PRIMARY ZONE EQUIVALENCE RATIO SENSORS

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Objectives

- To develop gas turbine primary-zone equivalence ratio sensors with the characteristics
  - : Measurement accuracy of ± 0.01
  - : Fast response time
    - - Potential for use in active combustion instability control
  - : Ease of implementation on various nozzle configurations
  - : Potential for use in actual gas turbine combustors

- Implement, test, and evaluate the sensor techniques in prototype lean premixed combustors made available by the industrial members of the AGTSR Program and FETC

Motivation

- In multi-nozzle gas turbine combustors, nozzle-to-nozzle differences in the equivalence ratio can result in excessive NOx and CO emissions and/or premature onset of unstable combustion

  : Fuel flow rate to each nozzle needs to be controlled to achieve uniform equivalence ratio distribution

Project Status

Two sensor techniques are under development:

Sensor 1: Flame chemiluminescence sensor

- **Based on variation of flame chemiluminescence intensity with equivalence ratio**
- **First stage tests on a single nozzle, optically- accessible combustor at Penn State have been completed**
- **Tests on a multi-nozzle combustor in progress**
  - » **Developing strategies for real-time equivalence ratio control in multiple nozzle configuration**

Sensor 2: Infrared absorption sensor

- **Based on the absorption of infrared light (3.39 mm) by methane**
- **Tested on a Pratt &Whitney TE nozzle and Solar Turbine’s Centaur 50 nozzle**

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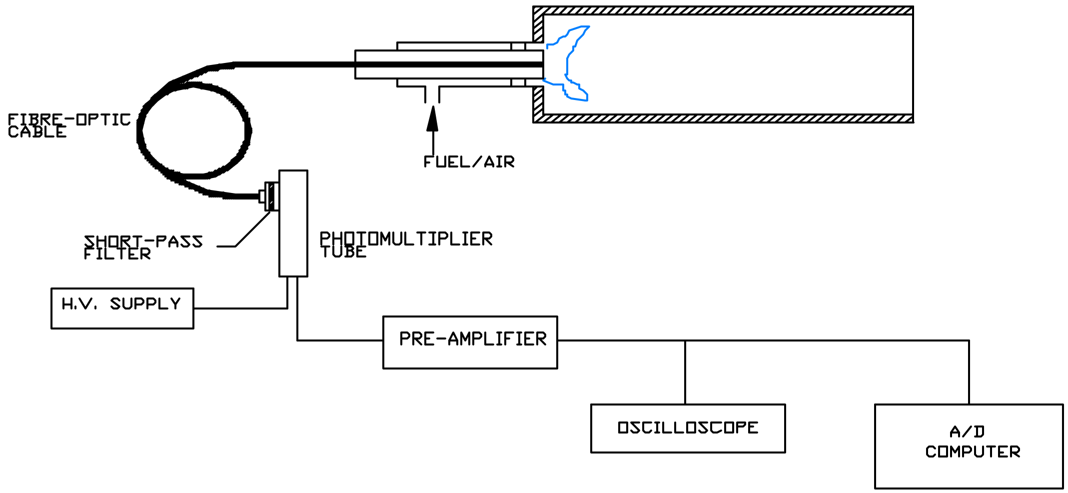
Sensor 1: Flame Chemiluminescence Sensor

- **Measures flame chemiluminescence intensity in the 350-550 nm wavelength range (CH^* and CO_2^*)**
- **Optical-fiber-based design for easy implementation on various nozzle configurations**
- **Can be used to determine nozzle-to-nozzle equivalence ratio variation**



Schematic of experimental setup at Penn State

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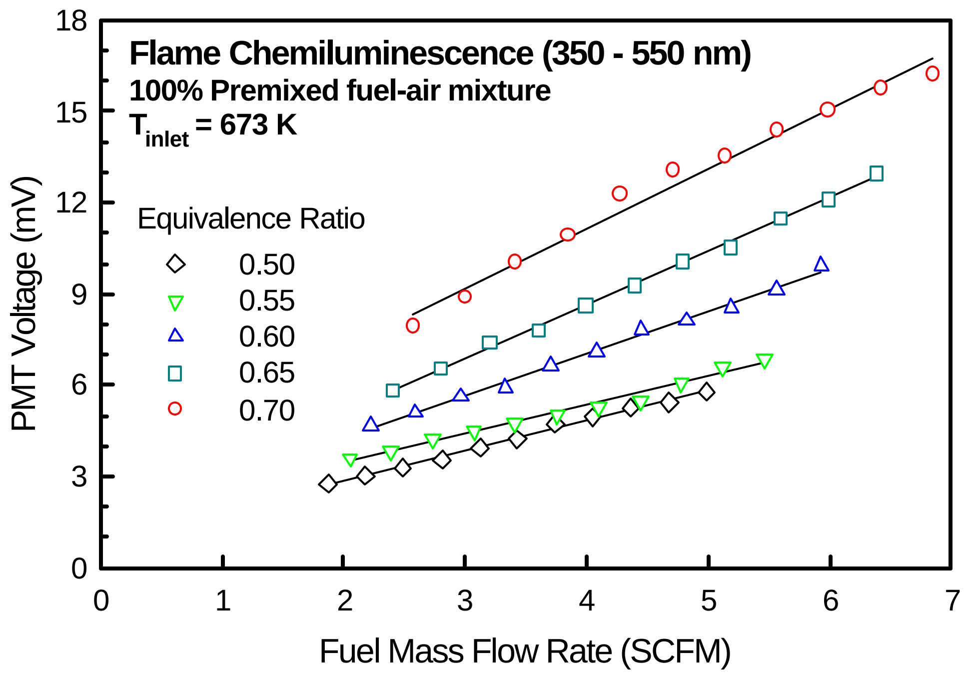
Sensor 1: Flame Chemiluminescence Sensor (contd.)

❒ **Application of the sensor in a single nozzle, optically- accessible combustor at Penn State**

: **Iso-equivalence ratio variation of flame emission intensity with fuel flowrate has to be determined**

: **Measurement of fuel flowrate, and chemiluminescence intensity would determine the equivalence ratio**



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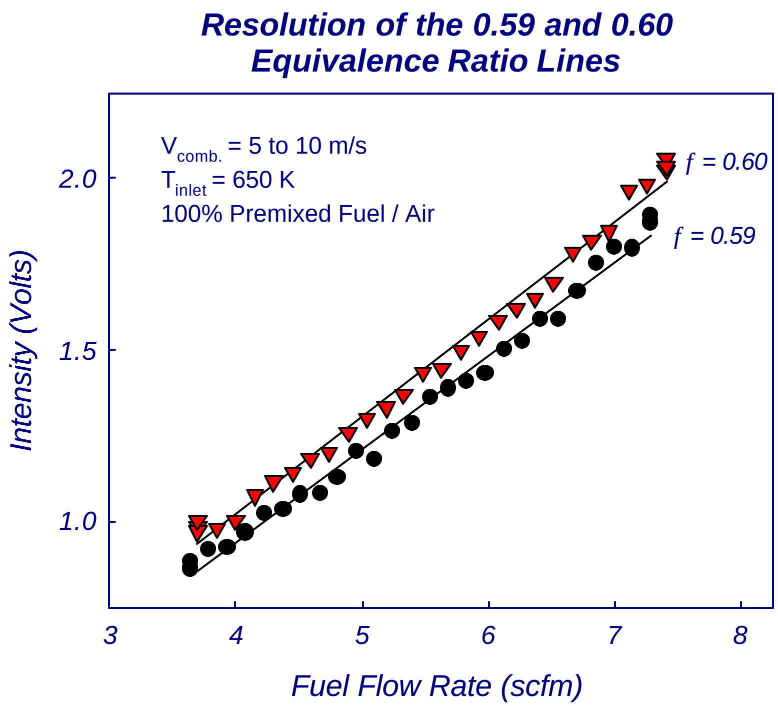
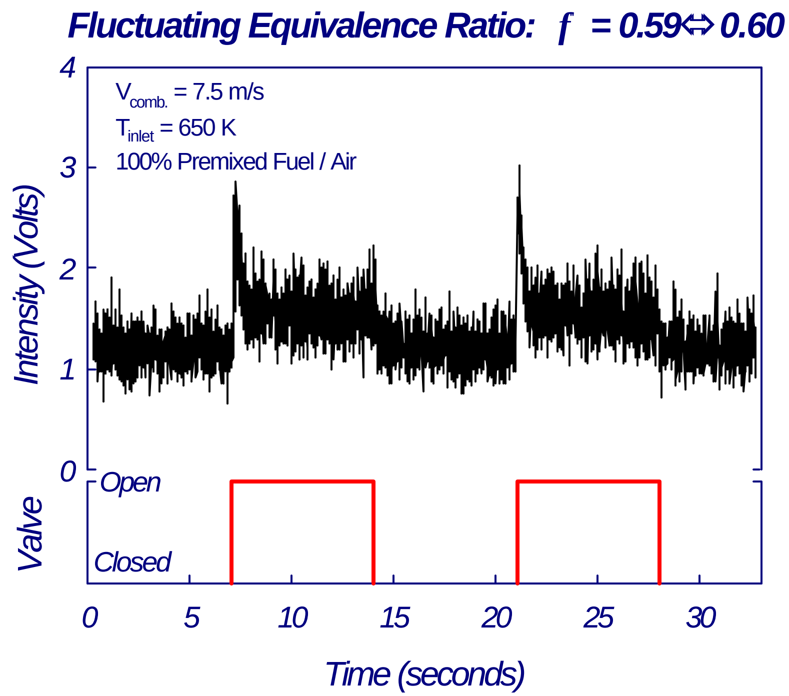
Sensor 1: Flame Chemiluminescence Sensor (contd.)



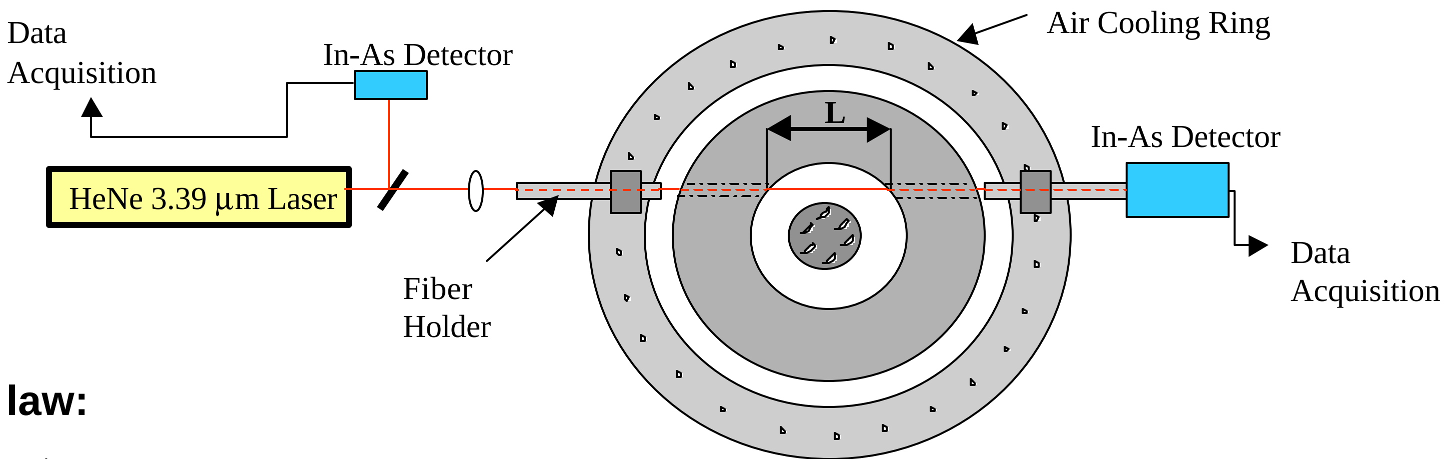


- ❒ **Equivalence ratio resolution of 0.01 is achieved**
- ❒ **Sensor has fast response time**

Sensor 2: Infrared Absorption Sensor

- Designed to measure fuel-air equivalence ratio inside a gas turbine combustor’s nozzle
- Line-of-sight based measurement gives average fuel concentration along the infrared beam path
- Fast response time
- Optical-fiber-based design allows easy installation in nozzles
- Multi-nozzle installation allows for nozzle-to-nozzle equivalence ratio variation measurement

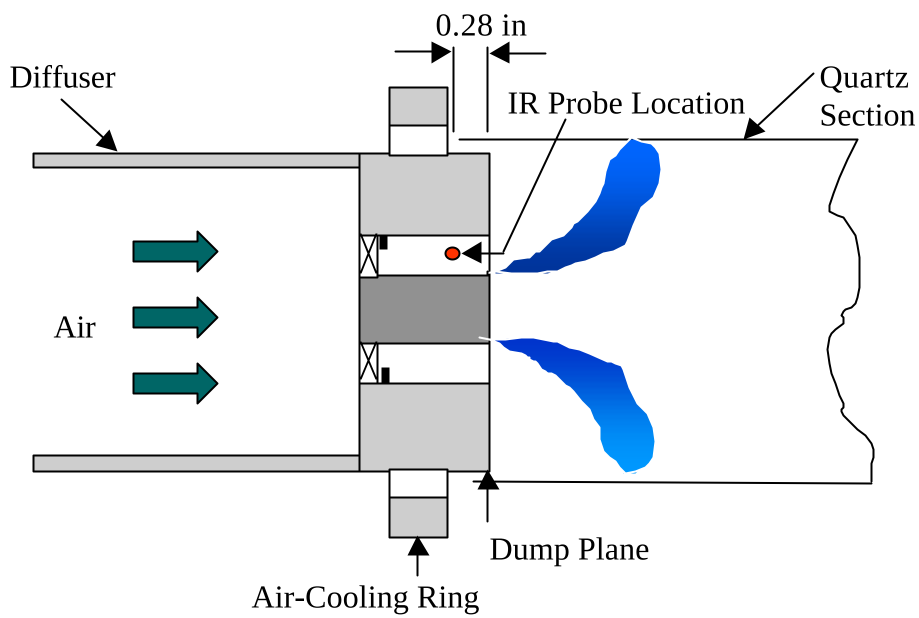
Sensor 2: Infrared Absorption Sensor (contd.)



- **Beer-Lambert law:**

$$\varepsilon = -\frac{1}{cl}\log_{10}\left(\frac{I}{I_o}\right)$$

- **'e' : molar absorption coefficient which is determined experimentally in a test cell**
  - » **Correlations with pressure and temperature are determined**
- **'l' : path length**
- **'c': molar concentration**

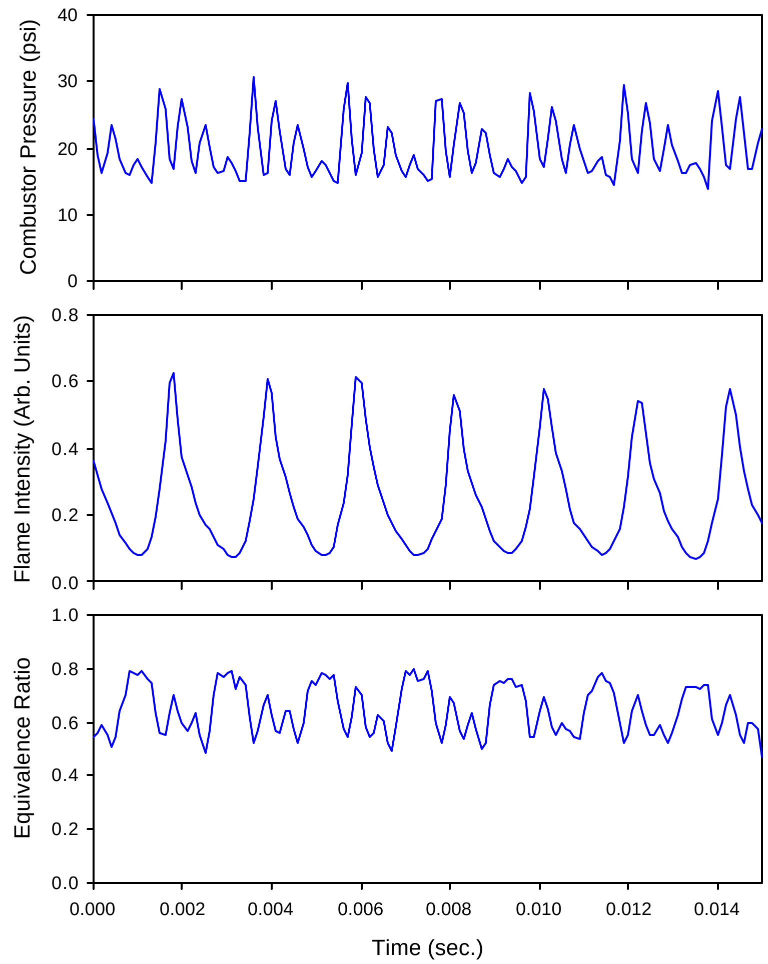


Sensor 2: Infrared Absorption Sensor (contd.)

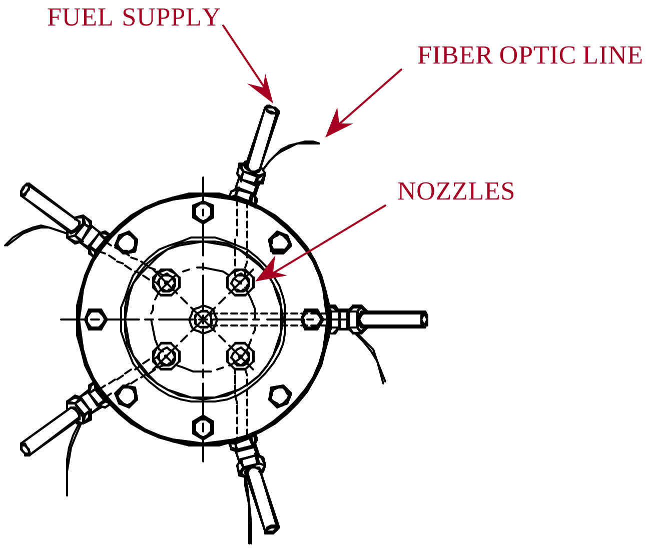
- **Application of sensor in a industrial fuel nozzle during unstable combustion**

  : Quantitative equivalence ratio measurement

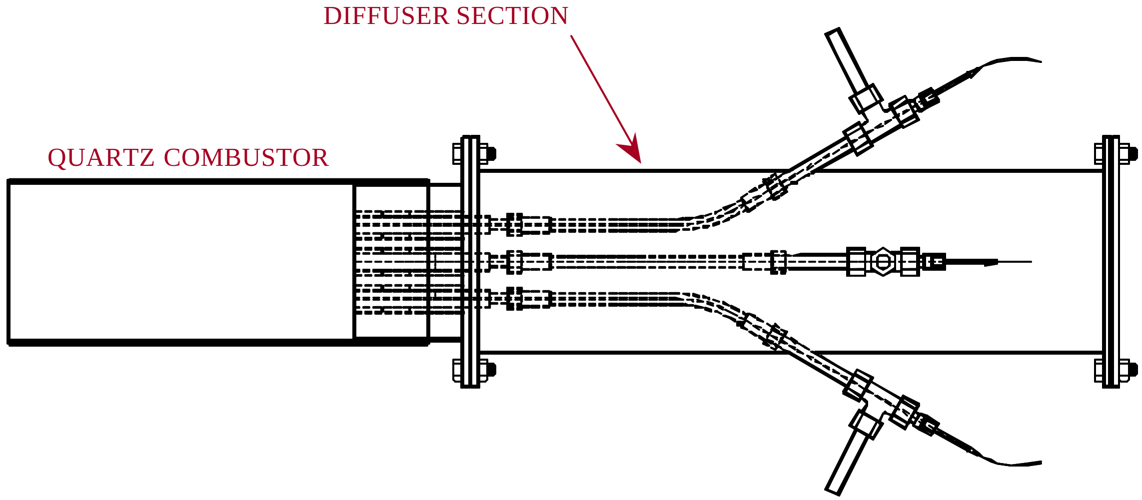
  : Can be used in combustion instability studies



Multi-Nozzle Combustor

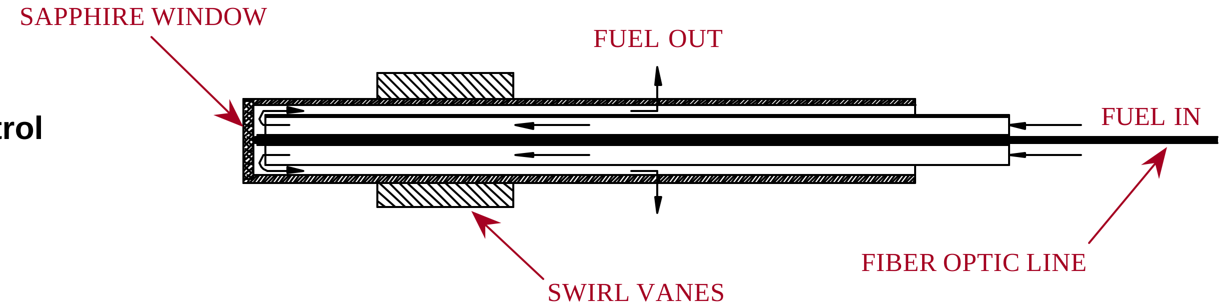


End View



Side View

- Individual nozzle fuel supply control
- Chemiluminescence probes mounted in each nozzle are monitored independently
- Fiber optic line is cooled by fuel



Nozzle Center Body

Future Work Plan

- Test flame chemiluminescence sensor in a 5-nozzle test combustor at Penn State
  - Develop and validate control strategies for use in multi-nozzle combustors
- Implement, test, and evaluate the probes in a full-scale, combustor test rig made available by the industrial members of the AGTSR Program and FETC