - Temperature Profiling
 - Sensor Development

Technical Progress and Outlook

- ***Verification of the technology for Air/Fuel Furnaces***
 - ***Air/fuel commercial furnace: Float glass manufacturing, rated at 170 Million Btu/hr with a 25 tons/hr of glass production.***
 - ***Individual burner pair air/fuel ratios are manually input in the control system by the furnace engineer.***
 - ***Furnace is fired in a cyclic mode, with a 20-minutes cycle***

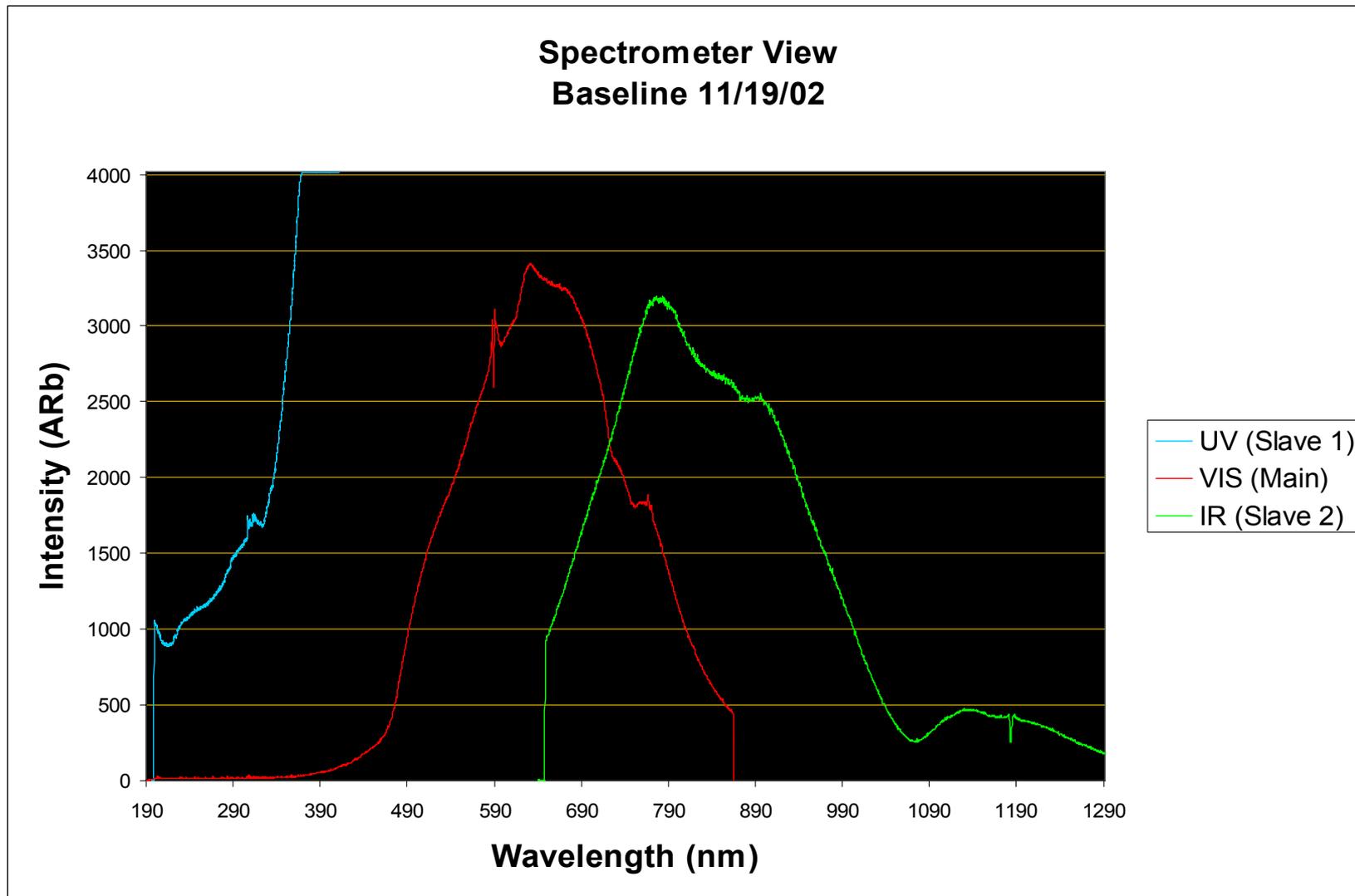


Periscope Setup

Technical Progress and Outlook

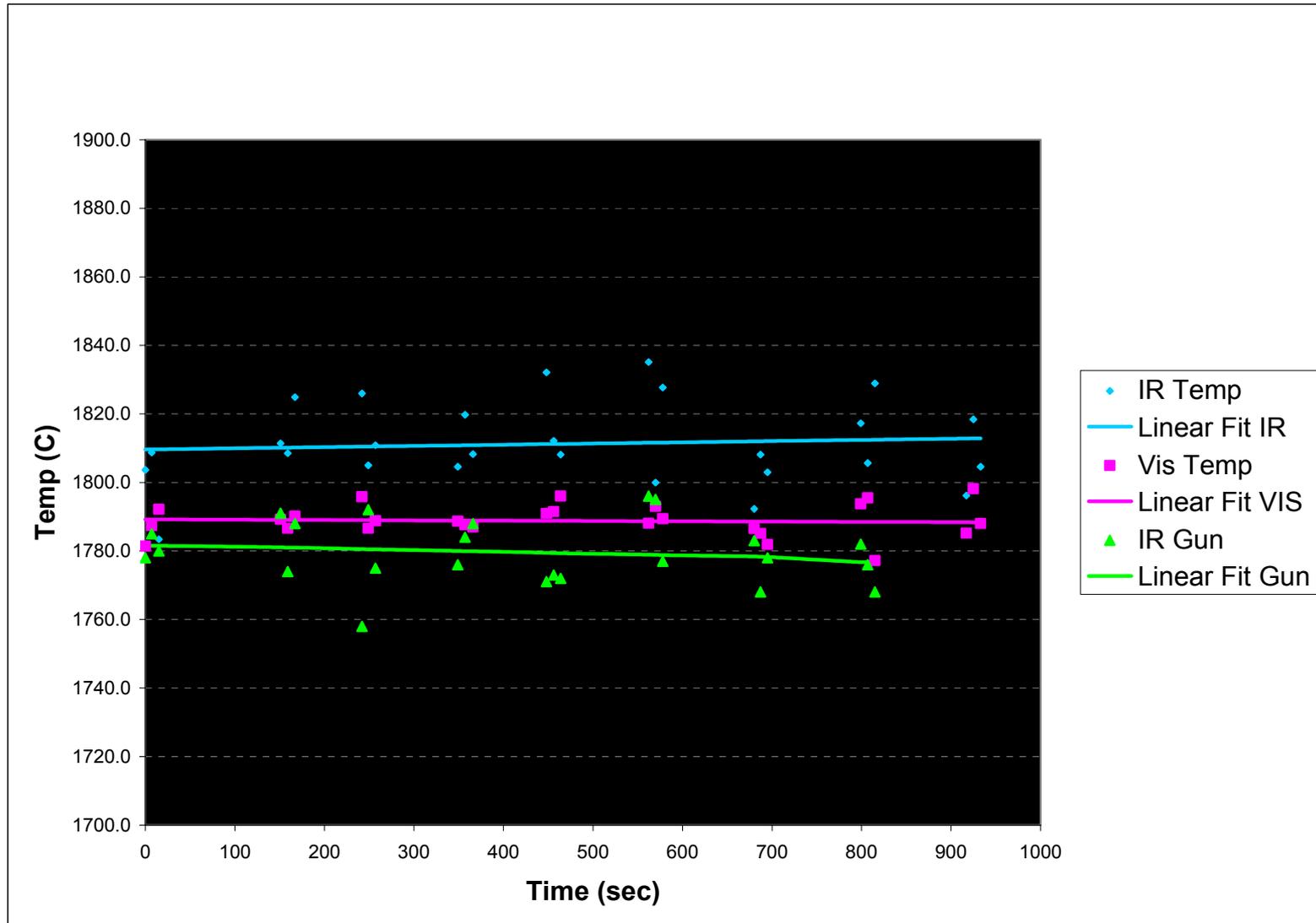
- **Major progress/accomplishments to date**
 - ***Spectrometer Upgraded to a Trifurcated Fiber Optics System to Obtain All Three Regions UV, VI, and Near IR.***
 - ***Temperature Calculations for VI and Near IR Region of Spectrum.***
 - ***Successful Air/Fuel Furnace Application***
 - ***Successful Decision Tree Classification***
 - ***Graphical User Interface Design***

Flame spectrum for UV, VI, and Near IR Region from a Commercial Glass Furnace

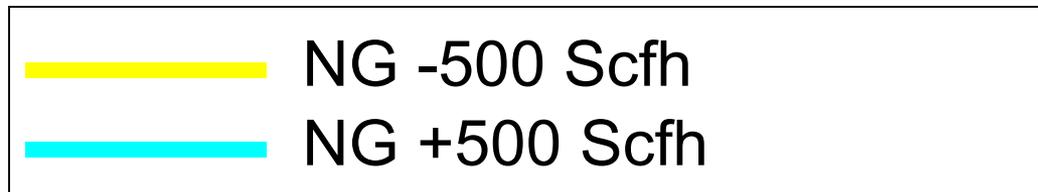
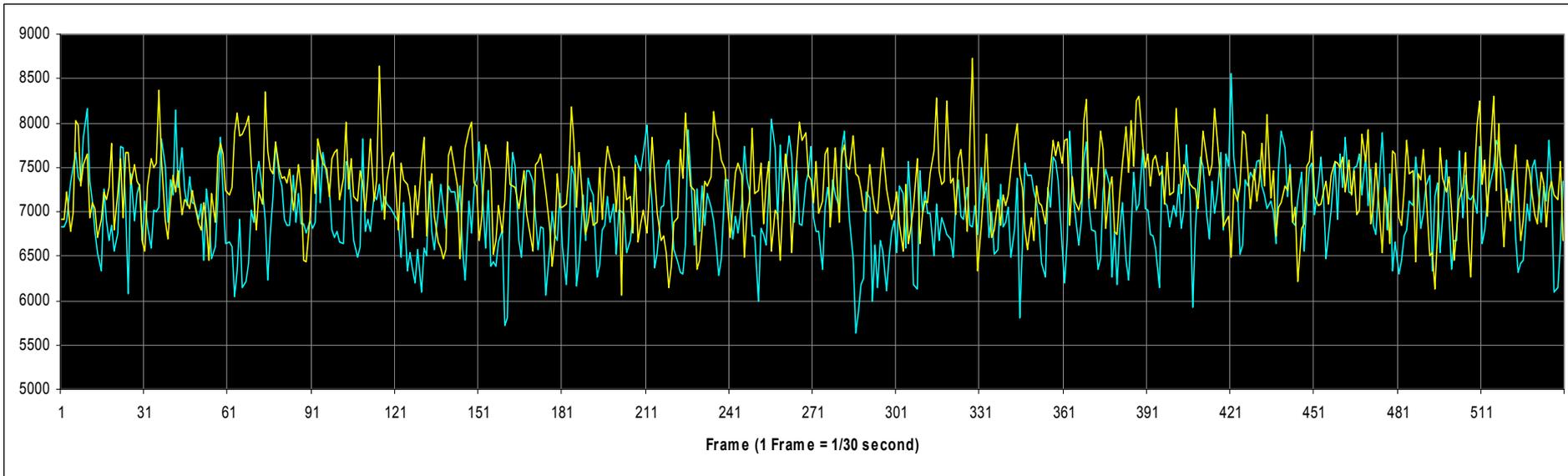


Flame Temperature Calculation Results

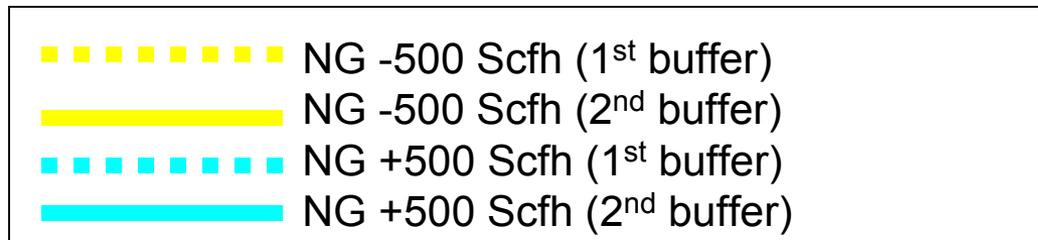
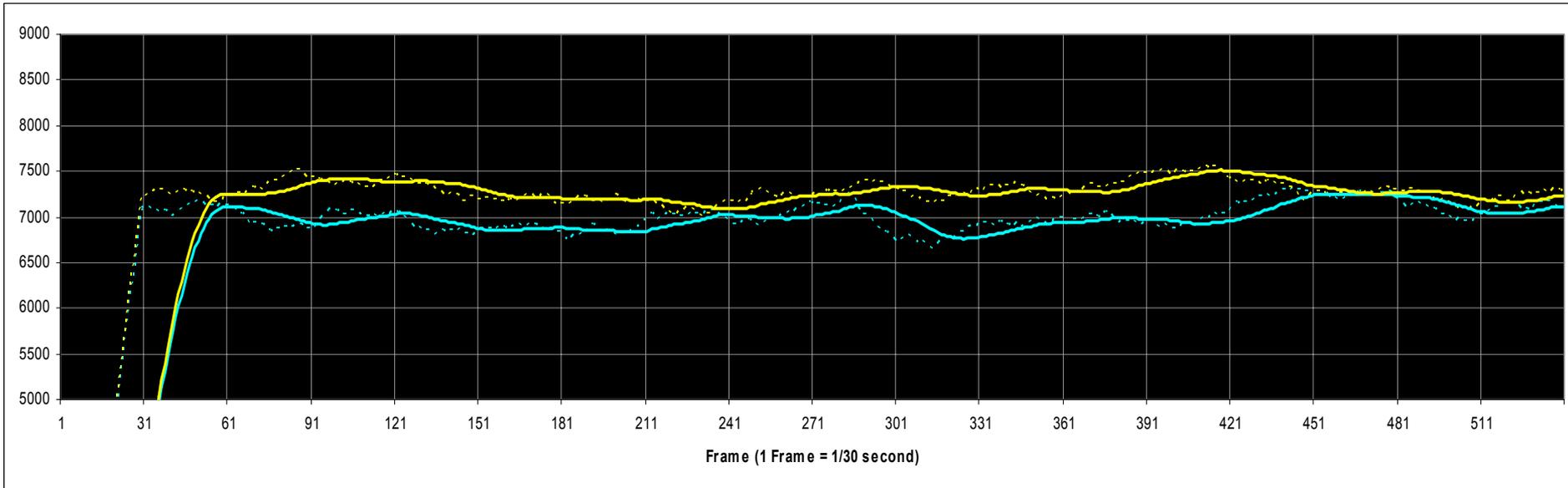
Using Black Body Model



Natural Gas Change Comparison Based on Flame's Feature #1 (Raw Data)



Natural Gas Change Comparison Based on Flame's Feature #1 (Second Level Buffer)

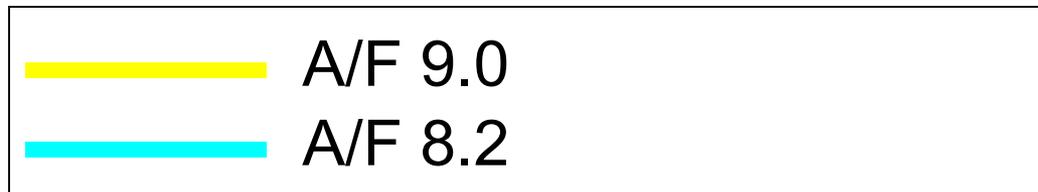
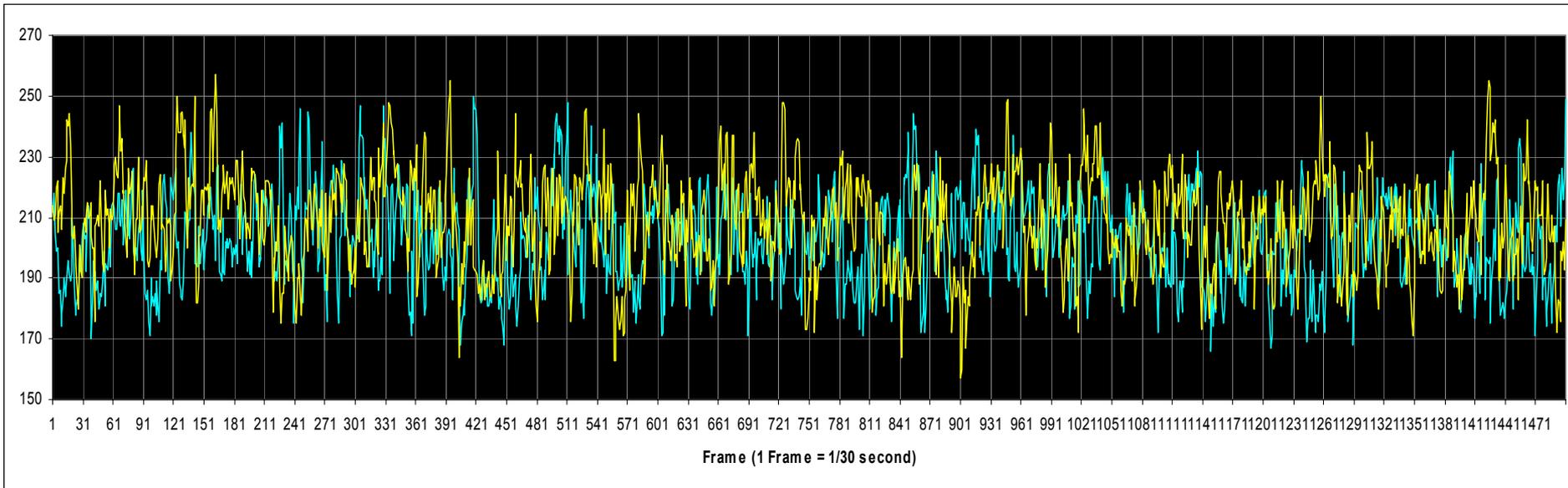


Decision Tree Classification Result for Natural Gas Change

Input Data type	Number of Input	Correctly Classified	Misclassified
Baseline	292	291	1
NG +500	274	272	2
NG -500	274	269	5

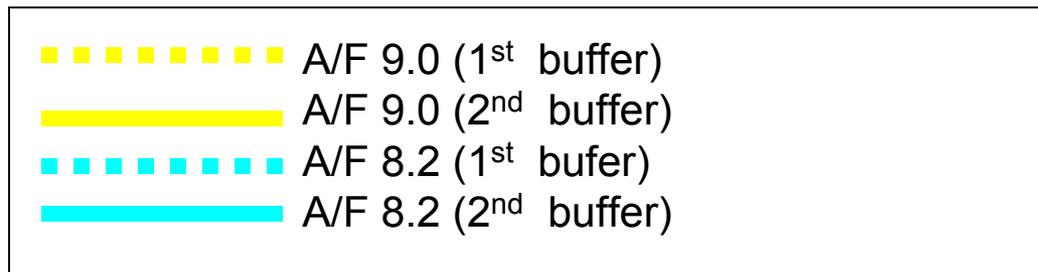
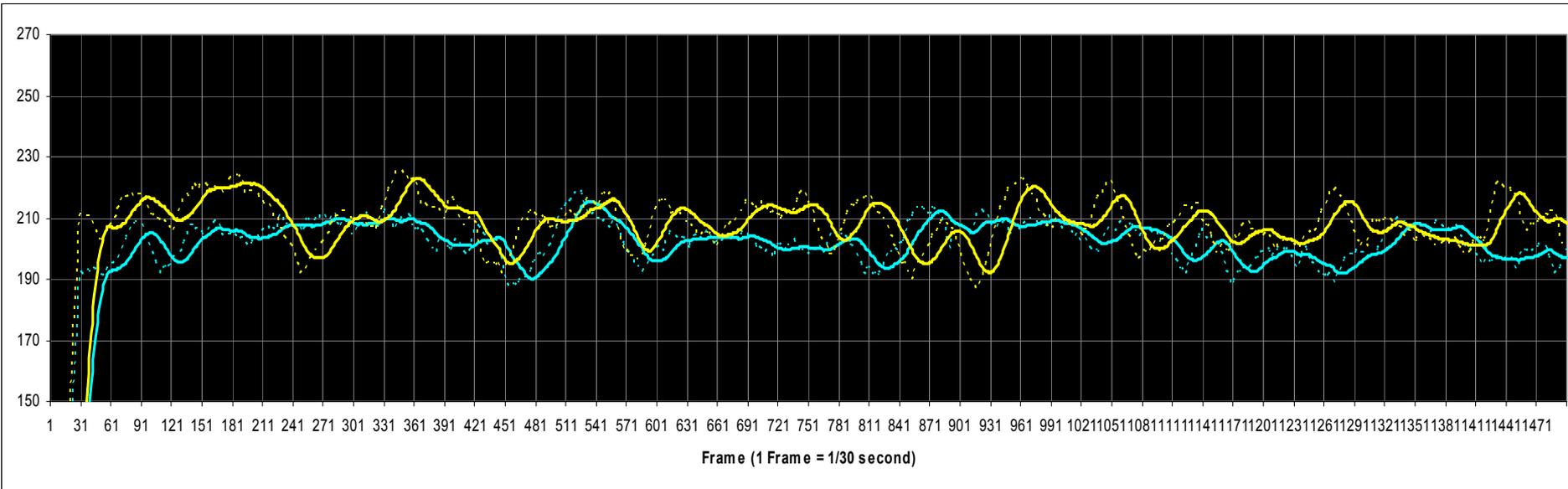
Total data classified: 840 Error rate: <1%

Flame Feature Plot at Two A/F Ratios



Flame Feature Output

(Second Level Buffer)

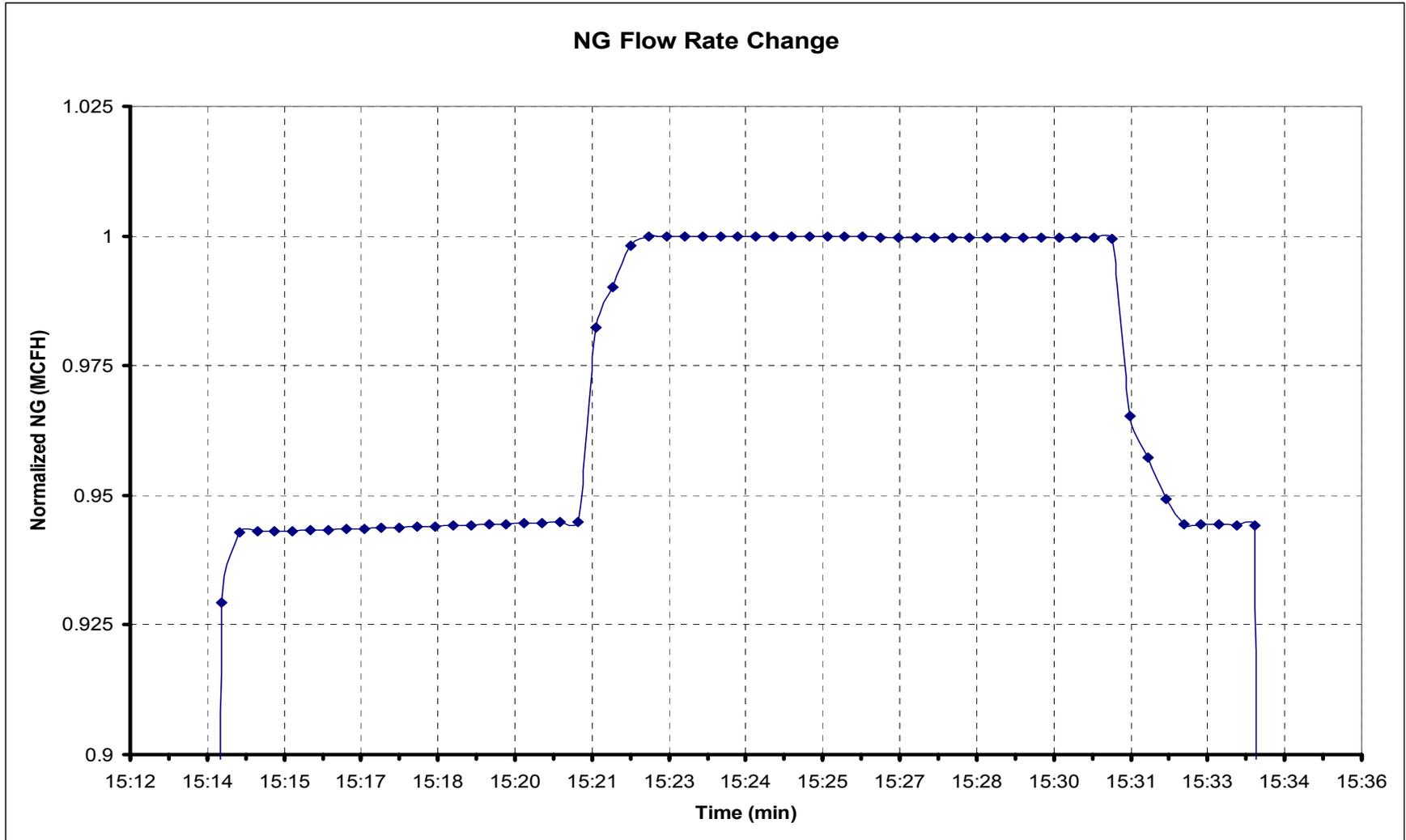


Decision Tree Classification Result

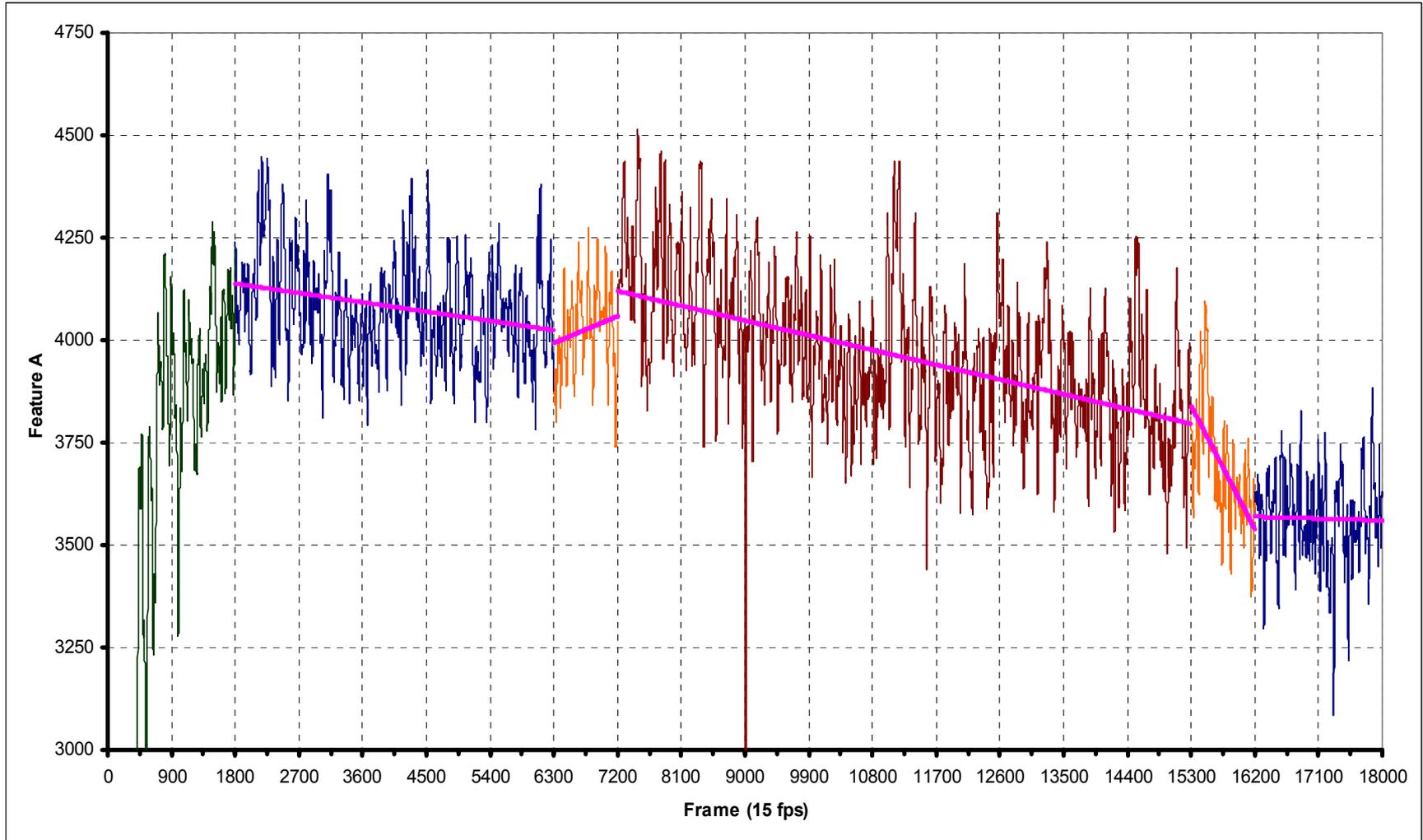
Input Data type	Number of Input	Correctly Classified	Misclassified
A/F at 8.2	735	733	2
A/F at 9.0	765	748	17

Total data classified: 1500 Error rate: $\approx 1\%$

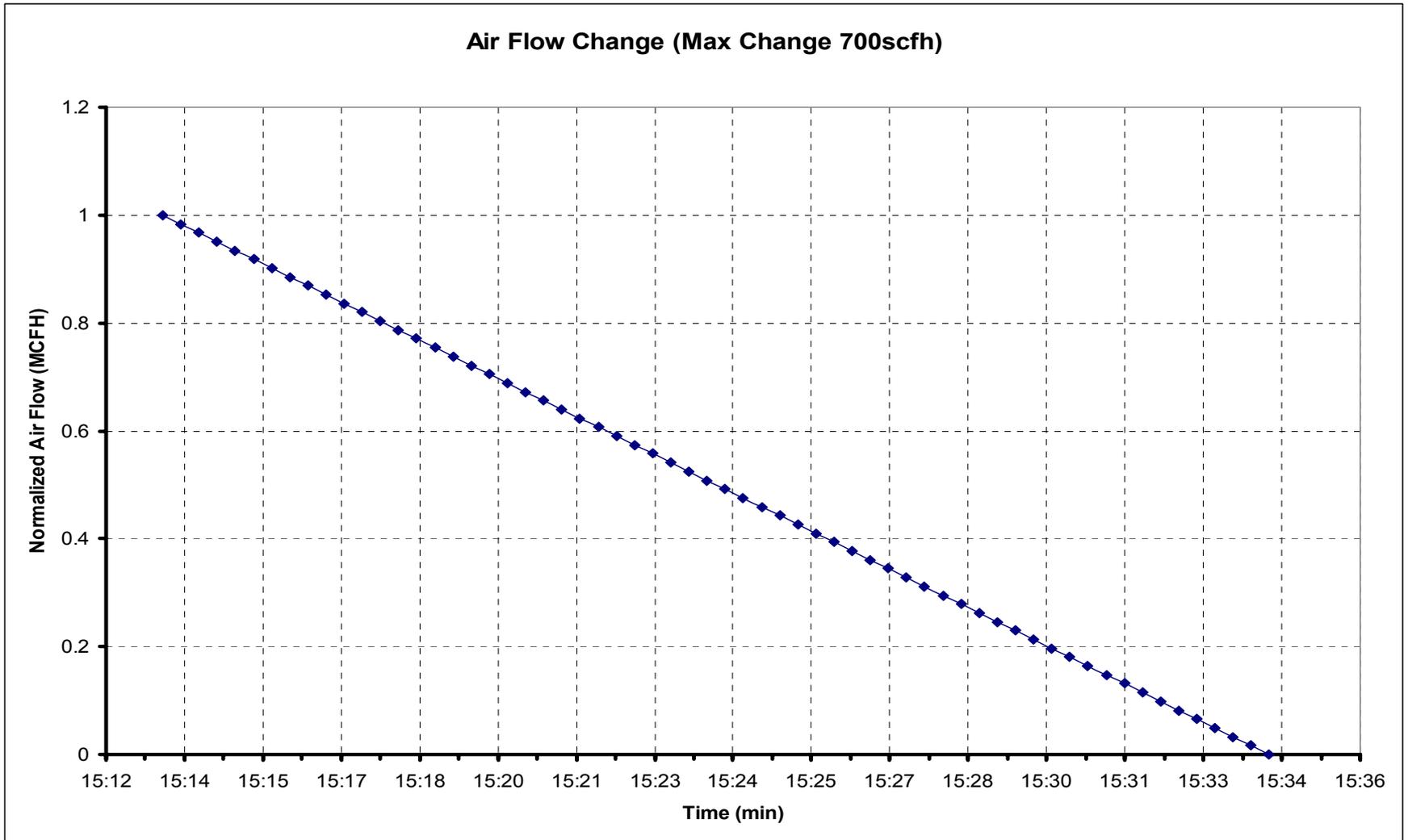
Burner Gas Flow Rate Change in a Stepwise Fashion



Flame Feature Behavior During the Entire Cycle



Burner Air Flow Rate Change During the Entire Cycle



Technical Progress and Outlook

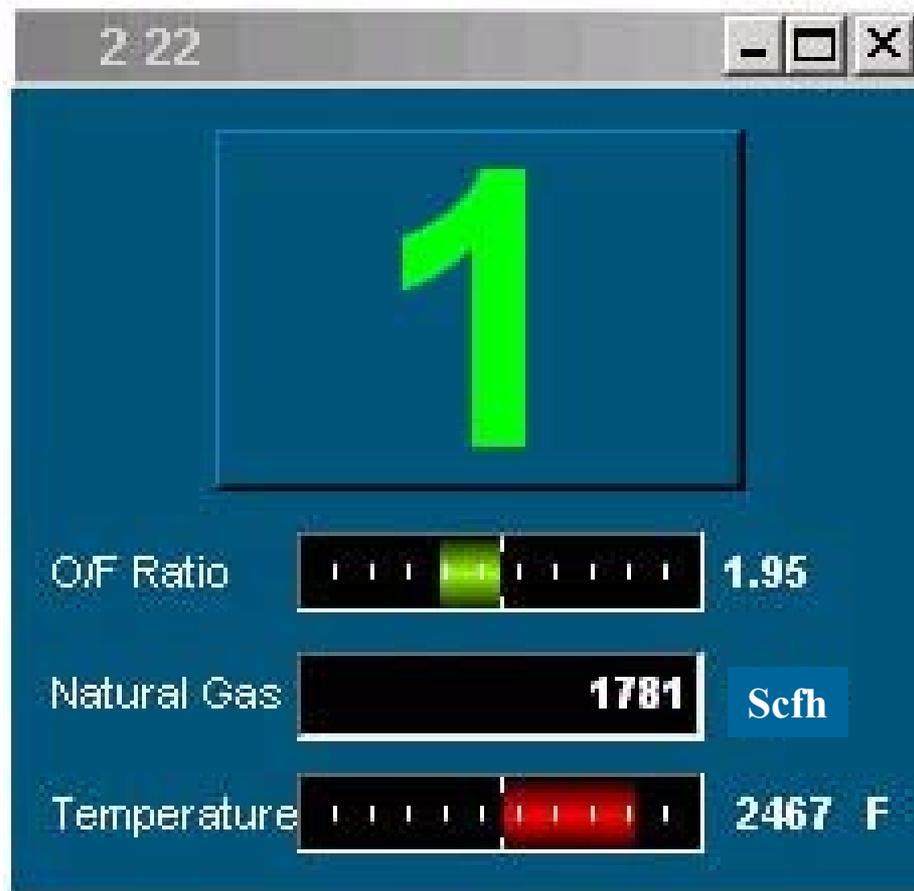
Future Technical Milestones/Goals

Milestone/Goal	Expected Completion Date	Comments
Complete prototype development and system evaluation	12/30/03	On schedule
Integration design with the control system of a glass manufacturing plant	12/30/03	On schedule
Data acquisition and analysis from a steel furnace	12/30/03	To be arranged
Project completion	12/30/03	

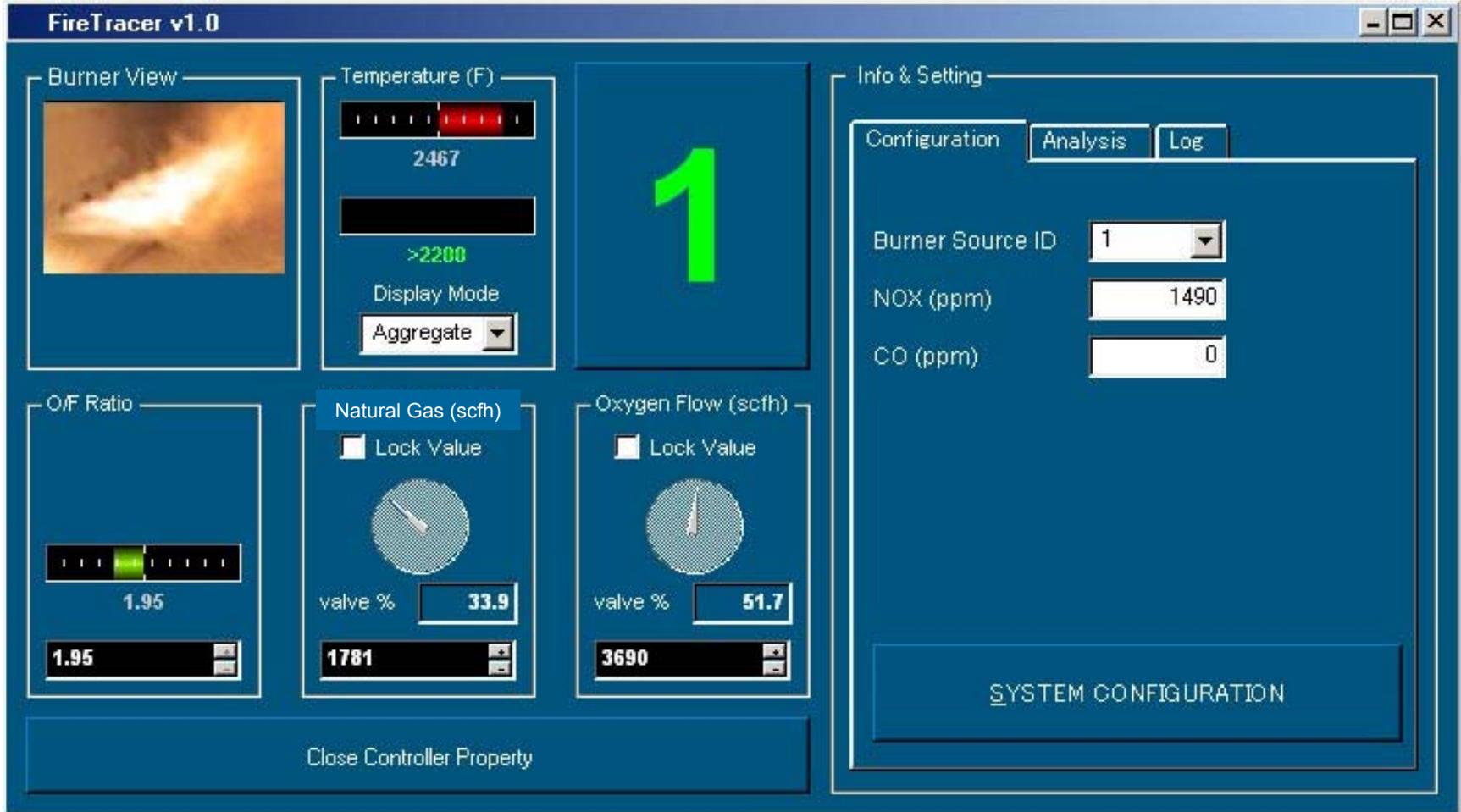
Technical Progress and Outlook

- **Expected progress toward milestones/goals**
 - *Integration with Plant Control System: Feasible*
 - *Completion of Graphical User Interface Compatible with Plant Control User Interface*
- **Possible barriers**
 - Compatibility with Plant Control User Interface

Screen Shot of Level 1 User Interface Design



Screen Shot of Level 3 User Interface Design



Technical Progress and Outlook

- **Industrial end-user involvement**
 - Demonstration at AFG Industries
 - Development of New Sensors Based on Input from AFG
 - Interested Companies:
 - AFG Industries
 - GS Inc.

Market Potential

- Two Demonstrations and off-line System Evaluation at AFG Plant
- Meeting with AFG and GS Executives, January 03
- Collaborative Effort to Finance Commercialization Phase
- Distributed Commercialization in Partnership with GS
- Patent Disclosures Filed

Market Potential

- **Other IOF Areas of Applicability**
 - Steel
 - Aluminum

- **Power Industry Using Pulverized Coal**
(Although not IOF, has direct impact on IOF)

Market Potential

- **Activities Beyond OIT Project**
 - Installation in at Least One AFG Plant
 - Pursue Distributed Commercialization through GS
 - Multi-sensor Development Using Same Technology

Programmatic Merit

- **Energy benefits**

- Glass Industry:

- Based on 3% Energy Savings and 5% Market Impact: 530 Billion BTU by 2010

- Steel Industry:

- Based on 3% Energy Savings and 1% Market Impact: 80 Billion BTU by 2010

Programmatic Merit

- **Economic and environmental benefits**
 - Reduced Cost through Saving Energy
 - Reduced Cost through Multi-purpose Sensing Capability
 - Reduced NOx Pollution through Combustion Optimization

Summary

- **Multi-sensing Capability of the System & Spin-off Sensors at Reasonable Cost**
- **Successful Results for both A/F and O/F Furnaces**
- **Equipment Upgrade**
 - Trifurcation of Spectrometer
 - VI/NIR Temperature Comparison
- **Temperature Profiling in VI Range**
- **Potential for Advancement of Technology for:**
 - 3-D Temperature Profiling
 - Combustion Research