ENERGY RESEARCH CONSULTANTS

Combustion Characterization Capabilities

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Since 1990, Energy Research Consultants (ERC) has studied and characterized a wide array of combustion systems and components for various applications in over 3,000 square feet of research facilities located in Laguna Hills, California. The following briefly describes the current capabilities in terms of facilities and diagnostics. ERC is continually evolving both facility and diagnostic capabilities and encourages discussion regarding applications for which the current capabilities appear to fall short.

Facilities

ERC has six test stands, three of which are primarily utilized for study of gas and liquid fired combustion systems and/or components. Two of the test stands are operated in an upfired manner and have exhausting capable of handling 6 lbs/sec of flow generated by devices fired with 1MW of fuel input. The second stand is designed for liquid fired operation at similar capacities. All facilities offer 3 axes of traversing with digital readouts for relative position. The fluid delivery systems are interchangeable between the three stands.

Air. ERC has four independent air generation sources producing the following flows:

- 0.05 lbs/s (40 SCFM) at pressures up to 150 psig
- 0.15 lbs/sec (120 SCFM) at pressures up to 125 psig
- 1.00 lbs/s at pressures up to 1.2 psig
- 2.00 lbs/s at pressures up to 3 psig.
- 0.80 lbs/sec at pressures up to 10 psig
- 1.0 lbs/sec vitiated air at 1340 F at 200 m/s

In addition, 50 kW of non-vitiated preheating is available. Monitoring of air pressure, flow, temperature, and humidity is available via transducers and associated data acquisition interfaces.

Liquid. ERC has experience running the following distillate and non-distillate liquids:

- Gasoline
- Diesel
- Calibration Fluid (MIL-C-7024D-Type II)
- Jet-A
- Fischer-Tropsch derived
- Bio Diesel
- heptane
- acetone
- water
- water/glycerin
- Viscor

Five pumps are available:

- 1 gpm distillate fuel @ 300 psig
- 3 gpm water @3000 psig
- 10 gpm water @ 300 psig
- 100 gpm water @ 150 psig
- 1.4 gpm distillate fuel @ 600 psig

In addition, low pressure, low flow rates (to below 1 g/s) operation can be accomplished using an enclosed pressure container driving liquids with an inert gas pressure head up to 150 psig. In all cases, computer based monitoring of liquid flow rate, temperature and pressure is available via transducers and associated data acquisition interfaces. Multiple liquid circuits can be operated and monitored simultaneously (e.g., pilot and main stages).

Gaseous Fuel. ERC can flow up to 1MW of natural gas. In addition, additional fuel handling to provide higher hydrocarbons such as ethane, propane and butane is available. Also, hydrogen and diluents such as carbon dioxide and nitrogen can be accommodated.

Diagnostics

ERC personnel have considerable experience with a wide range of diagnostics as applied to a variety of reacting and non-reacting sprays. Applications range from complex reacting gas turbine combustor environments to individual injector characterization under quiescent ambient conditions. In addition, a variety of conventional diagnostics are also available.

Combustion Diagnostics

Fuel/Air Mixing Probes. For the characterization of fuel/air mixing in gaseous systems, ERC employs both intrusive and non-intrusive methods. Extractive probes can be used to pull a sample out of the flow and conveyed to the emissions analyzer package where a doped constituent (e.g., natural gas, carbon dioxide) can be monitored. This approach offers high accuracy and relatively high efficiency. These probes are typically employed in non-reacting cases, but can also be used in reacting flows depending on the details of the flow and conditions.

Laser Induced Fluorescence (LIF). If non-intrusive measurements are required of fuel or reaction species, either point or planar laser induced fluorescence (PLIF) can be utilized in both reacting and non-reacting flows. The specific species and methods employed will vary depending upon the type of information desired. Both continuous and pulsed lasers are available. For point measurements, a photomultiplier is used. For planar methods, a scientific 16-bit intensified CCD camera is available. In most cases, the non-intrusive methods are more time intensive to apply that the intrusive methods and tend to provide less accurate information. With any of these techniques, the fuel concentration (either liquid or gaseous) in the air can be characterized and therefore optimized. A UV sensitive, intensified CCD camera is available for quantitative optical patternation.

Laser Anemometry. To characterize the flowfield in reacting and non-reacting systems, a two-component laser anemometry system is available that features frequency domain processing. This method is used to provide a measure of a single component or of the total velocity at various points throughout the domain. This information is useful in defining the extent and strength of aerodynamic features such as recirculation zones, separation regions, and the like. Time resolved information can also be obtained and analyzed to search for periodic flow behavior that might be associated with shedding off a bluff body or some other instability in the system.

Digital Particle Image Velocimetry. To characterize the flowfield in reacting and non-reacting systems, a digital particle image velocimetry (DPIV) system is available that features state-of-the-art timing components and analysis methodologies. This method uses a set of Nd:YAG lasers in conjunction with specialized imaging cameras to provide the instantaneous 2D velocity distribution over a plane using imaging principles. From the results, the global motion of the the flowfield can be determined. In addition, a series of instantaneous results can be time averaged to provide mean velocity as well as standard deviation or other moments of the velocity. In some cases, DPIV can be more time efficient to apply compared with Laser Anemometry, but each technique has its own strengths.

Phase Doppler Interferometry (PDI). A two component phase Doppler interferometry system with frequency domain processing (both TSI FSA3500 and Aerometrics DSA 3200) is available which can be applied in a variety of ways to reacting systems. While primarily utilized to measure the joint distribution of particle size and two components of velocity at a point, it can also be utilized to measure flow field velocities in the absence of droplets or in the presence of droplets. Data reduction programs have been developed at ERC to provide tabulated results in a wide variety of formats. PDI provides considerable information regarding the spray behavior and characteristics. In particular, it can provide the inlet conditions necessary for accurate computation fluid dynamics calculations. ERC personnel regularly apply PDI to reacting sprays and have extensive experience in reducing and tabulating data for model validation and/or further interpretation, including time resolved details and frequency analysis.

Planar Elastic Light Scattering Imaging (PELSI). ERC maintains a variety of optics to produce sheets or beams of laser light from either cw (e.g., Ar^+) or pulsed (e.g., Nd:YAG) lasers. Such lighting, when scattered by droplets in a reacting spray, can be imaged onto an advanced CCD video camera (Canon L2 Hi-8). The camera can operate as both a video recorder or as a digital still camera with full user control over exposure (aperture and shutter speed). Close-up adapters are available to provide up to 30X magnification. In addition, ERC has the capability to extract frames from the video to conduct analysis (e.g., line profiles, comparison of images, etc.) as well as produce high quality video presentation of phenomena of interest. Various filters are utilized to isolate laser wavelengths and chemiluminescence from species of interest. The Nd:YAG laser can generate 4 ns pulses with energy levels sufficient to "freeze" the spray structure even with extreme magnification. This is useful in characterizing the highly complex breakup region.

Infrared Extinction/Scattering (IRES). ERC has the capability to measure the time-averaged concentration of vapor present within unconfined hydrocarbon sprays using a two-wavelength extinction technique. While a line-of-sight technique, spatially resolved information can be obtained for axisymmetric fields by deconvolving a series of parallel scans. This technique has been utilized to obtain time-resolved information as well, and can also be used in single phase situations to monitor fuel concentration.

Chemiluminescence Imaging. ERC has a variety of filters and cameras that can be used to image species such as OH, CH, or C2 which are helpful in determining the location of reaction zones. In addition to full field imaging, point measurements of radical species can also be useful in identifying dynamics associated with heat release and/or stability monitoring.

Emissions. For reacting sprays, ERC has the capability of measuring emissions including unburned hydrocarbons, oxygen, carbon monoxide, carbon dioxide, and oxides of nitrogen. In-situ samples are obtained using water-cooled extractive probes. ERC has implemented sophisticated data reduction tools for quality assurance, analysis, interpretation, and presentation of results. The spatial distribution of gaseous fuel can be determined through the use of microprobes and a flame ionization detector.

Combustion Dynamics. High sensitivity dynamic pressure probes are available with which to quantify the frequency and magnitude of combustion oscillations. Coupled with chemiluminescence, these probes can provide insight into the coupling between pressure and heat release.

Temperature. A variety of thermocouples are utilized to obtain in-situ temperature measurements.

Calibration Devices. ERC has a wide variety of calibration devices, methods, and experience for quality control of all diagnostics and instrumentation.

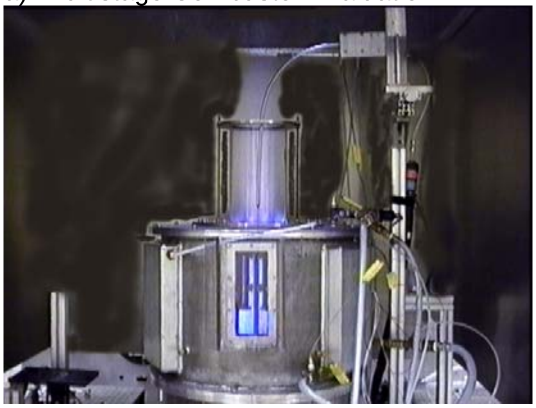
Modeling

ERC applies commercial CFD codes (Fluent or OpenFOAM) to model reacting and non-reacting systems.

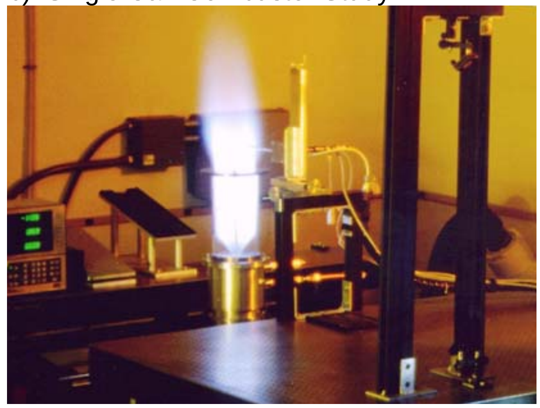
Other Services

In addition to characterization of combustion systems and/or components, ERC can also provide assistance in development of test facilities, including design and fabrication of test stands, traverse systems, sampling systems, and specification, installation, and guidance on various diagnostics such as those outlined above. ERC can also put together data acquisition systems and do programming. ERC also has experience in the development, application, and interpretation of statistically designed evaluation methods which are being utilized in leading companies today for quality assurance. These methods, when applied to complex devices can provide an efficient cost effective means to identify the key factors that control performance of the devices. ERC can also provide analysis of results and provide interpretation of phenomena associated with combustion systems. We are happy to discuss your application and explore ways in which we can work with you.

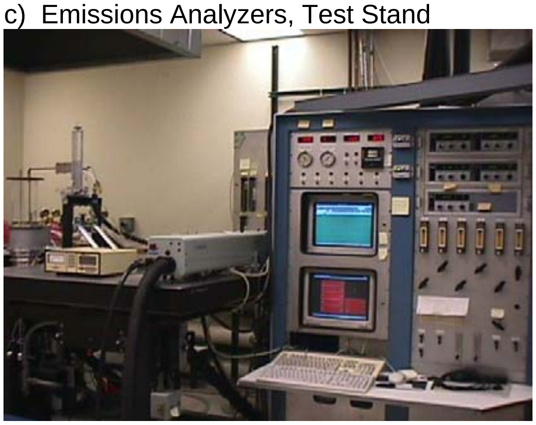
a) Multistage Combustor Evaluation



b) Single Can Combustor Study



c) Emissions Analyzers, Test Stand



d) Spray Fired Combustor Test Facility

e) Vitiator

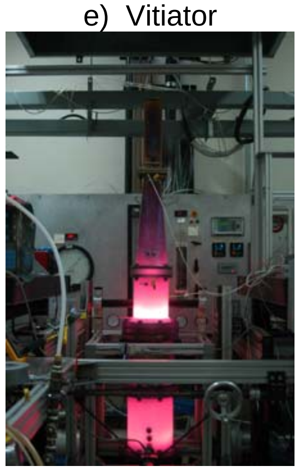


Figure 1. Example Test Stands

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