3-DAY SHORT COURSE
Impact of Coal Derived Synthesis and Hydrogen Gas (SHG) Fuels Relevant to Gas Turbines

Dates: August 3-5, 2004 (Tuesday through Thursday)
Place: WVU National Research Center for Coal and Energy (NRCCE)
Registrar: NETL Event Management, 304-285-4750
Course Development Coordinator:

Karen Thole, UTSR Academic Advisory Board
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DOE/NETL Contact: Tom J. George, 304-285-4825
SCIES Contact: Bill Day, 860-404-0759

Course Abstract

A short course on the impact of coal derived synthesis and hydrogen gas (SHG) fuels relevant to gas turbine is being developed by research experts in the fields of combustion, aero/heat transfer, and materials. This short course is being developed to serve the needs of a gas turbine community while addressing the DOE's focus on turbines fueled with coal derived synthesis and hydrogen gas (SHG). The course is being developed by the Academic Advisory Board (AAB) of the University Turbine Systems Research Program.

SHORT COURSE
Impact of Coal Derived Synthesis and Hydrogen Gas (SHG) Fuels
Relevant to Gas Turbines

The University Turbine Systems Research Program is a program funded by the U.S. Department of Energy and coordinated through the South Carolina Institute for Energy Studies. This program supports university research to develop advanced energy systems that incorporate turbines. Through the University Turbine Systems (UTSR) Program, faculty engage students in research and learning related to turbine issues. A Peer Review Workshop was held by the UTSR Program on October 2003 in Clemson, South Carolina. During that workshop members from the university community gathered in a stakeholder session in which a number of improvements to the program were suggested. The overall consensus of the group was that the university members wanted to take a more active role in the UTSR Program through the formation of an Academic Advisory Board (AAB).

One of the primary missions that were outlined for the AAB was to provide educational support to the gas turbine community, which includes individuals from the government, industry, and academia sectors. As such, one of the specific activities for the AAB is to develop and implement short courses that contain material relevant to current needs. In particular the first proposed short course, which will serve as a pilot program, is aimed to serve an immediate need of DOE/NETL on the impacts that synthesis and hydrogen gas (SHG) fuels have on gas turbine development. These impacts can be assessed from a perspective of the three traditional research areas funded by the UTSR Program that include Combustion, Aero/Heat Transfer, and Materials. The course syllabus, presented in this document outlines course content, that will to the greatest degree current knowledge allows, link the topic areas to the challenge of adapting to SHG environments. An evaluation of the course by participants is being designed to help determine course improvements to maximize showing these linkages.

Background

In planning this course, a number of individuals working in industry were contacted to identify the issues related to SHG fuel usage in gas turbines. These individuals included Dick Tuthill (Pratt & Whitney), Jerry Simons (GEPS), Norm Schilling (GEGRC) and Bob Battiste (GEPS). From these discussions, a number of common themes developed whereby critical issues included the following for the three different topical areas:

Combustion Area. This appeared to be the most critical area in terms of requiring more overall changes for gas turbine development. The identified issues include the lower overall heating values for SHG fuels, flame stabilization with ultra-lean conditions, the propensity of a premixed SHG fuel/air mixtures for flashback, steam or nitrogen injection to dilute the flame temperature, and residence time requirements for the combustion process with increased flows associated with SHG's. These issues must be addressed while achieving superior ultra-low emissions for these alternatively fueled systems. A critical constraint/boundary condition that determines requirements for the combustion process is the nature of the generation of SGH fuels and their subsequent preparation for use. Furthermore, extraction of energy from these fuels in advanced cycles will often involve additional components that will impact the overall system efficiency.

As a result, some overview of these components is also provided to provide broader perspective relative to the overall energy extraction process.

Aero/Heat Transfer Area. From a heat transfer perspective, many of the same issues are still present as with the previous gas turbine development except amplified. The cooling air management limits how hot the turbine can be and as such film-cooling is extremely important. Because steam or nitrogen is injected into the combustor for most systems and because of the increased mass flow for the SHG fuels combustion products, there is an increase in the overall heat transfer to the components. Typical gas turbines use one-third of the intake air for cooling surfaces thereby reducing the likelihood of molten particles depositing on component surfaces. Another significant issue is the deposition of particles onto component surfaces that lead to increased roughness effects on heat transfer. These particles are ingested into the engine despite filtering techniques.

Materials Area. The various materials issues resulting from the use of SHG fuels differed relative to natural gas operations will be presented. These issues include the need to account for the sulfur contamination that leads to degradation of the fuel nozzles, hot gas corrosion, increases in deposition, degradation processes in high moisture environments with contaminants, and premature spallation of thermal barrier coatings due to corrosive attacks by surface deposits.

Syllabus Development. Some of the companies active in the UTSR were interviewed to help shape the content of this course. It should be emphasized that in all of the discussions with the industry representatives, they stressed the importance of understanding the overall system rather than just components. If changes to a particular component were made, an overall reduction in the gas turbine efficiency could result. Rather than to attempt to address this important point fully in the pilot course, a separate stand alone course is being considered.

Topics for the Short Course

Instructors were identified for each of the areas listed above. Listed below are the syllabi from those individuals who have expressed a commitment to teaching a half-day or full-day course in the topic areas (note an abbreviated CV of the instructors are given in Appendix A).

Combustion I and II: Dr. Greg Jackson (U Maryland) and Dr. Vince McDonell (U California-Irvine)

1. Introduction to Advanced Cycles
   - Advanced cycles and their impact on fuels and combustor operating conditions
     - Synthesis gas composition as a function of feedstocks and plant operation
     - Use of synthesis gas
     - Impact on synthesis gas composition on combustion
     - Impact on overall plant performance
   - Gasification technology / Fuel reforming
     - Heterogeneous reactors, partial oxidation, reforming
     - Integration of gasifiers/reformers with combustion
   - Zero-emissions combustion and Solid Oxide Fuel Cells
     - Options for gas turbine and air separation plant integration
     - Membranes for zero emissions

- Cycle analysis
- Solid Oxide Fuel Cells

2. Fundamentals of Combustion and Reactors for Advanced Cycles
   - Review of Combustion Fundamentals
     - Review of Basic Combustion Processes
     - Review of Emissions Issues from Combustion
     - Introduction to Fuel Composition Effects

   - Gas-phase combustion of gasified or reformed fuels
     - Fuel Composition Effects
     - Extinction, emissions, ignition characteristics, and turbulent combustion
     - Approaches to modeling combustion systems with alternative fuels

   - Heterogeneous reactors for advanced combustion systems
     - Catalytic reactions – stability and limits of catalysts for advanced combustion systems of alternative fuels
     - Modeling approaches to catalytic reactors for combustion and reforming
     - Fundamentals of membrane technology for zero emissions combustion and for solid oxide fuel cells
     - Membrane performance and physics
     - Models for oxygen membranes and solid oxide fuel cells in advanced cycles

3. Research Progress and Opportunities in Advanced Gasification and Zero Emissions Combustion Systems

Aero/Heat Transfer I: Dr. Jeffrey Bons (Brigham Young University)

1. Review of mechanisms responsible for surface degradation (30 minutes)
   - Erosion/Spallation of TBCs
   - Corrosion
   - Deposition
   - Anticipated changes with use of synthesis gas

2. Measurements from actual hardware (1 hr)
   - Signatures of each degradation mechanism
   - Magnitude of effect
   - Spatial extent
   - Spatial transitions
   - Film cooled regions
   - Anticipated changes with use of synthesis gas

3. Surface roughness characterizations (30 minutes)
   - Historical roughness characterizations
   - Current statistical representations
   - The status of k_s–type modeling

- Modeling roughness in CFD

4. Influence of surface roughness on performance (1 hr)
   - Convective heat transfer
   - Aerodynamic skin friction
   - Synergies with free-stream turbulence
   - Synergies with pressure gradient
   - Other effects: compressibility, cooling, etc…

5. Design and operational considerations (30 minutes)
   - Surface evolution with time – maintenance issues.
   - Interaction between mechanisms
   - Conduction through deposition layers and TBCs
   - Anticipated changes with use of Syngas

Aero/Heat Transfer II: Dr. Karen Thole (Virginia Tech)

1. Internal and External Cooling Methods (1.5 hours)
   - Fundamentals of heat transfer related to the turbine section
   - Fundamentals of cooling methods for internal airfoil cooling
   - Fundamentals of cooling methods for external airfoil cooling
   - Conjugate heat transfer analyses of turbine airfoils

2. Augmentation of Internal and External Airfoil Heat Transfer (30 minutes)
   - Airfoil roughness effects due to dirt deposition
   - Cooling hole blockage effects due to dirt

3. Secondary Flows in Platform Regions (1 hour)
   - Effects of combustor exit profiles on secondary flow development
   - Effects of end-wall contouring on secondary flow development
   - Turbine end-wall heat transfer

4. Tip Heat Transfer (1 hour)
   - Effects of blade tip heat transfer
   - Film-cooling methods for the blade tip

Materials I: Dr. Rich Wenglarz (SCIES/Clemson)

Even after the best available fuel gas cleanup, limited quantities of fuel impurities will enter turbines that operate with coal syngas. Impurities in the syngas combustion gases can potentially produce hot section flow path materials loss due to corrosion, erosion, and spallation of coatings and also deposit buildup on surfaces. These processes can degrade airfoil and end-wall surfaces from their initial finely specified and manufactured tolerances to result in decreased turbine power and efficiency.

This course will describe mechanisms and issues related to degradation of hot section materials and surfaces in syngas turbines. Topics will include:

1. Introductory Discussion
    - Overview of types of degradation
    - Perspective on gas cleanliness for syngas turbines
    - Flow path degradation for current syngas turbines
    - Higher inlet temperatures for future syngas turbines

2. Mechanisms of Turbine Flow Path Degradation
    - Delivery of impurities to turbine surfaces
        - Inertial impaction
        - Turbulent eddy diffusion
        - Thermophoresis
        - Brownian diffusion
    - Interaction of impurities with turbine surfaces
        - Erosion
        - Corrosion
        - Deposition
    - Mechanisms of deposit buildup
        - Particulate removal forces
        - Particle attachment forces
        - Deposit detachment
        - Turbine factors affecting buildup

3. Erosion/corrosion/deposition test/experimental methods
    - Alternative methods for turbine assessments
    - Advantages/disadvantages of alternative methods
    - Inexpensive approach to evaluate erosion/corrosion/deposition degradation
    - Extrapolation to turbines

4. Observations from Past Experiments with Alternate Fuels
    - Description of test results
    - Test interpretation-fundamental characteristics/regimes
        - Effects of gas temperature-transition temperature
        - Degradation regime below transition temperature
        - Degradation regime above transition temperature
        - Effects of surface temperature
    - Materials/flow path protection implications
    - Example turbine flow path degradation predictions using experiments

5. Perspectives on Syngas Turbines from Past Tests/Experience

Materials II: Dr. Fred Pettit and Dr. Gerald Meier (Univ of Pittsburgh)

1. Current Status of Materials Issues in Gas Turbines Using Natural Gas
    - High Temperature Corrosion in Turbine and Compressor Sections
        - Oxygen and Mixed Gas Attack (1 hr)
        - Hot Corrosion (1 hr)
        - Erosion (1/2 hr)

        - Protection Schemes Considering Alloys and Coatings in Use (1 hr)
        - Testing Methods (1/2 hr)
    - Mechanical Property Issues (1/4 hr)
2. Contaminants Resulting from Use of SHG fuels for Combustion (¾ hr)
3. Materials Issues Resulting from Use of SHG fuels for Combustion
    - High Temperature Corrosion
        - Oxidation and Mixed Gas Attack (1/2 hr)
        - Hot Corrosion (1 hr)
        - Erosion (1/2 hr)
        - Effects on Current Protection Schemes (1/2 hr)
        - Test Methods (1/4 hr)
    - Mechanical Property Issues (1/4 hr)

Course Materials and Development Philosophy

Course materials including a Leaders Guide and Turbine Course Manual are being prepared with enough detail that a person knowledgeable in the particular field could deliver the course in various settings. The Leader's Guide will include a reproducible copy of each handout and a copy of all media used. In addition to the Leaders Guide a course book will be developed for participants to use during the course and to take home for future reference by participants. An example of best practices for a Leader's Guide is for it to contain the following information for each 5-15 minute course segment: Project Name, Time, Segment Title, Topic Objective, Detailed Topic Outline, Equipment Needed, Handouts Needed, Software Needed, Media Needed, Signatures of Review/Approval.

This course is being developed by the AAB for use by members of the UTSR community. The pilot delivery of the course will be August 3-5 in Morgantown, WV. Although the purpose of the pilot course is to provide immediate useful training to participants, the participant feedback from participants in the pilot course will be used to finalize course materials. By engaging a number of UTSR community members in the development and review of the course and course materials, the goal is to build a course and materials of maximum utility for turbine education, at performing member universities but also elsewhere within the UTSR community as needed.

COURSE DEVELOPER CURRICULUM VITAES

Jeffrey P. Bons

Associate Professor of Mechanical Engineering, Department of Mechanical Engineering, Brigham Young University, Tel (801) 422-8036, email = jbons@byu.edu

Education:

BS, Aeronautical Engineering, Massachusetts Institute of Technology, 1988
MS, Aeronautical Engineering, Massachusetts Institute of Technology, 1990
PhD, Aeronautical Engineering, Massachusetts Institute of Technology, 1997. Dissertation topic – turbine internal cooling.

Gas Turbine Related Experience:

2002 –present: Associate Professor at BYU, research and instruction in gas turbine related disciplines.
1997-2002: Associate Professor at the Air Force Institute of Technology, WPAFB, OH, research and instruction in gas turbine related disciplines.
1992-1994: Research engineer, Propulsion Directorate of Wright Laboratory WPAFB, OH, research in turbine film cooling.
1988-2002: Active duty service in US Air Force. Honorable discharge at the rank of Major in July 2002.

Selected Recent Gas Turbine Related Publications:

1. Jensen, J.W., Squire, S.W., Bons, J.P., and Fletcher, T.H., "Simulated Land-Based Turbine Deposits Generated in an Accelerated Deposition Facility," accepted for presentation at the 2004 IGTI conference in Vienna, Austria.
2. J.P. Bons and S.T. McClain, "The Effect of Real Turbine Roughness and Pressure Gradient on Heat Transfer," presented at the 2003 IGTI in Atlanta, GA.
3. Bons, J.P., "St and c_f Augmentation for Real Turbine Roughness with Elevated Freestream Turbulence", *ASME Journal of Turbomachinery.* Vol. 124, pp. 632-644, Oct. 2002.
4. Bons, J.P. , Taylor, R.P., McClain, S.T., and Rivir, R.B., 2001, "The Many Faces of Turbine Surface Roughness," *ASME Journal of Turbomachinery,* Vol. 123, Oct. 2001, pp. 739-748.
5. J.P. Bons and J.L. Kerrebrock, "Complementary Velocity and Heat Transfer Measurements in a Rotating Cooling Passage with Smooth Walls", *ASME Journal of Turbomachinery*, Oct 1999, pp 651-662.
6. J.P. Bons, C.D. MacArthur, and R.B. Rivir, "The Effect of High Freestream Turbulence on Film Cooling Effectiveness", *ASME Journal of Turbomachinery*, Oct 1996, pp814-825.

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EDUCATION

Ph.D. in Mechanical Engineering, *Cornell University* January 1994
Ph.D. Dissertation: *Spherically Symmetric Droplet Combustion of Sooting and Multi-component Fuels*
Minors: Chemical Engineering and Control Systems

M.S. in Mechanical Engineering, *Cornell University* January 1991
B.S. in Mechanical Engineering, *Rice University* May 1988

PROFESSIONAL HIGHLIGHTS

Associate Professor, Dept. of Mechanical Engineering, 1997 - present
UNIVERSITY OF MARYLAND, College Park, Maryland.

- Director of Reacting Flow Laboratory and faculty member of Center for Environmental Energy Engineering.
- Managing research contracts over past four years with total committed funding of over $2 million
- Developing – through an integrated experimentally validation program – detailed surface chemistry for catalytic oxidation of H_2 and CH_4 on Pd catalysts and steam-reforming of small hydrocarbons for H_2 production over Rh catalysts.
- Implementing novel application of intrinsically low dimensional manifolds for extracting critical aspects of surface chemistry mechanisms for experimental validation.
- Developing novel meso-scale, liquid-fueled power supply utilizing catalytic reactor
- Leading combined experimental and modeling program on effects of fuel composition on extinction and instabilities in low emissions flames.
- Developed new graduate course on advanced analysis of fuel cells and internal combustion engines and implemented new approach to graduate thermodynamics course based on molecular thermodynamics including implementation of molecular simulations.
- Developed with Naval Surface Warfare Center unique modeling capability for biomass plasma gasification and combustion in onboard ship waste destruction

Research & Development Engineer, 1993 - 1997
PRECISION COMBUSTION, INC., New Haven, Connecticut.

- Led research and development efforts on industrial and government contracts related to ultra-low emissions catalytic combustors and to alternative catalytic ignition systems for gas turbines.
- Designed and tested low-NO_x combustors for ground-based gas turbines and hybrid electric vehicles; developed new concepts for catalytic combustors.
- Co-inventor on patented catalytic ignition systems for multiple applications.
- Modeled reacting flows in complex systems with commercial CFD package.

Evaluations Engineer 1987 - 1988
LYONDELL PETROCHEMICAL CO., Channelview, Texas.

- Modified large FORTRAN model of semi-empirical kinetics in pyrolysis furnaces for on-line plant optimization.
- Analyzed crude oils for refinery performance.

HONORS

National Science Foundation CAREER Award Recipient, 1999

Co-Inventor on Three Patents for Catalytic Ignition Devices, 1996, 1998, & 1999
Outstanding Paper in Terrestrial Energy Systems - AIAA, 1993 & 1997

RECENT PROFESSIONAL SERVICE

Service on University of Maryland Senate and Educational Affairs Subcommittee
Participant at DOE program review on Emissions Reduction from Gas Engines, 2003
Panel reviewer for several NSF, EPA, & NASA programs, 2000-2002
Reviewer of proposals for DOE, USDA, and California Energy Comm., 2000-2003
Session Organizer and Chair for ASME Turbo Expo', 1999
Reviewer of papers for over 10 archival journals
Organizing Committee for APS Division of Fluid Dynamics Meeting, 2000

SELECTED RECENT ARCHIVAL PAPERS

Crane, D.T. and Jackson, G.S. (2004), "Optimization of Cross Flow Heat Exchangers for Thermoelectric Waste Heat Recovery", *Energy Conversion and Management*, **45**(9-10), 1565-1582.

Robbins, F.A., Zhu, H., and Jackson, G.S. (2003), "Transient Modeling of Combined Catalytic Combustion / CH_4-Steam Reforming", *Catalysis Today*, **83**, 141-156.

Wolf, M.M., Zhu, H., Green, W.H., and Jackson, G.S. (2003), "Kinetic Model for Polycrystalline Pd/PdO_x in Oxidation/Reduction Cycles", *Applied Catalysis, General: A*, **244**(2), 323-340.

Kramer, J.F., Reihani, S.S., and Jackson, G.S. (2002), "Low Temperature Combustion of Hydrogen on Supported Pd Catalysts", *Proceedings of the Combustion Institute*, **29**, 989-996.

Sidwell, R.W., Zhu, H., Kee, R.J., Wickham, D.T., Schell, C., and Jackson, G.S. (2002), "Catalytic Combustion of Premixed Methane-Air on a Palladium-Substituted Hexaluminate Substrate", *Proceedings of the Combustion Institute*, **29**, 1013-1020.

Dakka, S.M., Jackson, G.S., and Torero, J.L., "Mechanism Controlling the Degradation of Poly(methyl-methacrylate) Prior to Piloted Ignition", *Proceedings of the Combustion Institute*, **29**, 281-287.

Jackson, G.S., Sai, R., Plaia, J.M., Boggs, C.M., and Kiger, K.T. (2002), "Influence of Hydrogen on the Response of Lean Methane Flames to High Strained Flows", *Combustion & Flame*, **132**, 503-511.

Fant, D., Jackson, G.S., et al., (2000) "Status of Catalytic Combustion R&D for the Department of Energy Advanced Turbine Systems Program", *J. Eng. Gas Turb. Power*, **122**(2), 293-300.

Jackson, G.S. and Avedisian, C.T. (1998), "Combustion of Unsupported Water-in-Heptane Emulsion Droplets in Convection Free Environment Experiments of Water-in Heptane Emulsion Droplets at Low Gravity", *Int. J. Heat Mass Trans.*, **41**(16), 2503-2515.

Jackson, G.S. and Avedisian, C.T. (1996), "Modeling of Spherically Symmetric Droplet Flames including Complex Chemistry: Effect of Water Addition on n-Heptane Droplet Combustion", *Combust. Sci. Tech.*, **115**, 125-149.

Jackson, G.S. and Avedisian, C.T. (1994), "The Effect of Initial Droplet Diameter in Spherically Symmetric Droplet Combustion of Sooting Fuels", *Proc. Roy. Soc. Lond.*, **A446**, 255-276.

SELECTED RECENT CONFERENCE PAPERS

McGrath, T.P., Buckley, S.G. and Jackson, G.S., "Propagation of Spherically Symmetric Hard Detonations in Open Environments of Fuel/Air Mixtures", Proceedings of the 3rd Joint Meeting of the U.S. Sections of the Combustion Institute.

Reihani, S.S. and Jackson, G.S., "Evaluation of Catalytic Combustion Surface Chemistry with ILDM's", Proceedings of Joint States Meeting of the Combustion Institute, March 2003.

Reihani, S.S., Kramer, J.F., Robbins, F.A., and Jackson, G.S., "Low Temperature Catalytic Combustion of Hydrogen for Heating Applications", Proceedings of Eastern States Section Meeting of the Combustion Institute, December, 2001.

Zhu, H. and Jackson, G.S., "Transient Modeling for Assessing Catalytic Combustor Performance in Small Gas Turbine Applications", ASME paper No. 2001-GT-0520, New Orleans, LA, June 2001.

Vincent G. McDonell

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Professional Preparation

University of California, Irvine	Engineering	B.S.	1985
University of California, Irvine	Engineering	M.S.	1987
University of California, Irvine	Mechanical Engineering	Ph.D.	1990

Appointments

10/99-present	**Associate Director**. UCI Advanced Power and Energy Program, University of California, Irvine
7/95-present	**Associate Director**. UCI Combustion Laboratory, University of California, Irvine
7/90-6/95	**Sr. Research Engineer**. UCI Combustion Laboratory, University of California, Irvine
1/88-7/90	**Air Force Laboratory Research Fellow**, University of California, Irvine, Combustion Laboratory
6/87-9/87	**Visiting Researcher**, Imperial College of Science and Technology, London, England

Areas of Research

- Liquid Sprays and Spray Formation Methods for Various Applications including Combustion, Coatings, Cooling, and Metal Powder Formation
- Low Emissions Continuous Combustion Systems for Gas Turbines, Boilers, and Furnaces.
- Methods for Statistically Designed Experiments and Analysis of Systems Using Statistically Designed Experiments
- Application of Computational Fluid Dynamics, Laser Diagnostics, and Conventional Diagnostics as Applied to Practical Combustion Devices and to Components of Practical Combustion Devices
- Characteristics of Alternative Gaseous and Liquid Fuels for Combustion Systems Including Emissions and Ignition Behavior
- Inference of System Performance Characteristics Based on Convenient Approaches to Monitoring
- Microturbine Generators (<500 kW Gas Turbine)
- Closed Loop Monitoring, Control and Optimization Combustion Processes for Improved Performance

Related Publications & Papers

1. V.M. Phi, J.L. Mauzey, V.G. McDonell, G.S. Samuelsen, and G.Pont (2003). CHARACTERIZATION OF EMISSIONS AND FUEL INJECTION PERFORMANCE FOR A COMMERCIAL MICROTURBINE GENERATOR (2003). Presented at the Fall Meeting of the Western States Section/The Combustion Institute, Paper 03F-22, October
2. R.L. Hack, V.G. McDonell, G.S. Samuelsen, J. Blust, P. Dutta, K.O. Smith, and D.K. Yee (2003). DESIGN AND TESTING OF A UNIQUE COMPACT GAS TURBINE CATALYTIC

COMBUSTOR PREMIXER (2003). Paper GT-2003-38778, Presented at IGTI Turbo EXPO 2003, Atlanta, GA.
3. V.G. McDonell and M. Kay (2003). FUEL COMPOSITION EFFECTS ON COMBUSTOR PERFORMANCE. Presented at the 1st International Conference on Gas Turbine Technologies, Brussels, Belgium, July 10-11 (
4. R.M. Flores, V.G. McDonell, and G.S. Samuelsen (2003). IMPACT OF ETHANE & PROPANE VARIATION IN NATURAL GAS ON THE PERFORMANCE OF A MODEL GAS TURBINE COMBUSTOR (2003). *ASME J. Engr. Gas Turbines And Power*, Vol. 125, No. 3, pp. 701708.
5. M.Y. Leong, C.S. Smugeresky, V.G. McDonell, and G.S. Samuelsen (2001). RAPID LIQUID FUEL MIXING FOR LEAN BURNING COMBUSTORS: LOW POWER PERFORMANCE (2001). *ASME J. Engr. Gas Turbines and Power*, Vol. 123, No. 3, pp. 574-579.
6. M.Y. Leong, V.G. McDonell, and G.S. Samuelsen (2001). EFFECT OF AMBIENT PRESSURE ON AN AIRBLAST SPRAY INJECTED INTO A CROSSFLOW (2001). *J. Prop. and Power*, Vol. 17, No. 5, pp. 1076-1084.
7. R.M. Flores, M.M. Miyasato, V.G. McDonell, and G.S. Samuelsen (2001). RESPONSE OF A MODEL GAS TURBINE COMBUSTOR TO VARIATION IN GASEOUS FUEL COMPOSITION (2001). *ASME J. Engr. Gas Turbines And Power*, Vol 123, Pp. 824-831.
8. S.G. Hill, V.G. McDonell, and G.S. Samuelsen (2001). CATALYTIC PILOTING OF A FULLY PREMIXED MODEL GAS TURBINE COMBUSTOR (2001). Paper 01F-44, Presented at the Fall Meeting of the Western States Section of The Combustion Institute, Salt Lake City, UT, 15-16 October.
9. V.G. McDonell and G.S. Samuelsen (2000). MEASUREMENT OF FUEL MIXING AND TRANSPORT PROCESSES IN GAS TURBINE COMBUSTION (2000). *Measurement Science and Technology*, Volume 11, pp. 870-886.
10. A. Ateshkadi, V.G. McDonell, and G.S. Samuelsen (2000). LEAN BLOWOUT MODEL FOR A SPRAY FIRED SWIRL STABILIZED COMBUSTOR (2000). *Proceedings of the Combustion Institute Volume 28*, pp. 1281-1288.
11. V.G. McDonell and G.S. Samuelsen (1996). ASSESSING THE PHYSICS OF SPRAY BEHAVIOR IN PRACTICAL COMBUSTION SYSTEMS (1996). *Recent Advances in Spray Combustion: Spray Combustion Measurements and Model Simulation*, Progress in Astronautics and Aeronautics, Volume 171, K.K. Kuo editor, Chapter 7, pp. 159-185.
12. V.G. McDonell and G.S. Samuelsen (1992). EFFECT OF FUEL INJECTION MODE ON FUEL VAPOR IN REACTING AND NON-REACTING METHANOL SPRAYS. *24th Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 1557-1564 ().
13. M. Adachi, V.G. McDonell, And G.S. Samuelsen (1990). NON-INTRUSIVE MEASUREMENT OF GAS SPECIES IN REACTING AND NON-REACTING SPRAYS (1990). *Combustion Science And Technology*, Vol. 75, Pp. 179.
14. V.G. McDonell and G.S. Samuelsen (1990). APPLICATION OF LASER INTERFEROMETRY TO THE STUDY OF DROPLET/GAS PHASE INTERACTION AND BEHAVIOR IN LIQUID SPRAY COMBUSTION SYSTEMS. *Combustion Science And Technology*, Vol. 74, Pp. 343.

Gerald H. Meier

EDUCATION: B. S. in Metallurgical Engineering, Carnegie Institute of Technology l964.
Ph.D. in Metallurgical Engineering, The Ohio State Univers ity l968
Postdoctoral Research Fellow, Universität Munster, Munster,West Germany, April l968-April l969.

ACADEMIC RANK: Professor, Department of Materials Science and Engineering, University of Pittsburgh.
(Initial Appointment: 1969, Associate Professor: 1973, Full Professor: 1979)

EXPERIENCE:

Pittsburgh Steel Company, Metallurgical Engineering Trainee, June l963-August l963.
U. S. Steel Research laboratory, Research Assistant, June l964-August l964.
Lockheed Palo Alto Research Laboratory, Visiting Scientist, June l975-August l975.
Technische Hogeschool, Delft, Holland, Visiting Research Professor, May l976-August l976.
Lockheed Palo Alto Research Laboratory, Senior Research Scientist, June l978-August l978 and January 1983-May 1983.

HONORS AND AWARDS:

Inland Steel Fellowship, The Ohio State University, l965-66.
NSF Traineeship, The Ohio State University, l966-68.
Outstanding Teacher Award, School of Engineering, University of Pittsburgh, April, l975.
Member, International Advisory Editorial Board for Materials at High Temperature
Bunshah Award for Best Paper in Structure/Property Relationship Symposium of the International Conference on Metallurgical Coatings, (with J. Caola and F. S. Pettit) 1986.
Chairman of Gordon Research Conference for High Temperature Corrosion, 1987.
University of Pittsburgh, School of Engineering, Board of Visitors, Outstanding Faculty Award, 1987.
Member, Editorial Advisory Board, Oxidation of Metals.
Bunshah Award for Best Paper in Coatings for Use at High Temperature Symposium of the International Conference on Metallurgical Coatings, (with F. S. Pettit) 1989.
William Kepler Whiteford Professorship, School of Engineering, 1992-present.
Andrew Carnegie Lecturer, ASM International, 1994.
Outstanding Alumnus, College of Engineering, The Ohio State University, 1996.
Elected Fellow of ASM International, 1996.

PROFESSIONAL SOCIETIES: Materials Research Society, ASM International

PUBLICATIONS: Professor Meier has authored or co-authored over 100 papers (23 in the last five years) and 1 book.

PATENT: J. C. Schaeffer, R. L. McCarron, G. H. Meier. R. A. Perkins, and J. R. Cullinan, "Ti-Cr-Al Protective Coatings for Alloys", U.S. Patent No. 5,783,315, July 21, 1998.

Fred S. Pettit

EDUCATION: B. Eng. (with Honors) in Metallurgical Engineering,Yale University, 1952.
M. Eng. in Metallurgical Engineering, Yale University, 1960.
Dr. Eng. in Metallurgical Engineering, Yale University, 1962.
Post-doctoral Fellow, Max Planck Institute fur Physikalische Chemie, 1962-1963.

ACADEMIC RANK: Harry S. Tack Professor of Materials Engineering, September 1992, Permanent Appointment.

EXPERIENCE:

Professor, Department of Materials Science and Engineering, University of Pittsburgh, Pittsburgh, PA, 1989 – Present
Office of Naval Research, Technical Liaison Office, Tokyo, Japan, June 1988-
September 1989.
Professor and Chairman, Department of Materials Science and Engineering, University of Pittsburgh, Pittsburgh, PA, 1979-1988.
Research Associate, Senior Research Associate, Group Leader, Supervisor and Senior Staff Scientist in Materials, Pratt & Whitney Aircraft Group, East Hartford, CT, August 1963-August 1979.

HONORS AND AWARDS:

Yale University Scholarship, 1949-1952
National Science Foundation Fellowship, 1962-1963
Chair, Gordon Research Conference on Corrosion, 1979
ASM Fellow, 1986
Bunshah Award for Best Paper in Structured Property, Research Symposium of the International Conference on Metallurgical Coatings (with J. Caola and G. Meier), 1986.
Bunshah Award for Best Paper in Coatings for Use at High Temperature Symposium of the International Conference on Metallurgical Coatings (with G.H. Meier), 1989.
Andrew Carnegie Lecture (Pittsburgh Chapter, ASM International), 1988.
Certificate of Commendation for Superior Performance by Office of Naval Research, 1989.
Edgar C. Bain Award for Valuable Contributions to the Metallurgical and Materials Professions, (Pittsburgh Chapter, ASM International), 1990.
William Kepler Whiteford Professor, University of Pittsburgh, September 1990-1992.
Board of Visitors Faculty Award, University of Pittsburgh, 1992.
Named to Faculty Honor Roll by Engineering Undergraduates, April 2000 and April 2001.
Outstanding Professor Award, selected by Students of Materials Science and Engineering Department, University of Pittsburgh, 1993 and 1997.

PROFESSIONAL SOCIETIES:

The Minerals, Metals and Materials Society of AIME
ASM International
The Electrochemical Society
Materials Research Society
Sigma Xi
Tau Beta Pi
American Association for the Advancement of Science
American Society for Engineering Education

PUBLICATIONS: Professor Pettit has authored more than 150 papers

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Prof. Thole received her Bachelors and Masters Degrees in Mechanical Engineering from the University of Illinois and Ph.D. from the University of Texas in 1992.

ACADEMIC EXPERIENCE

2003-present	Professor, Mechanical Engineering Department, Virginia Tech
2000-2003	Associate Professor, Mechanical Engineering Department, Virginia Tech
1999-2000	Assistant Professor, Mechanical Engineering Department, Virginia Tech
1994-1998	Assistant Professor, Mechanical Engineering Department, University of Wisconsin-Madison
1993-1994	Post-Doctoral Researcher, Institute of Thermal Turbomachinery, University of Karlsruhe, Germany

RECENT PUBLICATIONS

Kang, M., Kohli, A., and Thole, K. A., 1999, "Heat Transfer And Flowfield Measurements In The Leading Edge Region of A Stator Vane Endwall," *Journal of Turbomachinery*, vol. 121, pp. 558-568.

Hermanson, K., and Thole, K.A., 1999, "Effect of Inlet Profiles on Endwall Secondary Flows," *Journal of Propulsion and Power*, vol. 16, pp 286-296.

Kang, M., and Thole, K. A., 1999, "Flowfield Measurements in the Endwall Region of a Stator Vane," *Journal of Turbomachinery*, vol. 122, pp. 458-466.

Radomsky, R., and Thole, K. A., 2000, "High Freestream Turbulence Effects in the Endwall Leading Edge Region," *Journal of Turbomachinery*, vol. 122, pp. 699-708.

Radomsky, R. R. and Thole, K. A., 2002, "Detailed Boundary Layer Measurements on a Turbine Stator Vane at Elevated Freestream Turbulence Levels," *Journal of Turbomachinery*, vol. 124, pp. 107-118.

Thole, K. A., Radomsky, R., Kang, B., and Kohli, A., 2002, "Elevated Freestream Turbulence Effects on Heat Transfer for a Gas Turbine Vane," *International Journal of Heat and Fluid Flow*, vol. 23, pp. 137-147.

Zess, G. A. and Thole, K. A., 2002, "Computational Design and Experimental Evaluation of Using a Leading Edge Fillet on a Gas Turbine Vane," *Journal of Turbomachinery*, vol. 124, pp. 167-175.

Colban, W. F., Thole, K. A., and Zess, G., 2002, "Combustor-Turbine Interface Studies: Part 1: Endwall Measurements," *Journal of Turbomachinery*, vol. 125, pp.193-202.

Colban, W. F., Lethander, A. T., Thole, K. A., and Zess, G., 2002, "Combustor-Turbine Interface Studies: Part 2: Flow and Thermal Field Measurements," *Journal of Turbomachinery*, vol. 125, pp.203-209.

HONORS AND AWARDS

College of Engineering Faculty Fellow, Virginia Tech, 2003-2006
ADVANCE Professorship, 2003-2008
Ingersoll-Rand Faculty Award in Mechanical Engineering, Virginia Tech, 2001
W. M. Rohsenow Prize for Best Presentation for the Gas Turbine Heat Transfer Committee, 1997
National Science Foundation CAREER Award, 1996

RECENT EXTERNAL FUNDING SOURCES

Over $3M in funded research over the past 9 years including:
National Science Foundation – CAREER Award (1996-2000); ADVANCE Grant (2003-2008)
Department of Energy–University Turbine Systems Research Program (1997-2003)
United Technologies–Pratt & Whitney (1996-2002)
Modine Manufacturing (1999-2003)

Richard A. Wenglarz

EDUCATION: B.S., University of Illinois, Engineering Mechanics
M.S., University of Illinois, Engineering Mechanics
Ph.D., Stanford University, Engineering Mechanics

EXPERIENCE: South Carolina Institute for Energy Studies, 2000 – present
Rolls Royce/Allison Division of General Motors, 1984 – 2000
Westinghouse R&D Center, 1977 – 1984
Bell Telephone Laboratories, 1972 – 1977
Bellcomm, Inc., 1969 – 1972
University of Newcastle Upon Tyne, UK, 1968 – 1969

INVITED SEMINARS/PRESENTATIONS:

- Von Karman Institute for Fluid Dynamics, Brussels, Belgium, Particle Laden Flows and Blade Erosion, with W. Tabakoff and A. Hamed, 1988
- Yale University, New Haven, Prediction of Deposition and Erosion in Advanced Energy Systems, 1987
- Central Electricity Research Laboratories, Leatherhead, UK, simplified experiments to evaluate erosion in turbines, 1985
- Cambridge University, Cambridge, UK, analytical models to evaluate erosion in turbines, 1985
- Kentucky Energy Cabinet Laboratories, Lexington, Technology Advances for Direct Coal-Fired Turbines, 1987

PUBLICATIONS/PRESENTATIONS (concerning alternate fuels for turbines):

"Alternate Fuels for Land-Based Turbines," with I. G. Wright, Proceedings of Materials and Practices to Improve Resistance to Fuel Derived Environmental Drainage in Land and Sea Based Turbines, EPRI Report 1009173, October 2003.

"Coal/Biomass Fuels and the Gas Turbine," with M. DeCorso, et.al., ASME Paper 96-GT-76, 1996.

"Rugged ATS Turbines for Alternate Fuels," with N. Nirmalan and T. Daehler, ASME Paper 95-GT-73, 1995. Awarded Best Paper for 1995 by ASME Coal, Biomass, and Alternate Fuels Committee.

"ATS Turbine Modification for Coal and Biomass Fuels," with N. Nirmalan and T. Daehler, Proceedings of the Advanced Turbine Systems Conference, Washington, D.C., November 9-11, 1994.

"Advanced Coal-Fuel Gas Turbine Systems," DOE/MC/EDR 16707, 1994.

"Application of RQL Coal Combustor Technology to Large Utility Gas Turbines," with C. Wilkes, P. J. Hart, and H. C. Mongia, ASME Paper 93-GT-360, 1993.

"Direct Coal-Fired Turbines for Combined Cycle Plants," with P. J. Hart and H. C. Mongia, Proceedings of Advanced Turbine Systems/Fuel Cells and Coal-Fired Heat Engines Conference, Morgantown, West Virginia, August 3-5, 1993.

"An Approach for Evaluation of Gas Turbine Deposition," Journal of Engineering for Gas Turbines and Power, Vol. 114, pp. 230-234, April 1992.

"Coal-Water Slurry Testing of an Industrial Gas Turbine," with C. Wilkes, et. al., ASME Paper 92-GT-260, 1992.

"Materials and Components Issues in Coal Fired Gas Turbine Systems," with V. K. Sethi, Paper #92124, National Association of Corrosion Engineers, 1992.

"Particulate Control Methods for Coal-Fueled Gas Turbines," with C. Wilkes, American Institute of Chemical Engineers Spring Annual Conference, New Orleans, Louisiana, March 31-April 2, 1992.

"Economics of Particulate Control Methods for Coal-Fueled Gas Turbines," American Institute of Chemical Engineers Spring Annual Conference, New Orleans, Louisiana, March 31-April 2, 1992.

"Hot Gas Filtration for Advanced Coal-Fueled Gas Turbine Systems," Proc. of EPRI Workshop on Filtration of Dust, San Francisco, California, March 11-13, 1992.

"Second Generation Pressurized Fluidized Bed Combustion Small Gas Turbine Industrial Plant Study," with J. Shenker, et. al., DOE/MC/21023-3142, July 1992.

"Commercialization of Coal-Fueled Gas Turbine Systems," with C. Wilkes, Proceedings of Coal-Fueled Heat Engines, Advanced PFBC, and Gas Stream Cleanup Conference, Morgantown, West Virginia, October 27-28, 1992.

"Development of a Coal-Fired Gas Turbine Cogeneration System-Status Report," with C. Wilkes, et. al., Proceedings of Coal-Fueled Heat Engines, Advanced PFBC, and Gas Stream Cleanup Conference, Morgantown, West Virginia, October 27-28, 1992.

"Atypical Corrosion From Coal Water Fuels," with V. K. Sethi and R. Gonzalez, Materials at High Temperatures, Vol. 9, No. 3, pp. 145-152, August 1991.

"Emissions Control for a Coal-Fueled Industrial Cogeneration System," with C. Wilkes, Proceedings of the Eighth Annual Coal-Fueled Heat Engine and Gas Stream Cleanup Contractors Review Meeting, Morgantown, West Virginia, July 16-18, 1991.

"Commercialization of Coal-Fueled Gas Turbines," with C. Wilkes, Proceedings of the Eighth Annual Coal-Fueled Heat Engine and Gas Stream Cleanup Contractors Review Meeting, Morgantown, WV, July 16-18, 1991.

"Effects of Residual Carbon on Deposition in Coal-Fired Gas Turbines," with R. Logan and J. J. Scanlon, Proceedings of 200th ACS National Meeting, Vol. 35, No. 3, Washington, D.C., August 26-31, 1990.

"Physical Aspects of Deposition From Coal Water Fuels Under Gas Turbine Conditions," with R. Fox, ASME Journal of Engineering for Gas Turbines and Power, Vol. 112, January 1990. This and the following paper also appear in abridged form in Materials and Components in Fossil Energy Applications, No. 81, August 1989.

"Chemical Aspects of Deposition and Corrosion from Coal-Water Fuels Under Gas Turbine Conditions," with R. Fox, ASME Journal of Engineering for Gas Turbines and Power, Vol. 112, January 1990.

"Flyash Adhesion in Simulated Coal-Fired Gas Turbine Environment," with R. K. Ahluwalia and K. H. Im, ASME Journal of Engineering for Gas Turbines and Power, Vol. 111, October 1989.

"Particulate Flows and Blade Erosion," with W. Tabakoff and A. Hamed, von Karman Institute for Fluid Dynamics Lecture Series Publications, 1988.

"Materials Issues for Direct Coal-Fueled Turbines," Proceedings of Pittsburgh Coal Conference, Pittsburgh, Pennsylvania, September 28-October 2, 1987. Also appeared in abridged form in Materials and Components in Fossil Energy Applications, No. 72, February 1988 and in Coal Fuels Newsletter, Vol. 3, No. 11, November 1987.

"Advanced Coal-Fueled Gas Turbine Systems," with C. Wilkes, et. al., Proceedings of Heat Engine and Gas Stream Cleanup Systems Contractors Review Meeting, Morgantown, West Virginia, April 21-23, 1987.

"Turbine Deposition, Erosion and Corrosion Evaluations Using a Simplified Test Approach," ASME Paper 87-GT-214, 1987.

"Direct Coal-Fueled Combustion Turbines," ASME Paper 87-GT-269, 1987.

"Combustion of Coal Water Fuels Under Gas Turbine Conditions," Proceedings of 12th International Symposium on Slurry Technology, New Orleans, Louisiana, March 31-April 3, 1987.

"Gas Turbine Component Screening Program," with F. Ames, et. al., DOE Report No. DOE/MC/21394-2199, December 1986.

"Alternate Combustion Turbine Designs and Cleanup Systems for Pressurized Fluidized-Bed (PFBC) Power Plants," with T. Lippert and M. A. Alvin, EPRI Report CS-4860, October 1986.

"Gas Turbine Component Screening," with C. Wilkes, et. al., Proceedings of Third Annual Heat Engine Contractors Meeting, Morgantown, West Virginia, May 6-8, 1986.

"Coal-Derived Liquid Fuel Performance Under Gas Turbine Conditions," with P. Mulik, et. al., Energy Progress, Vo. 5, No. 3, September 1985.

"Combustion and Deposition, Erosion and Corrosion Tests of Coal Turbine Fuels," with C. Wilkes and D. Clark, ASME Paper 85-JPGC-GT-8.

"Deposition, Erosion, and Corrosion Protection for Coal-Fired Gas Turbines," ASME Paper 85-IGT-61, Presented at Beijing International Gas Turbine Symposium and Exposition, Beijing, China, September 1-7, 1985.

"Gas Turbine Component Screening," with C. Wilkes, et. al., Proceedings of Second Annual Heat Engine Contractors Meeting, Morgantown, West Virginia, April 29-May 1, 1985.

"Combustion Turbine Designs and Cleanup Systems for Pressurized Fluidized Bed Combustion Power Plants," with T. Lippert, Proceedings of EPRI Utility PFBC Conference, Williamsburg, Virginia, June 20, 1984.

"Combustion Turbine Design Guidelines Based on Deposition-Corrosion Considerations: Coal-Derived Liquid Studies," with P. R. Mulik, et. al., EPRI Report AP-2739, Vol. 2, June 1983.

"Low Temperature Turbines for Turbocharged Boiler Power Plants," with S. J. Drenker, ASME Paper 84-GT-209, 29th International Gas Turbine Conference, Amsterdam, Netherlands, June 3-7, 1984.

"Evaluation of Gasification and Gas Cleanup Processes for Use in Molten Carbonate Fuel Cell Power Plants," with E. J. Vidt, et. al., Final Report DE-AC21-81MC16220, 1983.

"Results of Ash Deposition Effects and Alleviation in Combustion Turbines," Conference on Combustion Turbine Systems Modification for Direct Coal Firing, Palo Alto, California, August 2-3, 1983.

"Erosion Considerations for Direct Coal-Fired Combustion Turbines," Conference on Combustion Turbine Systems Modifications for Direct Coal Firing, Palo Alto, California, August 2-3, 1983.

"Erosion Potential Resulting From Particulate Flow in a Multistage Turbomachine," ASME Fluids Engineering Conference, 18th Cavitation and Multiphase Flow Forum Proceedings, Houston, Texas, June 20-22, 1983.

"Combustion Turbine Design Guidelines Based on Deposition-Corrosion Considerations: Vol. 1: Residual Fuel Oil Studies," with T. P. Sherlock, et. al., EPRI Report AP-2739, February 1983.

"Turbine Deposition Evaluations Using Simplified Tests," with A. Cohn, Paper No. 83-GT-115.

"Evaluations of Particulate Fouling in Gas Turbines and Fuel Cells," Engineering Foundation International Conference on Fouling of Heat Exchange Surfaces, White Haven, Pennsylvania, October 31-November 5, 1982.

"An Assessment of Deposition for Power Plant Molten Carbonate Fuel Cells," 162nd Electrochemical Society Meeting, Detroit, Michigan, October 17-22, 1982.

"Corrosion and Deposition Results From Pressurized Passage Tests with Heavy Ash Bearing Fuels from the SRC II Process," with C. J. Spengler, G. A. Whitlow, S. Y. Lee, P. R. Mulik and A. Cohn, ASME Paper No. 83-GT-185.

"Evaluation of Gasification and Gas Cleanup Processes for Use in Molten Carbonate Fuel Cell Power Plants," with E. J. Vidt and M. A. Alvin, Proceedings of Second Annual Contractors Meeting on Contaminant Control in Hot Coal Derived Gas Streams, Morgantown, West Virginia, February 17-19, 1982.

"Boundary Layer Effects on Impingement and Erosion," ASME Fluids Engineering Conference, 17th Annual Cavitation and Poly-Phase Flow Forum Proceedings, St. Louis, Missouri, June 7-11, 1982.

"As Assessment of Erosion in PFBC Power Plant Turbines," with S. J. Schneider, ASME Paper No. 82-GT-194.

"Rugged Turbines for PFBC Power Plants," ASME Fluids Engineering Conference, Symposium on Particulate Laden Flows in Turbomachinery, St. Louis, Missouri, June 7-11, 1982.

"An Assessment of Corrosion/Deposition Potential for PFBC Power Plant Turbines," with M. A. Alvin, Seventh International Conference on Fluidized Bed Combustion, Philadelphia, Pennsylvania, October 25-27, 1982.

"Combustion Turbine Deposition Observations From Residual and Simulated Residual Oil Studies," with G. A. Whitlow, et. al., ASME Paper No. 82-GT-87.

"The High Temperature Combustion of Residual Fuel Oil – Some Deposition Product Considerations," with G. A. Whitlow, et. al., Proceedings of the Second Conference on Advanced Materials for Alternative-Fuel-Capable Heat Engines, Monterey, California, August 24-28, 1981.

"Predictions of Combustion Turbine Performance in Pressurized Fluidized-Bed Combustion Power Plants," with M. A. Alvin and S. J. Schneider, EPRI Report No. CS-1845, May 1981.

"Erosion Response for a Turbine Alloy and Its Oxide Scale," with W. Tabakoff, ASTM Symposium on Industrial Methods for Testing in High Temperature Environments, Phoenix, Arizona, May 12, 1981. Also in the ASTM Journal of Testing and Evaluation, Vol. 10, No. 6, November 1982, pp. 298-302.

"Use of Cascade and Small Turbine Tests to Determine Erosion of Utility Turbines," with M. Menguturk, Trans. of the ASME, Journal of Engineering for Power, Vol. 104, No. 1, January 1982, pp. 58-63.

"An Assessment of Deposition in PFBC Power Plant Turbines," Trans. Of the ASME, Journal of Engineering for Power, Vol. 103, No. 3, July 1981, pp. 552-560.

"Pressurized Fluid-Bed Combustor-Gas Cleaning-Turbine Systems Integration for Economic Electric Energy Cost," with D. L. Keairns, et. al., 6th International Conference on Fluidized Bed Combustion, Atlanta, Georgia, April 1980.

"Modeling of Turbine Flow Path Degradations Due to Particle Laden Expansion Gases," with E. F. Sverdrup, Workshop on Mechanisms of Erosion in Hot Flowing Media, Ft. Meyers, Florida, May 1978.