

FINAL REPORT

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ULTRA LOW GAS TURBINE EMISSIONS USING
CATALYTIC AND NONCATALYTIC POROUS COMBUSTORS

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EXECUTIVE SUMMARY

In this Final Report, we summarize the accomplishments we have made with the three years of support from the Department of Energy Advanced Turbine Systems research program. In this Executive Summary, we emphasize our interactions with the gas turbine industry, the students involved, the archival publications are cited (and included in the Appendix). Technical details are in the main body of the final report and are in the main body of the Appendices.

1.0 Summary of NOVEL OPTICAL AIR-TO-FUEL RATIO PROBE

Since the quality of mixing of fuel and air can greatly influence the pollutant emissions of a gas turbine combustor, we are developing diagnostic tools that permit the in-situ measurement of fuel/air mixedness. We have developed a fairly inexpensive fiber-optic probe that can measure time-resolved fuel concentrations even in the high temperature environment downstream of the combustor. Our mixing probe development program is described in Section 1. Development of the probe has been a significant fraction of a Ph.D. Thesis by Mr. R. Mongia (1999) and has been reported at Turbo Expo 97 and published in the International Combustion Symposium as Mongia et al. (1997). This publication is attached as Appendix A.

Furthermore, this probe was well received at Solar Turbines (with Dr. R. Steele) as a part of a Summer Internship Program 1996. At Solar Turbines, the probe was used to measure with 100 microsecond response time, the local air-to-fuel ratio emerging from a laboratory premixer. A concise report of the research accomplished at Solar Turbines is included as Appendix B.

The probe has shown further promise and is now part of a Summer Internship Program 1997 (with Dr. J. Lovett) with GE at Schenectady NY. The goal here is to observe if acoustic oscillations in the combustor lead to fluctuations in the air-to-fuel ratio.

2.0 Summary of CATALYTIC COMBUSTION

The principal objective of our Advanced Turbine Systems program is the development of numerical models that combine detailed surface and gas phase chemistry with 2-D fluid flow in channels, in a package suitable for use on workstations. It is our goal that the gas turbine industry will be able to use these models as a guide in the design and development of catalytic combustion applications.

Our approach consists of two concurrent, complementary components. One of these is the development of a detailed numerical model of the catalytic combustion process that can be used to explore various physical processes occurring in the catalyst. The other is an experimental program utilizing catalytic combustors developed and used in our laboratories. The laboratory experiments are designed and performed to obtain the data required to test the model, and the model is used to guide the efficient selection of experimental parameters for further experiments.

This synergy between model and experiment is the guiding principle behind our catalytic combustion program, described in Section 2. The Thesis of Ms. Bond (1996) was the basis of our presentation and publication in the International Combustion Literature (Bond, et al. 1997); the publication is attached as Appendix C.

Most recently, we have collaborated with Visiting Scientist, Dr. Andreas Schlegel, from the Paul Scherrer Institute in Switzerland, who was a Swiss Fellowship. Together, we combined the aforementioned optical probe with a combustion catalyst and demonstrated that poor temporal mixing, which produces excessive NO_x in lean premixed flames, has almost no effect on the very low NO_x produced in a catalytically stabilized combustor. This well received paper was presented at Turbo Expo 97 (Schlegel, et al. 1997) and is attached as Appendix D.

As an example of technology transfer, we note that Dr. L. Smith from our research group has joined the venerable catalyst company of PCI in New Haven, CT.

3.0 Summary of RADIATION FEEDBACK IN CATALYTIC AND NONCATALYTIC COMBUSTION

Due to the potential importance of radiant feedback to catalytic combustion applications, we pursued a parallel research program using non-catalytic ceramic radiant burners to quantify and model the effects of radiant feedback on premixed natural gas combustion. The same model-experiment synergy described above exists in our radiant feedback research program, which is described in Section 3. This research culminated in a Ph.D. Thesis of Dr. M. Rumminger (1996) and was presented and published at the International Combustion Symposium (Rumminger, 1997); this paper is attached as Appendix E. A second paper on catalytic radiant burners was presented at the 3rd International Workshop on Catalytic Combustion; the paper is in review (Rumminger, Hamlin, and Dibble; 1997). A third paper is near submission (Rumminger and Dibble 1998). Dr. Rumminger was awarded a two year Post Doctoral Fellowship at NIST, Gaithersburg, MD, where he investigates a wide variety of combustion problems.