ITEM NO.: 5
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STAFF EVALUATION OF A DRAFT RESEARCH FINAL REPORT

TITLE:	Energy Efficient, Ultra-Low-NO_x Industrial Gas Burners
CONTRACTOR:	University of California, Irvine (UCI)
PRINCIPAL INVESTIGATOR:	G. Scott Samuelsen
AMOUNT:	$225,000
DURATION:	36 months

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I. SUMMARY

The State Implementation Plan requires significant reductions in nitrogen oxides (NO_x) emissions. This study developed and demonstrated technologies for the energy-efficient operation of natural gas burners, with an emissions target of single-digit part-per-million (ppm) nitric oxide (NO) levels. Emissions of carbon monoxide, total hydrocarbon, and air toxics were minimized. The technologies developed included optical diagnostic techniques to measure temperature and species in the burner flame; a numerical code to incorporate a mixing model and chemical kinetic models; active control methods to achieve ultra-low-NO_x performance in practical systems; and robust sensors for these active control methods. The usual technologies to achieve very low levels of NO_x from combustion sources, such as selective catalytic reduction and selective non-catalytic reduction, are very expensive. Industry will be able to use the results of this study to develop cheaper technologies to achieve similar levels of NO_x reduction from natural-gas-fired boilers.

II. TECHNICAL SUMMARY

Objective

The objective of this study was to develop and demonstrate technologies for the energy-efficient operation of natural gas burners, capable of achieving ultra-low emissions of NO_x, while minimizing the emissions of CO, total hydrocarbons, and air toxics.

Background

Future industrial burners may need to achieve extremely low levels of NO_x and CO emissions. The development of ultra-low-NO_x burners demands a detailed understanding of the NO_x formation processes within the burner. These burners must be reliable, inexpensive, suitable for a range of industrial applications, and equipped with combustion control devices. Reductions in the emissions of NO_x from gas-fired boilers are characteristically associated with decreases in combustion efficiency and increases in CO emissions. Although there has been a substantial reduction in the emissions of NO_x from gas-fired burners, this reduction has been accomplished by an empirical approach that appears to be near its limit.

In 1990, the California Institute for Energy Efficiency (CIEE) established a program to investigate the feasibility of attaining low levels of NO_x and CO in industrial burners and assess the viability of active control. In this study, UCI cooperated with industry in the development of ultra-low-NO_x burner technologies. Two key burner manufacturers were selected to work with the academic team: Coen Company and Maxon Burner Company. They were involved in both the design and experimental stages of the technologies. During this program, UCI demonstrated that rapid mixing of fuel and air provided low NO_x and low CO emissions in a model industrial, natural gas-fired burner. A proof-of-concept active control demonstration was also completed. UCI then developed tools for the design of systems to operate burners with ultra-low NO_x emissions.

Project Summary

This project consisted of two tasks: (1) technology development and support research on a small-scale model burner, and (2) application of the resulting information to large-scale boiler and furnace simulators. The second task also provided support and guidance input for practical burner applications and demonstrations.

Task 1 - Technology Development and Support Research

Task 1 continued and expanded on the previous study (see Background above). Measurements and modeling were conducted on a laboratory-scale, generic industrial burner. Parametric variations and exhaust emissions measurements were conducted to determine relationships between input parameters and low-emissions performance. This involved tests to develop a better understanding of the effect of fuel-air mixing on burner flame stability, NO_x formation, combustion efficiency, and overall thermal efficiency. UCI also evaluated air toxic by-products of NO_x control.

UCI developed:

- numerical modeling codes to better understand observations from the burner tests
- an in-situ optical diagnostic technique to measure temperature and species profiles in the flame
- an active burner control system to achieve low emissions, system efficiency, and stability
- robust sensors for the active control system.

In general, UCI studied the aerodynamic, chemistry, heat, and mass transfer mechanisms needed for ultra-low-NO_x emissions. Relationships were found between input parameters (e.g., fuel jet velocity and swirling air velocity), fuel-air mixing, and performance. Counter-swirl fuel injection provided the fastest mixing prior to reaction, and achieved the best performance at higher excess air levels.

Task 2 - Boiler and Furnace Simulators

For Task 2, two ultra-low-NO_x simulators were developed and demonstrated to test and evaluate two specific burner applications: boiler burners and high temperature burners. UCI teamed with industrial burner manufacturers to develop and test burner strategies for low NO_x emissions and control. The boiler burner partner was Coen Company, and the high temperature burner partner was Maxon Corporation. Both manufacturers provided the actual hardware that was tested. The objective was to achieve ultra-low-NO_x emissions and high system efficiency, in combination with active control and a minimum of air toxics emissions.

Task 2A - Coen Boiler Simulator

The small-scale burner was tested in the facility and shown to exhibit the same characteristics of the large-scale, commercial burners. This validated the test facility for working on smaller-scale burners with the intent of scaling up to commercial sizes. The staged burner concept was found to be unsuited for ultra-low NOx emissions without the addition of flue gas or another diluent. Coen is now pursuing other burner strategies for further reducing NO_x emissions.

Task 2B - Maxon High Temperature Burner

High-temperature combustion inherently produces high levels of NO_x. One solution is to design burners with geometric parameters that optimize the degree of fuel and air mixing. These geometric parameters include tip geometry, fuel jet effective area, fuel jet injection location, air swirl, number of jets, and jet swirl. UCI built a new furnace test facility and modularized a Maxon industrial burner to investigate the effect of burner geometric parameters. They established a closed-loop, feed-forward control scheme for the Maxon burner. Tests to simulate a high-temperature furnace application revealed no significant effect on NO_x emissions, despite a wide variation in range for a number of geometric parameters.

III. STAFF COMMENTS

This draft final report was reviewed by staff from the Research Division and the Stationary Source Division, as well as by faculty at the University of California, Davis. UCI also received funding for this project from the SCAQMD and the CIEE. Although all three contracts expire by the end of this fiscal year, SCAQMD and CIEE have not yet received their draft final reports. ARB staff would like to update the Research Screening Committee at its next meeting on project reviews by these agencies and by staff from the California Energy Commission.

Overall, this is a very thorough report with excellent figures and graphics that explain the results. UCI conducted a sound study, with careful measurements. The techniques are state of the art and appropriate for the problem at hand. The results should be useful to develop advanced technologies for achieving ultra-low-NO_x emissions.

The first task provided important information. NO_x and CO emissions are usually hard to control simultaneously, but UCI determined how to optimize performance based on burner geometry. It is an important finding that a counter-swirl configuration offers the most rapid mixing, and thereby the best performance. Additional measurements may reveal why this approach is able to simultaneously control NO_x and CO. In order to enhance the applicability of the proposed design, it may be useful to study the interaction of chemistry with fluid dynamics and conduct further computational fluid dynamic modeling.

Overall, the results may help manufacturers develop natural-gas-fired burners with ultra-low-NO_x emissions. However, the second task was focused on particular company designs, meaning that the results may be of limited general use. This is because the design of burner components, such as quarls, is very specific to each company's design.

Specific Comments:

Although staff believes that the report was well written, a few errors have been noted and should be corrected. Given the number of figures and tables, it would be helpful to provide lists of figures and tables as part of the Table of Contents. Because SCAQMD helped to fund this project, the disclaimer language should refer to the AQMD as well as the ARB. In addition, due to legislative requirements specific to the AQMD, the summary must include the following:

- Comparative assessment of results achieved versus expected results or objectives
- A brief discussion of any problems encountered during the project and how they were resolved
- Comparative assessment of actual costs of project to AQMD (and project in general) versus budgeted costs (e.g., cost overruns or savings).
- The report should contain a list of frequently used abbreviations (e.g., 'S' for "input swirl intensity") and a Table of Figures.
- Figures 6.10 through 6.14 are missing (pages 26-39) and should be provided.
- Although the executive summary and "goals and objectives" section both refer to three tasks, the Table of Contents refers to two tasks. Apparently, Task 3 has been folded into Task 2. The final report should have a consistent organization.
- The introduction should mention other low NO_x systems, such as the Alzeta's radiant burner, Catalytica's catalytic burner, and Altex's low-NO_x burner. Comparisons would be helpful.
- Although this project focused on optimizing and controlling the burner parameters, suggestions were made to address thermal environment effects and diluent addition (FGR). These parameters should be discussed, with language that suggests that trends probably would not change significantly, but that absolute values may vary from real-world applications. Also, it should be noted that FGR could affect stability, especially at the high levels currently used to achieve single digit NO_x in boiler applications.
- Page 5, Table 3.1 National and California Ambient Air Quality Standards. The intent of this table is unclear, but it appears to compare ambient air quality standards and emission standards (BACT). If so, emission standards for burners

should be listed. The appropriate AQMD rules would include 1146, 1146.1, and 1146.2 for boilers. Also, related text on page 4 (last paragraph) references a "Table 1". Should this Table list the NOx and CO limits for different classes of industrial burners?

- Page 29, Figure 6.3 illustrates f(NOx) and g(n). Language should be added that these are somewhat arbitrary functions for illustration of a performance index that could be developed for advanced control algorithms. Due to SCAQMD rules, few (if any) burners operate above 30 ppm NOx, and none are permitted above 40 ppm, which is the highest boiler burner standard. As other discussion in the report notes, the competition consists of aftertreatment technologies that achieve <5 ppm NOx.
- Similarly, the discussion on active control should also be qualified, stating that the weightings of the control parameters are arbitrary for purpose of illustrating the potential for control algorithms. For example on page 52, NOx, combustion efficiency, and system efficiency were equally weighted. A preferred weighting of the control function would favor NOx instead of efficiency, since emissions are regulated and end users are required to meet these regulations or risk enforcement actions.
- Page 46, Table 6.1. The "Results Summary" introduces the phrase "squeezing" without prior explanation in the text. This needs to be remedied. One option is to insert this table after page 47, which has a limited description of what is meant by squeezing. The other option would be to describe the concept of squeezing on page 45. Note that on page 45, the last paragraph of text refers to Table 8. Should this be Table 6.1?
- Section 9 - Hazardous Air Pollutants and Ozone Precursors should specify the limits of detection for each of the substances subjected to analysis. Only in this way would references to 'not detected' be meaningful.

IV. STAFF RECOMMENDATIONS

Staff recommends the Research Screening Committee accept this draft final report, subject to inclusion of appropriate additions and revisions in response to the staff comments, and any changes and additions specified by the Committee.