PENETRATION HEIGHT CORRELATIONS FOR OIL-IN-WATER UNSTEADY EMULSIONS OF A LIQUID JET IN CROSS FLOW AT GAS TURBINE CONDITIONS

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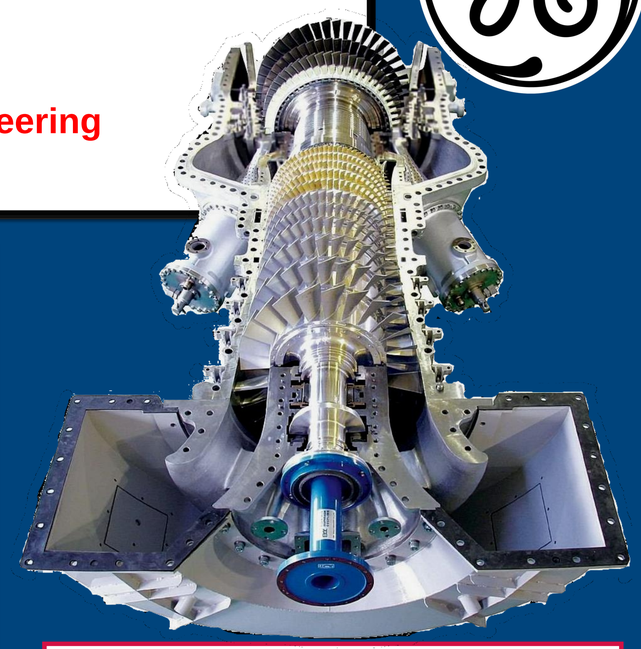

Abstract

A series of combustion rig tests were analyzed to determine liquid jet penetration heights of oil-in-water unsteady emulsions in a gaseous cross flow. Data was taken ranging the water to fuel ratio at several engine loads. The goal of this study is to develop a transfer function to model penetration heights over the engine load range and compare with emissions requirements to predict emission compliant water to fuel ratios without risk of combustion liner wetting and coating spallation. In this study correlations were developed at lower and upper range engine loads while the mid range shows an unclear transition pattern that needs to be addressed in further research.

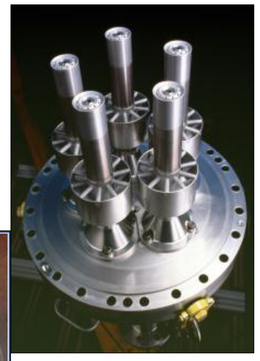

Figure 1: Fuel Nozzle

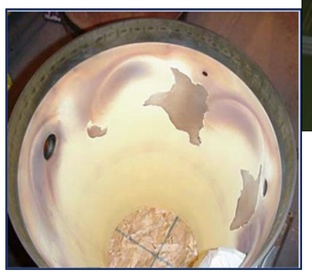

Figure 2: Coating Spallation

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Background

While operating on a liquid fueled diffusion flame NOx emissions are a major concern because of flame temperatures reaching high levels. An unsteady emulsion system is implemented mixing the fuel with water upstream from injection as a means to cool the flame and bring down firing temperature. Coating spallation is at risk and predictive methods are needed

Analysis

The geometry and method of injection is most similar to a Liquid Jet in Cross Flow. Numerical Analysis was done around this basic theory.

$$C = f\left(\frac{\rho_j}{\rho_g}, \frac{u_j}{u_g}, \frac{\rho_g u_g^2 d}{\sigma}, \frac{\rho_g u_g d}{\mu_j}\right).$$

$$C = f(q,\ We_g,\ Re_j)$$

q represents the ratio of the liquid momentum to the gas phase momentum., which is the key variable to determining jet trajectory.

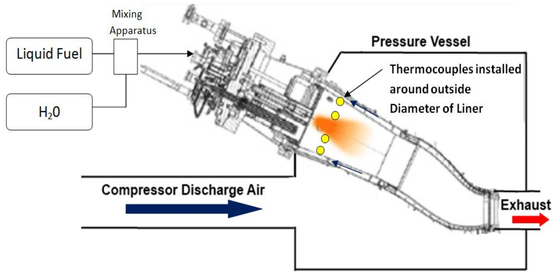
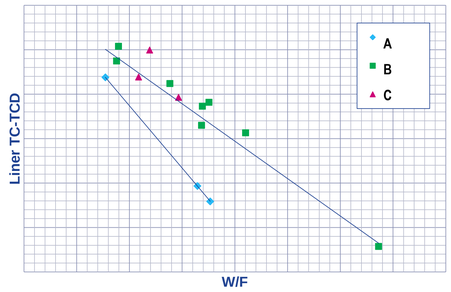


Figure 3: Simple Explanation of Experiment Set-up

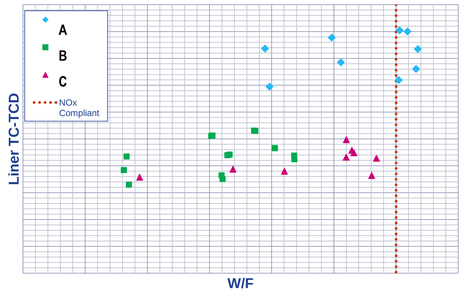
Results

For these experiments the thermocouple temperatures were used as a means of determining the jet penetration. In the low load ranges 10-30% load a clear trend relating the penetration to water fuel ratio was observed. This relates closely to the principles of the liquid jet in cross flow. When analyzing the mid load range data there was large amounts of scatter and a valid correlation could not be formed. At base load conditions the data strays away from the principles of the liquid jet in cross flow , and is not dependant on the water fuel ratio but rather more dependant on pressure. A transition phase is apparent in this data, but more data is needed to characterize the transition.

10-30% L



Base load



Conclusion

- Initial approach to Liner Wetting transfer function Developed
- Base Load conditions able to meet emissions without threat of liner wetting
- Limit W/F rate at low Loads to prevent liner wetting

Future

- Definition for acceptable "liner wetting" limits
- Defining a requirement for W/F vs. Load
- High Air Blast Temp expected to assist in the jet breakup-new hardware configuration tests
- More test points needed in the mid-load range to characterize behavior
- Further Development of transfer function model with new test data

References

1. Ashgriz, Nasser. (2011). *Handbook of Atomization & Sprays: Theory and Applications.* New York: Spriger.

2. Lefebvre, Arthur H & Ballal, Dilip R. (2010. *Gas Turbine Combustion: Alternative Fuels and Emissions.* (3th ed). Boca Raton, FL: CRC Press.