BNL-52625
Formal Report

PROCEEDINGS OF THE 2001 NATIONAL OILHEAT RESEARCH ALLIANCE TECHNOLOGY CONFERENCE

Held at
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973-5000
APRIL 30 - MAY 1

Editor
Roger J. McDonald

April 2001

Sponsored by the

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UNDER CONTRACT NO. DE-AC02-98CH10886 WITH THE
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CONFERENCE DEDICATION

The 2001 National Oilheat Research Alliance Technology Conference is dedicated to the spirit and efforts of Oilheat Industry and its members who have worked so hard with unwavering vision for the last six years to make NORA a true reality in this new millennium with bright anticipation for the future of the oilheat.

ACKNOWLEDGMENTS

The 2001 National Oilheat Research Alliance Technology Conference required the dedicated effort of many people to make it successful. The editor of this report would like first to thank the authors for their efforts and splendid cooperation in submitting papers promptly. The BNL staff also wishes to recognize the contributions to our work by our U.S. DOE program manager, Ronald Fiskum, and thank him for his leadership. The editor also greatly acknowledges the hard work and effort required by the entire BNL program staff to make this meeting a success. Most of all the staff at BNL wish to thank all of our 2001 National Oilheat Research Alliance Technology Conference co-sponsors and participants for their active participation.

PMAA PETROLEUM MARKETERS ASSOCIATION OF AMERICA
1901 N. FORT MYER ST. ■ SUITE 1200 ■ ARLINGTON, VA 22209 ■ 703-351-8000

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I. INTRODUCTION

The 2001 National Oilheat Research Alliance Technology Conference, April 30 – May 1, held at Brookhaven National Laboratory (BNL), is sponsored by the **United States Department of Energy, Office of Power Technology (US DOE/OPT)** and the **Petroleum Marketers Association of America.** The meeting is also co-sponsored by the:

New York State Energy Research & Development Authorityy
New England Fuel Institute
National Association of Oil Heat Service Managers
Fuel Merchants Association of New Jersey
Pennsylvania Petroleum Association
Empire State Petroleum Association
New York Oil Heating Association
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Oil Heat Institute of Eastern New York
Oil Fuel Institute of Central New York
Hudson Valley Oil Heat Council
Brookhaven Science Associates

BNL is proud to acknowledge all of our 2001 sponsors, with their help and support this has correctly become an oilheat industry conference. It is quite gratifying to see an industry come together to help support an activity like the technology conference, for the benefit of the industry as a whole and to celebrate the beginning of the National Oilheat Research Alliance.

This meeting is the fourteenth oil heat industry technology conference to be held since 1984 and the first under a new name, NORA, the National Oilheat research Alliance, and the very first in the new century. The conference is a very important part of the effort in technology transfer, which is supported by the Oilheat Research Program. The Oilheat Research Program at BNL is under the newly assigned program management at the Office of Power Technology within the US DOE. The foremost reason for the conference is to provide a platform for the exchange of information and perspectives among international researchers, engineers, manufacturers, service technicians, and marketers of oil-fired space-conditioning equipment. The conference provides a conduit by which information and ideas can be exchanged to examine present technologies, as well as helping to develop the future course for oil heating advancement. These conferences also serve as a stage for unifying government representatives, researchers, fuel oil marketers, and other members of the oil-heat industry in addressing technology advancements in this important energy use sector. The specific objectives of the conference are to:

- Identify and evaluate the current state-of-the-art and recommend new initiatives for higher efficiency, a cleaner environment, and to satisfy consumer needs cost-effectively, reliably, and safely;
- Foster cooperative interactions among federal and industrial representatives for the common goal of sustained economic growth and energy security via energy conservation.

Introductory remarks will be provided by William "Bill" Horak, Ph.D. Chairman, Department of Energy Sciences and Technology, BNL, who will welcome the assembly on behalf of Brookhaven National Laboratory. Dr. Horak will emphasize BNL's continued commitment to advancing oil heat technology and effecting technology transfer to the private sector. John Huber, the new President of the National Oilheat Research Alliance and former Vice President & Chief Counsel, of the Petroleum Marketers Association of America (PMAA), will follow by welcoming the participants on behalf of NORA and PMAA and presenting his views on the subject and then he will introduce the Master of Ceremonies, Richard Mohrfeld, current Chairman of the PMAA Heating Fuels Committee. Mr. Mohrfeld will introduce the Keynote Address, which will be given by Mr. Jack Sullivan, Executive Vice-President and CEO of the New England Fuel Institute.

Seventeen technical presentations will be made during the two-day program, all related to oil-heat technology and equipment, these will cover a range of research, developmental, and demonstration activities being conducted within the United States and Europe, including:

- High-flow Fan Atomization Burner (HFAB) Development and Field Trials
- Field Test of the Flame Quality Monitor
- NORA/DOE/ BNL Oilheat Five-Year Research Plan
- US Department of Energy's Building Cooling Heating and Power for Buildings Program
- NORA Education Committee Report
- Marketing Oil Heat in Europe: A study in contrasts
- Diagnosing Burner Problems with Recorded Data "The solution to any problem is obvious...once it is found"
- Variable Firing Rate Oil Burner Using Pulse Fuel Flow Control
- Oil-Fired Hydronic Heating Appliances with Reduced Electric Power Consumption and Battery Backup
- Peep Into The Nozzle Using Computational Fluid Dynamics
- Results of a Parametric Investigation of Spray Characteristics Using a HFAB Type Atomizer
- Progression and Improvements in the Design of Blue-flame Oil Burners
- Biodiesel as a Heating Oil Blend Stock
- Lab Tests of Biodiesel Blends in Residential Heating Equipment
- Alternative Fuel Oils and the Effect of Selected Properties in Combustion
- New York State Premium Low-Sulfur Heating Fuel Marketplace Demonstration
- The Need for a New Fuel Oil Stability Specification

Adjournment

Following the final group of technical presentations the formal portion of the conference will be concluded with brief closing remarks by Roger McDonald, editor, conference organizer and senior program manger for the Combustion Equipment Technology (Oilheat R&D) program. Following the conference there will be an additional opportunity to tour the Oilheat Research Laboratory at BNL.

Oilheat Research Laboratory

During the scheduled open house time periods, before and after the formal conference sessions, conference participants will be welcome to visit the BNL Oilheat Research Laboratory located in Building 526 which is currently being equipped with new instrumentation. Equipment demonstrations of some of the advanced oil-fired heating systems under development at BNL will be available depending on available time constraints imposed by the recent renovation activities. BNL will also provide numerous visual displays based on prior and ongoing research related to Oilheat Research.

II. Technical Presentations

Paper No. 01-01

High-flow Fan Atomization Burner (HFAB) Development and Field Trials

Thomas Butcher, Ph.D., Yusuf Celebi and George Wei

Brookhaven National Laboratory
Department of Energy Sciences and Technology
Energy Resources Division
Oilheat Research
12 North Sixth St.
Upton, NY 11973
631-344-7916
butcher@bnl.gov

High-flow Fan Atomization Burner (HFAB) Development and Field Trials

Thomas Butcher, Ph.D., Yusuf Celebi and George Wei, BNL

BNL has been actively developing burner concepts based on low-pressure, air atomization. Our interest is to make technology available which can lead to burners on the market with substantial performance improvements, including:

- Low firing rates
- Low excess air/high efficiency
- Modulating or two-stage firing rates
- Low NO_x emissions
- Low electric power consumption

This paper provides a summary of the current system configuring, results of recent field tests, and work-in-progress on advancements.

Current System Description

In the past, we have demonstrated basic combustion performance with this concept, and recent work has involved improvements to our burner prototype and field testing. Through this process we decided to focus on a single firing rate –0.35 gph; to simplify the development process. This rate was chosen for two reasons: 1) it is beyond the range of conventional pressure atomized burner and 2) this firing rate matches design heating load in many homes.

Figure 1 show the air tube and flame tube arrangement in the current prototype system. All of the air enters a 1 ½" o.d. tube which runs the length of the air tube. Most of this air passes through the atomizer and forms the spray. Air pressure is 6" H_2O (1500 Pa). A small fraction of the air ("secondary air") passes outward through radial holes in the center tube into the air tube. This secondary air serves two purposes: 1) it puts more air into the combustion zone to allow higher firing rates without increasing the nozzle diameter and 2) it provides a small air flow through the annular space between the nozzle and the air tube walls to keep the electrodes cool and prevent backflow of combustion products. When configured in this way, the burner has become termed the High Flow Air-Atomizer Burner or "HFAB".

The flame tube in front of the nozzle controls the rate and physical distribution of exhaust products recirculated from the combustion chamber into the flame zone. High recirculation rates lead to low NO_x emissions and transparent or blue flames. The burner has been developed with a yellow flame to enable use with a conventional primary control with cad cell flame sensors. While NO_x levels depend on the specific boiler or furnace, the current HFAB configuration produces 55ppm NO_x @ 3% O_2 in a typical steel boiler. This level is about 40% lower than the conventional retention head burner operating at 0.6 gph in the same boiler. The HFAB uses a microprocessor-based primary control with pre- and post-purge features and interrupted ignition. This control recognizes a flame with a cad cell resistance of approximately 5000 ohms. In steady state

the cad cell resistance as configured with the HFAB is about 500 ohms and this is easily "seen" by any conventional control. A brushless motor/blower integrated set is currently used to supply all air to the burner. This has a 7.3 inch diameter, 4-inch height and an electric power draw of 39 watts at operating conditions. This unit has 110V AC direct input and integral motor electronics.

The fuel pump used is separate from the fan. It is pulsed solenoid pump with an integral pressure regulator and bleed valve. The pump can "dry lift" about 8 feet and has a maximum pressure of 30 psi. As configured in the HFAB, the pump's regulator is set for 20 psi. In the nozzle the fuel pressure required for good atomization and combustion is much lower – about 1psi. between the pump and the nozzle there is an orifice to control the firing rate. The system is configured with higher pressure and the orifice to assure reliable operation of the pressure regulator and to reduce sensitivity to fuel line/filter blockage. Total power draw of the operating burner is 53 watts, which is considerably lower than the best current pressure atomized, retention head burner which is approximately 150 watts.

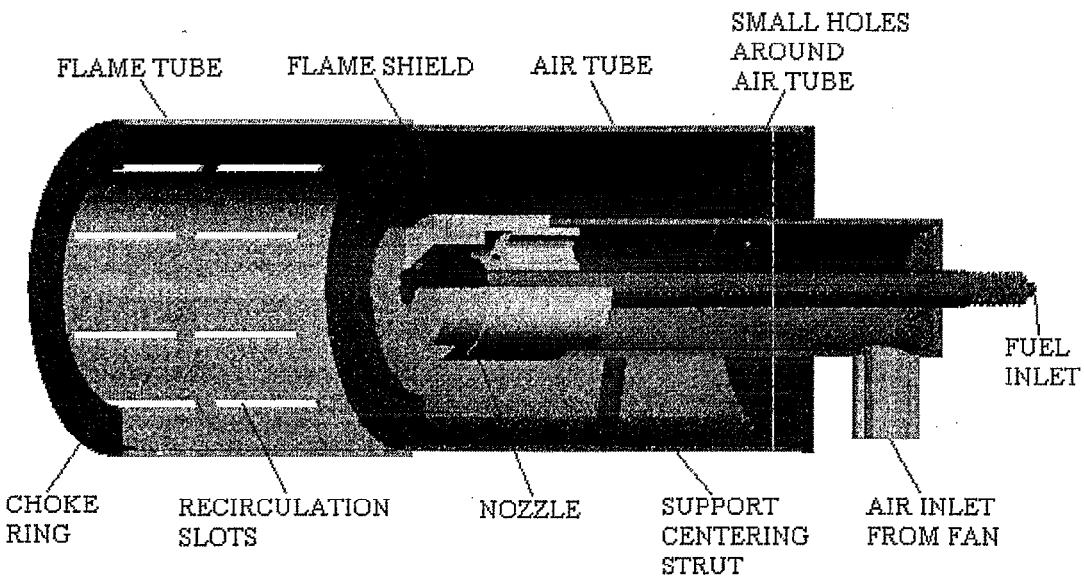

Figure 1 Illustration of the HFAB burner head

Field Tests Description

The purposes of the field tests are to: 1) evaluate the ability of the HFAB to meet the homes domestic hot water and space heating needs with such a low firing rate, and 2) to identify areas where improvements are needed.

The field tests were conducted in a typical ranch home, housing 2 adults and 4 children. The boiler is a typical steel boiler with a horizontal fire-tube heat exchanger, chimney vented with no barometer damper. The vent is a single story, outside brick chimney. Domestic hot water at this home is provided from a 40 gallon indirect tank, treated as a

priority zone. The boiler is operated in a cold start mode. During the tests, a data acquisition system was installed at the site to measure key system temperatures.

Field Test Results

Tests were conducted with the burner in the field for separate time intervals during the 2000/2001 heating season. Typically excess air was 25%, CO was under 5 ppm, and smoke number was zero. With the HFAB flue gas temperature varied, of course, with time from start and boiler water temperature. Figure 2 provides a comparison of the flue gas temperature with the HFAB burner and a conventional retention head burner at 0.75 gph. No problems with condensation in the chimney were noted during the test period. Steady state efficiency with the HFAB is 88% which can be compared with 84% with the higher firing rate burner.

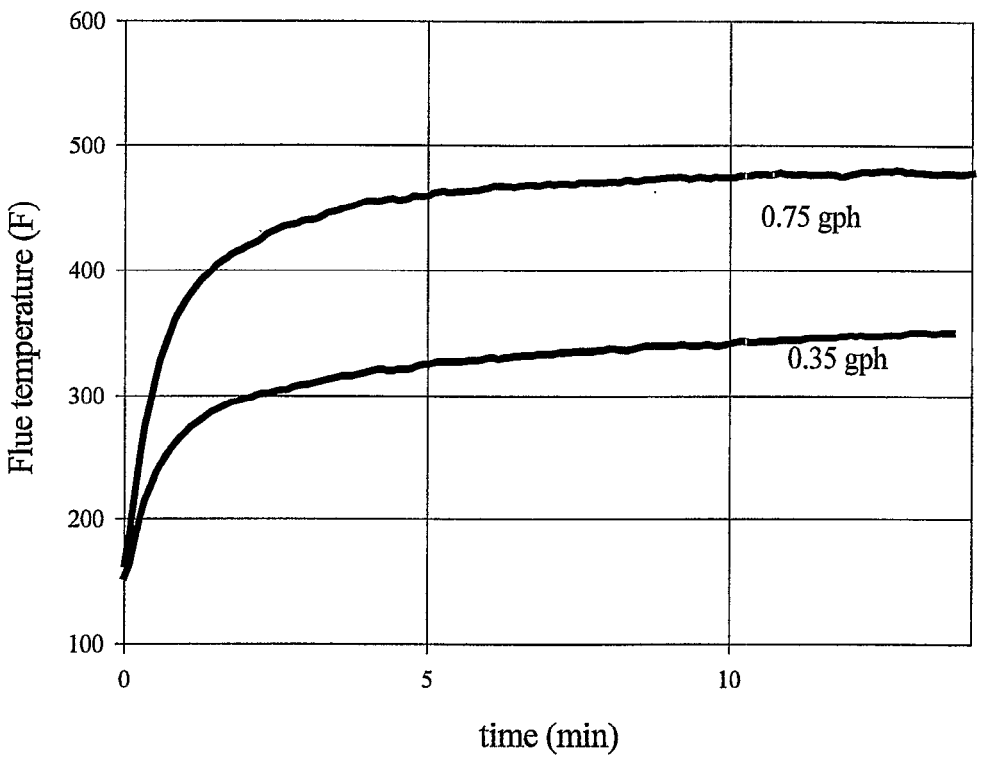

Figure 2. Flue gas temperature trend during startup. Comparison of conventional (0.75 gph) and low firing rate HFAB (0.35 gph) burners.

In comparing the HFAB with the higher firing rate burner, one very obvious difference is in cycling rate. Figure 3 shows a comparison of cycling patterns, as indicated by flue gas temperature for the two burners over two similar winter night-time periods.

In evaluating the ability of the burner to meet the heat demand of the house, the burner input could be compared to results of a heat loss calculation for the home. As an

alternative, the input could be compared to the heat-delivery capacity of the installed baseboard radiators and this is seen as a better measure of the ideal burner input rate. If the burner rated input matched the delivery capacity of the baseboards, the burner in a simple, single zone home would cycle only once every time the home thermostat called

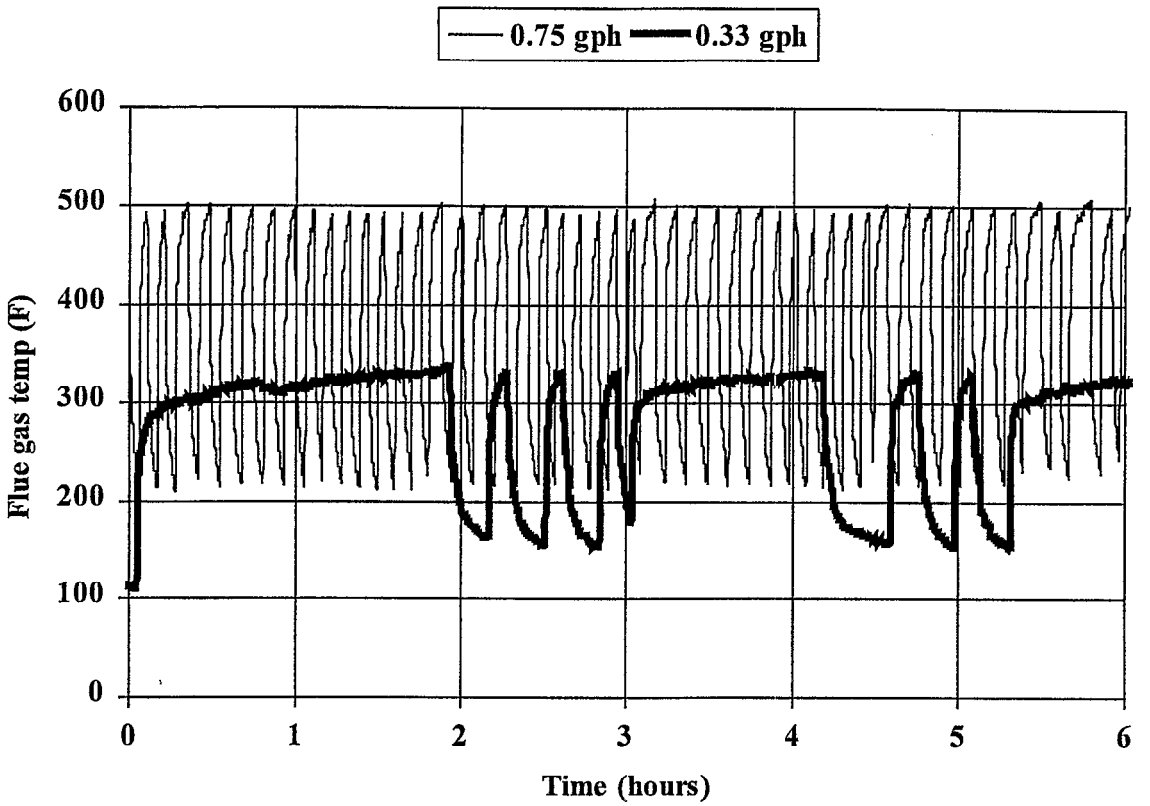

Figure 3. Comparison of cycling patterns on two similar cold nights. Conventional retention head burner at 0.75 gph and HFAB at 0.35 gph.

for heat. If the capacity of the hydronic system is smaller than the heat load of the house increasing firing rate will not provide more heating capacity but only increase cycling rate. In a more typical case, the capacity of the baseboard exceeds the design heat load and sizing the burner based on this, for heating, is conservative.

Two simple methods could be used to estimate hydronic system delivery capacity. In the first, the total length of baseboard is measured, and this is multiplied by rated delivery per foot of installed length. This number depends upon average temperature but 400 BTU/ft hr might be used as typical. The second method involves a measurement in which all zones are made to call for heat and the cycling pattern of the burner in response to this is measured.

This cycling test might be started after the house has been cooled. A measurement period of approximately 1-hour is suggested. Cycling patterns could be determined manually or using a simple flue gas temperature recorder. If the home has programmable thermostats they can all be set to recover at the same time in the morning and the cycling pattern can be measured during this recovery period. To estimate hydronic system capacity, the following information is needed:

η - Steady state combustion efficiency
f - Burner fractional on-time during the test period
Q - Firing rate (gal/hour)

With these, hydronic system capacity can be estimated as:

$$HC = \frac{Q \cdot \eta \cdot f \cdot 140{,}000}{100}$$

where HC = capacity in BTU/hr.

Boiler jacket loses have not been included here with the assumption that these contribute heat to the home and are considered part of the hydronic capacity.

The test house has 4 zones. Based on installed length of baseboard, capacity is estimated to be 70,000 Btu/hr. Based on the burner cycling test, the estimated capacity is 52,000. From the measured capacity the ideal firing rate for this home would be about 0.42 gph, again, based only on heating needs.

During the course of this test period outdoor design temperatures (7 F) were not reached. The lowest outdoor temperature observed was about 12 F, and no problems in meeting house heat demand were observed.

In earlier studies of the efficiency of hydronic distribution systems by BNL the capacity of the hydronic system in 3 other homes was measured using a different test procedure [1]. Table 1 summarizes these results in terms of measured capacity at the as-found boiler water set temperature and the corresponding ideal firing rate for heating. A boiler system efficiency of 85% was assumed to calculate the ideal firing rate.

Table 1. Results of Measured Hydronic System Capacity in Selected Homes (data from [1])

Home Description	Supply Temp (F)	Capacity (BTU/hr)	Ideal Firing Rate (gph)
small ranch	181	10,900	0.10
typical ranch	178	18,100	0.15
colonial	196	51,300	0.43

These results show essentially that the home heating load can be well met with a fairly low firing rate and this is generally accepted. The greater need for firing rate is seen in

domestic hot water. As would be expected, and as prior BNL tests have shown [2], reducing firing rate directly reduces hot water capacity in terms of first hour rating. During the test period measurements were made to evaluate the practical impacts of reduced firing rate on the ability of the system to meet actual home hot water demand. Under ideal conditions the indirect tank would provide hot water above some nominal temperature every time the house called for it. Based on DOE test procedures we have taken 110 F as the minimum acceptable domestic hot water supply temperature. To evaluate the "quality" of the domestic hot water supply a flow meter and supply temperature measurement are needed. However, installing a flow meter requires cutting into the system and for the purposes of this work an alternative approach was taken. A set of three surface thermocouples were installed on the hot water supply system. One right at the top of the tank, a second 18 inches from the tank outlet, and the third about 4 feet from the tank outlet. All of these are attached to the outer surface of the domestic hot water pipe. By observing the patterns of these sensors it can easily be determined when a domestic hot water call is in progress and the supply temperature.

Under nearly all conditions, with both low and high firing rates the results indicate that the system easily meets the demand, providing hot water at temperatures over 110 F. With the low firing rate burner the supply water temperature decreased below acceptable levels only when there was a large laundry load. Figure 4 shows the results measured during this time. This figure includes three separate charts over the same time period. The top is the temperature measured right at the tank. The middle chart shows the temperature measured on the domestic hot water line 18 inches from the tank, and the bottom shows the temperature measured 48 inches from the tank. Marked on the bottom chart are times when hot water draws occurred. When there is no draw in progress the measured temperature at this point drops over time in a very repeatable way. During draw periods the temperature at this point may be increasing, steady, or decreasing very sharply as the temperature at the tank top decreases.

In general the results of the field tests have been very positive and indicate that the burner can meet the heat and hot water demand quite well for nearly all conditions. Improvements are still required with the burner to enable operation at the lowest excess air levels without coke deposits accumulating over time within the flame tube. This work is in progress but the HFAB concept appears to offer a very interesting low firing rate option.

Also in progress is the development of a two stage version of this burner and a matched smart control system. This work is being done under a collaboration between BNL, Insight Technologies, and Heat Wise, Inc. and is sponsored by the U.S. Department of Energy and New York State Energy Research and Development Authority. The burner prototype as currently configured operates between 0.38 and 0.55 gph. At present a prototype system has been built and preliminary field trials of the burner and control started. The system starts and then operates in either low or high fire based on the controls assessment of current need. The prototype is being refined and developed towards commercialization. The commercial version envisioned will have a higher turndown ratio.

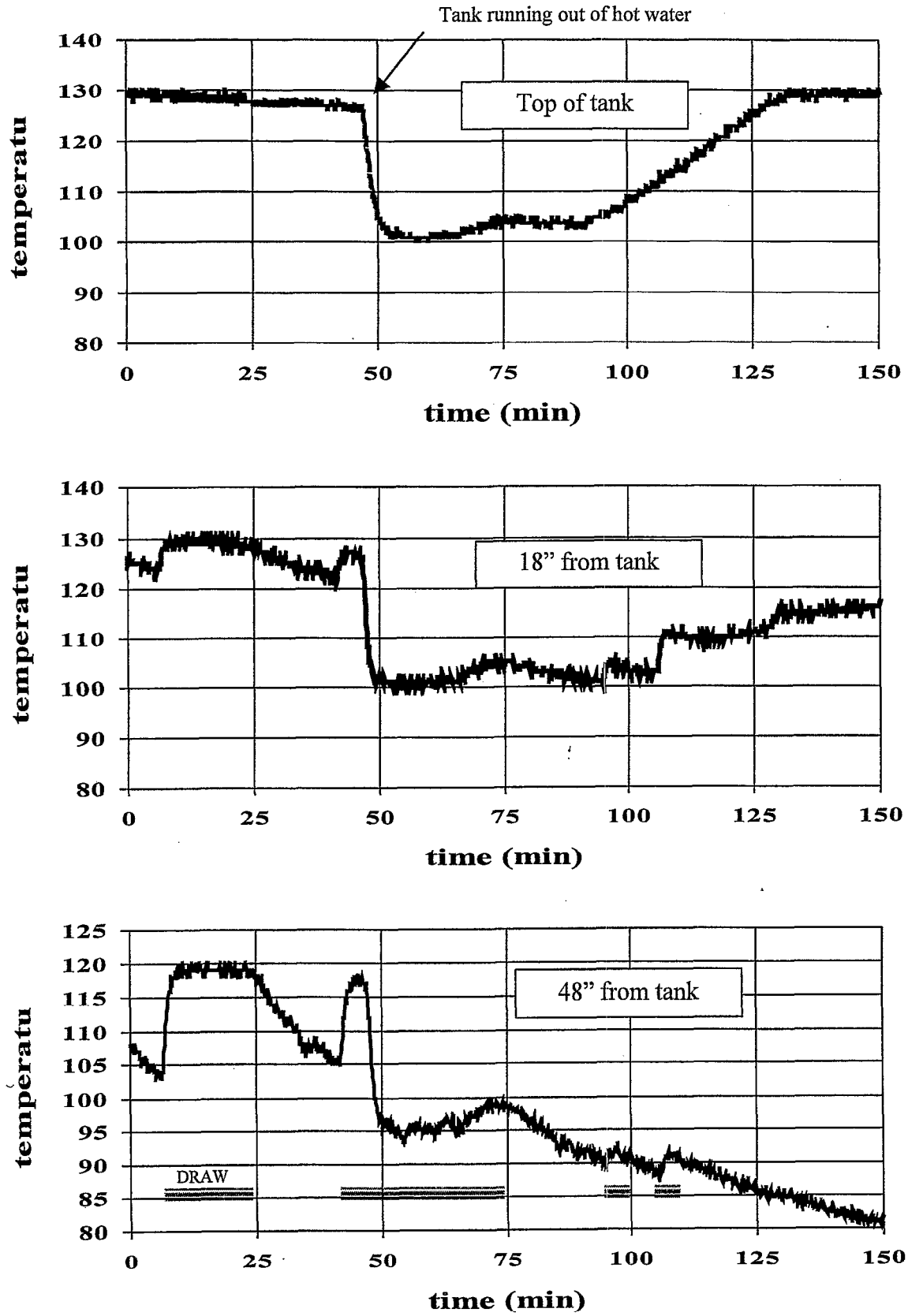

Figure 4. Results of study of domestic hot water delivery with low firing rate, HFAB burner.

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1. Andrews, J.A. Brookhaven National Laboratory, personal communication.

2. Butcher, T., Krajewski, R., Leigh, R. Celebi, Y., Fisher, L., and Kamath, B. Residential oil burners with low input and two-stage firing. ASHRAE Transactions 1997, V. 103, Pt. 1.

Paper No. 01-02

Field Test of the Flame Quality Monitor

Henry E.Troost, PE, Honeywell International, Thomas Butcher, PhD, Brookhaven National Laboratory, and Andrew M. Rudin, Insight Technologies, Inc.

Henry E. Troost
Honeywell International
1985 Douglas Dr. N.
Golden Valley, MN 55422
763-954-6581
henry.troost@honeywell.com

Thomas Butcher
Brookhaven National Laboratory
Department of Energy Sciences and Technology
Energy Resources Division
Oilheat Research
12 North Sixth St.
Upton, NY 11973
631-344-7916
butcher@bnl.gov

Andrew M. Rudin
Insight Technologies, Inc.
1150 Walnut Ave.
Bohemia, NY 11716
800-424-3484
arudin@insighttechnologies.net

Disclaimer: This presentation was prepared with the support of the U.S. Department of Energy, under Award No. DE-FC26-00NT40994. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of the DOE.

Abstract

This presentation provides an overview of the development and current commercial implementation of the Flame Quality Indicator concept developed at Brookhaven National Laboratory. The paper also describes an on-going field study of this new product. This field test is sponsored by the U.S. Department of Energy, National Energy Technology Laboratory (NETL). The project is co-sponsored by Honeywell International and Insight Technologies. The paper reviews background data on the concept of Flame Quality and the initial development. This is followed by a review of the commercialization of the Flame Quality concept by Honeywell, in a cooperative effort with Insight Technologies, to bring the technology to market in a low cost product. The field test project is providing data to substantiate dealer payback and improve competitiveness of oil heating appliances.

Introduction

Honeywell has been involved in the development of controls for use in oil-fired equipment since the late 1800's. As production processes have moved forward to new technology platforms, Honeywell has provided upgraded performance and features in new series of control offerings.

As early as the 1920's and 1930's, flame sensing was accomplished with a bimetallic sensor which was placed into the equipment flue and interfaced with Electro-mechanical logic circuits to rely on the temperature of the flue gas to provide indication of the combustion process. As hard as it may be to understand, many of these devices are still being used in replacement applications today.

The next step in the evolution occurred in the 1970's when a cadmium sulfide sensor, that changed resistance when exposed to light, was introduced into the market. This new technology was combined with the same basic electro-mechanical logic circuits to provide a control that would react to the combustion process through the visual light emitted from the combustion process. This control technology has proven to be exceedingly reliable overall and continues to be the control of choice for a majority of controls installed in the marketplace today.

During the early 1980's, electronic microprocessor technology was introduced to the oil-fired equipment marketplace in the commercial application areas where cost was not as much of a factor. This new technology continued to use the same cadmium sulfide flame sensor in many of the applications. Some small improvements in flame monitoring were made, but the controls continued basically, to look for flame / no-flame status of the combustion process.

Beginning in the late 1980's, Brookhaven National Laboratory initiated a program to identify practical sensor concepts which could monitor changes in the performance of an oil burner over time. The goal was to design a very inexpensive system which could lead to

burners being serviced before heat exchanger fouling occurs, thereby reducing efficiency of the oil-fired appliance. Many technical approaches were explored in this work including: semiconductor CO sensors, zirconium oxide oxygen sensors, flue temperature, heat exchanger pressure drop, flame spectral emission peaks, and two-color flame temperature measurements. While many of these approaches are interesting and may offer better performance, the simple Cad Cell (broad band, flame brightness) was selected for further development work. The Cad Cell has the advantages of low cost, it is widely used, and exhibits good sensitivity to Flame Quality changes. Additional information on the BNL background work can be found in References 1 and 2.

Flame Quality Basics

The cadmium sulfide flame detector is sensitive to the changes in emission of Visible/near-IR light from the oil burner flame and can be used to indicate changes in the combustion process. The amount of light incident on the Cad Cell depends upon flame temperature, flame soot concentration, and flame length. Changes in the flame can effect these factors. Low excess air, for example, can lead to a long flame, with high soot concentration, and more light to the Cad Cell. However, this information is hidden by a number of variables in the appliance and application. The ability to separate the Flame Quality information from the appliance / application conditions is the basics of the Brookhaven National Laboratory development.

One of the largest variables is the effect of combustion variation with the length of the burner "on" cycle time. As has been reported in earlier Brookhaven Laboratory reports on Flame Quality, the cadmium cell resistance continues to change over a continuous run period of the oil-fired appliance. As will be discussed in the information regarding the implementation of this concept, this factor is overcome by selecting a warm-up period sufficient to provide a more stable combustion process, then use the same time period each time a comparison is made.

The next variable is the natural tendency of a flame to modulate its intensity, or "flicker", over a very short time period making instantaneous readings subject to significant error.

Finally, there are the variables that occur in the application that cause transient changes in the combustion process, but do not actually indicate a change in the combustion process requiring service. These variables can be strong wind loads causing draft changes, voltage dips causing pump pressure changes, and many other temporary variations in the combustion process. This is overcome by defining an acceptable range of variation from the initial reading and a required number of occurrences of readings outside of the acceptable range. Reference "Troubleshooting Guide" from the field test kit, Addendum No. 1

Implementation

In the early to mid 1990's a number of companies field-tested the Flame Quality concept in different product offerings. All of these products required that the burner be retrofit with an additional cadmium sulfide flame detector necessitating a fair amount of additional wiring be added to the appliance. The installation of a second Cad Cell sensor required disassembly of the burner during installation of the Flame Quality system and had the potential to change the burner airflow design. Additionally, the low volume opportunity drove the total cost of installation beyond a level that a majority of the contractors found acceptable. Insight Technologies was arguably the most widely known and distributed offering of this generation control.

In the mid 1990's Honeywell began development of a microprocessor based oil primary control as the next level of proven control technology. Introduced in 1999, this control was provided with a communications connection that allows for the field connection of other equipment to enhance the performance of the control and installed equipment. This "data port" provided a more cost effective opportunity to implement the Brookhaven Flame Quality algorithm.

Honeywell and Insight Technologies identified an opportunity to leverage the field and application experience that Insight Technologies had gained through their development of the Flame Quality Indicator with Honeywell's manufacturing and oil primary knowledge to move the Flame Quality Indicator technology to a more cost effective platform.

The design concept was to use the Honeywell oil primary control data port to provide the Cad Cell information to a new Flame Quality mechanical platform, based on the Insight current product, but did not require the addition of a Cad Cell, power connection, or extensive wiring to the appliance.

The many improvements in the algorithm, to address burner "on" cycle time, short cycles, flame signal stability and others, would all be incorporated into the new Flame Quality Monitor.

The Flame Quality Monitor (FQM) is connected to the Honeywell oil primary control by a simple wire harness with a plug connector on each end. Thus, installation can be made in a few minutes without any disruption to the appliance. In this first of several planned implementations of this technology, the FQM provides a simple contact closure to the dealers choice of alarm options, battery powered, 24v powered alarms, home security systems, etc.

After the connections are made, the installer selects the appropriate warm-up period for the particular installation conditions, then the burner is adjusted and checked for CO_2, stack temperature and smoke number to assure that the appliance is operating optimally. The "calibration" button is pushed and the appliance allowed to run for the warm-up period. At the end of the warm-up period, the FQM takes a series of readings to determine an

appropriate value for the Cad Cell resistance and records the initial reading into memory. Each subsequent cycle that exceeds the selected warm-up period results in an additional series of readings being compared to the initial reading. If a reading exceeds the allowable variation, and there has been a sufficient number of these "out-of-range" readings to warrant service, the alarm is triggered.

In summary, although the basic concept of monitoring Cad Cell resistance, and using that information to provide a measure of change in Flame Quality, was developed by BNL, the actual Honeywell implementation has improved the concept in six important ways:

1. The amount of "warm-up" delay is field selectable by the service technician.
2. The Cad Cell resistance is measured using a unique algorithm, not a single reading.
3. The determination of "need for adjustment" is determined through an additional algorithm, not a single reading.
4. The installation is a simple connection between the Oil Primary and Flame Quality controls with no additional hardware installation requirements.
5. A separate Cad Cell is not required.
6. An additional power supply is not needed.

Application Options

How is the output of the Flame Quality Monitor going to be used by the Oil Service Dealer to enhance the typical oil customer's satisfaction?

1. Connect the Flame Quality Monitor alarm output to a simple bell alarm and have the occupants call for service when the alarm sounds.

2. Connect the Flame Quality Monitor alarm output to the building security system as a non-safety alarm.

Product Advantages to the Contractor

Perhaps even more exciting than early warning and proactive service for problem sites is the opportunity to extend the cleaning period of all the contracted sites. It is probable that a significant majority of installations do not require annual cleaning and may run acceptably for two or more heating seasons. Thus the potential savings to the contractor is enormous when the cleanings are moved from an annual basis to an "as needed" basis.

What does the future look like?

This paper started with a short review of the history of flame detection and brought us up to the present where we can install a device which will give notice of the need for appliance cleaning and early warning of malfunction. So, it would be logical to carry this to the next step, where will we go from here?

Currently, Honeywell has introduced a Telephone Access Module (TAM) into the Home Comfort Market. This device is installed in conjunction with a thermostat, temperature and humidity sensors in a furnace. The module is programmed to identify the site, the contractor and specific performance limits such as maximum and minimum temperatures. If any of the programmed limits are exceeded the device dials a toll free 1-800 number to a central station. The central station then identifies the contractor and sends a fax or pager message within 5 minutes with all of the related site and performance diagnostic information.

Honeywell is exploring the viability of merging the current Honeywell Flame Quality Monitor with the Internet interface offered by Insight Technologies to produce a moderately priced product that will transmit Flame Quality data, building temperature, actual burner "on-time", and other performance data. Since the actual run time of each burner can be provided to the contractor, the "K" factor for each site becomes very accurate and is only affected by changes in fuel flow through the burner. The affects of visitors, vacations, wind loads, etc. are all negated.

The Field Test

The U.S. Department of Energy's National Energy Technology Laboratory (NETL) solicited for participants in a project to demonstrate energy savings potentials of new technologies. The field testing of 100 Flame Quality Systems by the consortium of Insight Technologies, Honeywell and Brookhaven National Laboratory was selected as one of the funded projects.

The following benefits will be assessed during the 2 year test program:

1. Improved efficiency as a result of burner adjustments "when needed"
2. Cleaning interval moved to "as required" versus "annual"
3. Reduced appliance and building damage from "running saturation"
4. Reduced cleaning on sooted systems
5. Reduced "off-hours" service needs

The largest potential savings both in the energy usage measurement and actual service time is the cleaning interval move to "as required". Current industry data indicates that annual service is not required on 80% or more of the oil-fired appliances. The other 20%, require service at one year or less. However, due to the lack of a measurement tool that identifies when an appliance needs servicing, all receive an annual "tune up". The 20% that required

service before the annual tune up ran at a lower than optimum efficiency for part of the year, thus wasting fuel for the building owner. The 80% that are being "tuned up" each year that don't require annual maintenance are costing both in lost productivity to our industry and promoting an image of high maintenance requirements on oil-fired equipment.

Current Field Test Status

This field test is being implemented with the cooperation and help of Santa Fuel, Inc., E.T. Lawson, Vincent R. Boltz, Inc., and Agway Energy Products. Each of these oil service dealers is installing a portion of the 100 test devices in their customers' homes and businesses.

At present, about 25 of the devices are installed and reporting burner performance, the balance will be installed shortly and ready to provide remote monitoring of burner performance data over the next heating season. Of course, some of these will be installed on tankless coil applications and will be reporting through the summer.

One of the first test site installations indicated a burner failure within the initial week following installation and provided over a week warning before the oil primary control went out on safety. This was a week of sooting and low efficiency operation that could have been prevented through the early service opportunity.

At each field test site both the Honeywell FQM and the Insight Technologies AFQI are installed. The AFQI serves as a connection to an Insight Webserver. This enables information on the flame signal trends, cycling patterns, flue gas temperature, and FQM status to be examined on the internet. During this test program project participants are monitoring the Insight web site closely to identify irregular behavior. Figure 1 shows the hardware installation at each test site. Figure 2 shows some example results available on the web site.

Description of the Advanced Flame Quality Indicator (AFQI)

Since the initial BNL developments the Flame Quality Indicator FQI system has evolved in some important ways. Licensee, Insight Technologies, has improved the circuit design to incorporate an 8 bit microprocessor, 10 bit A/D converter and international standard modem that makes the AFQI a flexible data collection platform that can be programmed to remotely monitor a variety of sensor inputs and perform specific control functions.

AFQI Monitoring Options

Some examples of the monitoring options with the AFQI platform include: optical sensing of the burner flame in both the UV/Vis and IR, oil tank level sensing, fuel filter pressure drop sensing, burner runtime and cycle data, combustion O_2, temperature in the smoke

stack, water supply/return temperature, and ambient room temperature. The AFQI also provides an alarm when the burner locks out in a failure mode.

Insight's monitoring infrastructure can provide the service organization with an immediate notification by pager, cellular phone or email via the Internet when any of the sensor inputs exceed a preset limit. Users have access to a secure online database for collecting, viewing, and graphical display of historical data on heating system performance for every AFQI installation. In this study, charts illustrating trends in flame quality, stack temperature, and burner runtime/cycles are displayed.

In this field test program, service of the heating equipment will be provided in conjunction with the Honeywell Flame Quality Module (FQM). It is intended that the AFQI, along with Insight's web-enabled monitoring capability, will provide continuous remote monitoring of all FQM installation sites.

The service data will be correlated with historical data collected by the AFQIs installed at each test site. BNL and Insight Technologies will work closely with the service organizations to determine the costs associated with service and maintenance of the accounts with the installed Honeywell FQMs.

The NETL field test will be conducted over the course of two heating seasons, with the FQM installed at 100 sites in cooperation with the fuel oil dealer normally providing service to these sites. At each of the 100 sites the AFQI system will also be installed to allow continuous monitoring of the flame quality remotely. Service requirements, incidents of system interruption (no heat calls), will be logged by the service organization.

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1. Butcher, T. Performance Control Strategies for Oil-fired Residential Heating Systems – Project Report. BNL Report 52250, July, 1990.

2. Butcher, T., W. Litzke, and R. McDonald. Development and Technology Transfer of the BNL Flame Quality Indicator for Oil-Fired Applications, BNL Report 61860, September 1994.

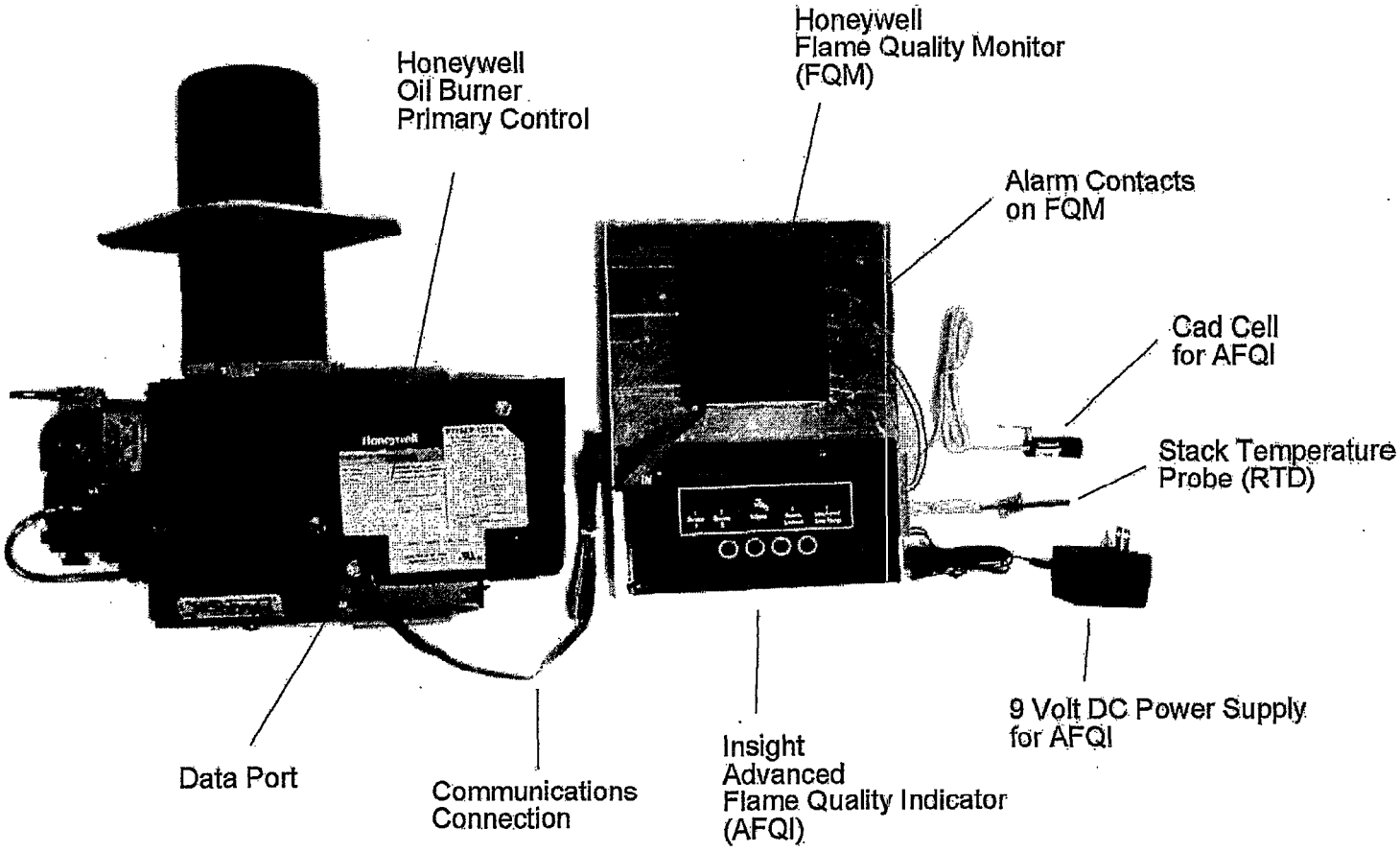

Figure 1. Photo of hardware installed at each test site. The Honeywell R7184 primary has a data port which provides data and power to the FQM. The AFQI is added to the installation to provide the remote monitoring capability via the Insight web site.

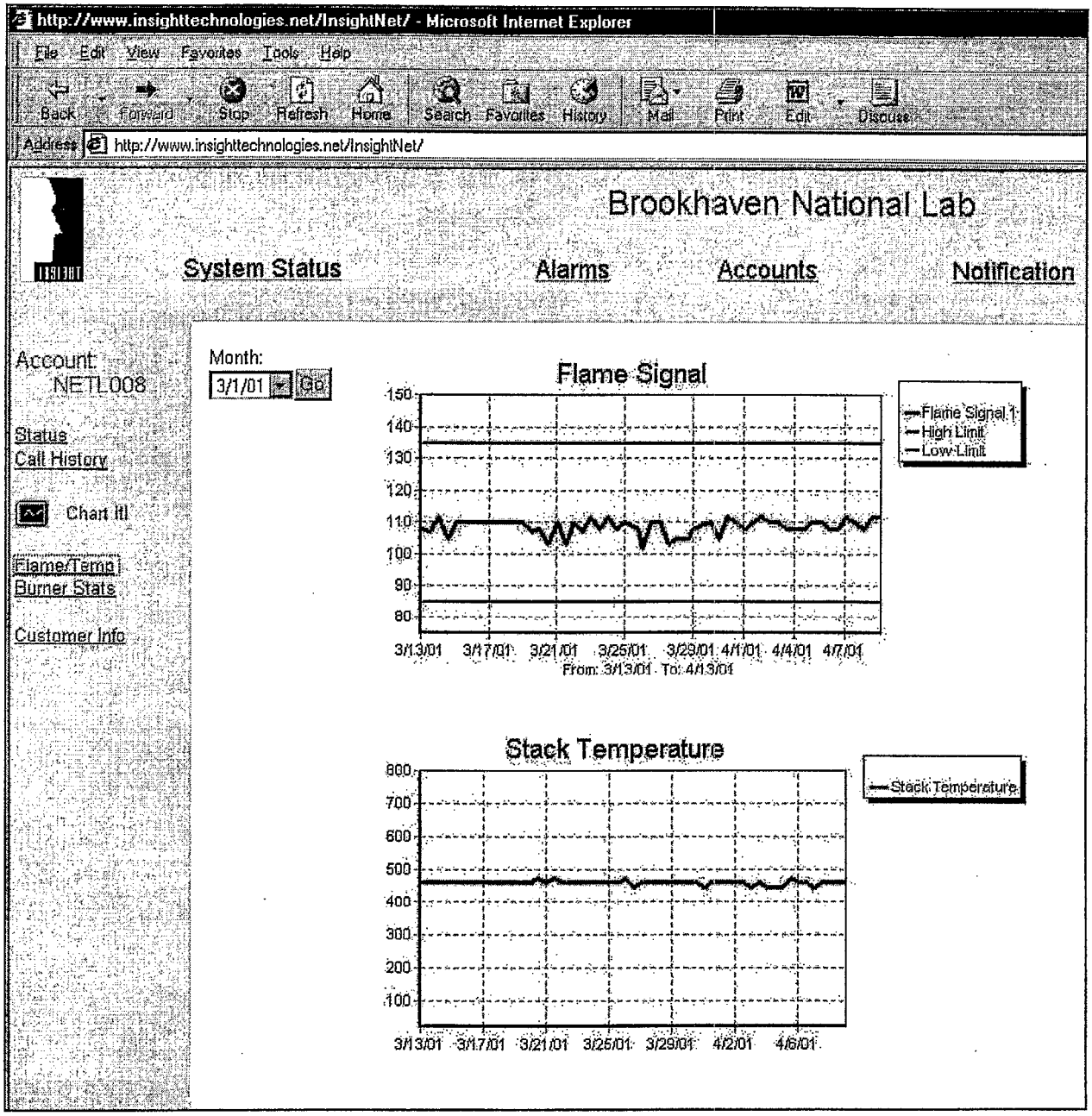

Figure 2. Example of an Insight web page for one field test site, showing measured trend in flame quality signal and flue temperature. Another page on the web site charts burner cycle information and run time.

Addendum No.1

Troubleshooting Guide

FQM Signal	Condition	Possible Cause
Out-of-Range "High"	Fuel rich	Combustion air supply blockage
		Backdraft, downdraft, defective draft control
		Blocked heat exchanger
		Poor atomization
		Excess fuel
		Oil accumulation on burner tube.
		Change in aromatic content of fuel oil
Out-of-Range "Low"	Fuel lean	Too much excess air.
		Partially clogged nozzle, filter, or oil line.
		Boiler leak into combustion chamber
		Cracked heat exchanger.
		Soot accumulation on burner tube.

Hard to Detect Alarm Causes

If an FQM alarm occurs and inspection of the heating appliance indicates proper operation, i.e., zero smoke, proper C02, excess air, then the following items should be checked:

Chimney Design and Location-It is possible that wind direction and resulting pressure changes from roof, adjacent buildings, trees, etc., can make major differences in the combustion air and drafting.

Combustion Air Supply-Check to see if the building has been changed since the initial adjustment, e.g., is there more or less combustion air available due to changes from sealing the building, changing windows or doors, etc.? Have doors or windows or outdoor air makeup systems been blocked or changed? Is there an exhaust or attic fan that is on or off?

Oil Tank and Oil Quality-has the tank been filled recently? Has the grade of fuel oil changed or a different supplier filling the tank, resulting in a change in fuel quality?

Fuel Filter and Oil Supply Lines-Is the filter clogged and restricting fuel flow to the oil burner fuel pump? Is the fuel filter or strainer dirty? Have the oil lines been damaged, restricting fuel flow?

Combustion Chamber and Combustion Environment-Check the integrity of the combustion chamber or refractory. Check for cracked boiler sections, sand holes, seal failures. In warm-air furnaces, be sure to check the integrity of the heat exchanger.

Draft Regulator-Check to assure that draft regulator is working properly.

Oil Pump-Check for proper pressure.

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Paper No. 01-03

NORA/DOE/BNL Five Year Oilheat Research Plan

Roger J. McDonald
Thomas A. Butcher, Ph.D.
and the
NORA/DOE Research Committee

Brookhaven National Laboratory
Department of Energy Sciences and Technology
Energy Resources Division
Oilheat Research
12 North Sixth St.
Upton, NY 11973
631-344-4197
mcdonald@bnl.gov

NORA/BNL/DOE Five-Year Oilheat Research Plan

The Energy Issue is complex and there is no single fix. We need a portfolio of solutions and clean Oilheat is an important part of the mix. Over 30 million Americans rely on Oilheat. It is delivered to more than 11 million American homes and businesses by 8,000 mostly small family businesses. Oilheat is clean, efficient, easy on the environment, economical, and secure. Further Research and Development are needed to help Oilheat continue to meet the burden of our growing economy's thirst for energy.

We need this program to keep Oilheat as a preferred energy choice not only for space and water heating, but cooling and power generation as well. This is desirable because of the inherent safety of heating oil, the flexibility of our fuel delivery infrastructure, and the thousands of well-trained Oilheat service technicians who are ready and able to rapidly deploy the new technologies developed by this program.

This R&D encompasses both short term projects capable of being completed and commercialized within a five year period, and long term projects which will have a major impact on Oilheat's future that we must start now but will take longer to complete. The R&D will be a cooperative cost sharing effort between the Department of Energy Office of Power Technologies, Brookhaven National Laboratory, the National Oilheat Research Alliance, Oilheat Equipment Manufacturers, Petroleum Refiners, and local Oilheat Dealers for the benefit of the American Public and Economy. We seek recognition of the role Oilheat can play in the National Energy Plan, and for an industry wide effort in the Oilheat Research and Development program described herein.

Background:

In the past 25 years Oilheat R&D has made remarkable progress. Improvements in the efficiency of oil burning appliances have saved Oilheat consumers 6 billion dollars. That is more than $500 saved for every $1 invested in R&D! This huge reduction in consumption has enhanced Oilheat's already environmentally clean performance. Future improvements underway, and envisioned in this plan will reduce consumption even further while dramatically lowering Oilheat's already modest environmental impact.

Anticipated Results:

- Energy Savings- We estimate that the deployment of the advanced technologies envisioned in this program will reduce heating oil consumption by 25%. This does not include any potential savings from BCHP integration.
- Emissions Reductions- Nitrous oxide emissions are the only significant emissions from oil burners. We plan to cut Oilheat NO_X emissions in half.
- Increased Reliability- The program will result in systems that are more reliable, require less maintenance, and are more resistant to electric power interruptions.
- Energy Security- The combustion efficiency gains to be achieved by this program as well as the work on biofuels and other alternatives provides for decreased dependence upon imported oil and improved energy security.
- Competition and Choice- This program seeks not only to identify new technologies but to also prove the benefits of this technology through field performance. This will provide consumers with new technology options and accurate information that they can use to make sound energy decisions.

Specific Initiatives:

Combustion

Current oil burner technology is economical, reliable, and easy to service. However, it has evolved almost as far as it can. We will need advanced technologies to achieve the goals of this program. The most severe limitation of the current technology is that the fire is too large for most residential applications, and units are sized for the coldest day of the year- leaving them oversized the rest of the year. The goal is to develop low cost practical options to achieve lower firing rates, and modulating operation. This will increase efficiency, decrease consumption, and lower environmental impact.

Reducing nitrous oxides, NO_X, emission is an important goal of this program, particularly if Oilheat's missions is expanded to cooling and power generation. We plan a three pronged attack for lowering NO_X emissions. The first is evolutionary. We can significantly lower NO_X emissions by further refining existing technologies. Industry participants will develop and commercialize moderate NO_X burners using existing boiler and furnace designs. The emphasis will be on near term commercial potential. The second approach is the development of fully integrated, very low NO_X appliances. The third will be to chart a course to an ultra-low- NO_X technology. This will involve not only a new approach to burning the fuel, but a change in the fuel itself.

We also plan to develop new diagnostic service tools. Not only will we need these new devices to properly service the new equipment developed by this program, but the reliability, efficiency, and cleanliness of the equipment in the field will be improved by providing better diagnostic tools to service technicians.

Each of these targets will involve Oilheat equipment manufacturers in the commercial development of the new technologies. It will also involve a generic R&D effort to study the fundamental aspects of combustion. This will provide manufacturers a resource to draw upon in their specific product development efforts. The final component of this work is field tests by service organizations so they can gain experience with the new technologies, and provide feedback. This will also speed up the acceptance by technicians that will insure success for any new technology.

Fuel Technology

The Oilheat Industry's top two service priorities are improved reliability and reduced heating equipment service costs. Half of all residential service calls are fuel related. The objectives for this part of the program are: to ascertain the leading causes of fuel degradation, to measure the effects on performance caused by changes in fuel characteristics brought on by the use of fuel additives, to develop methods that will improve fuel quality and stability, and to investigate alternative fuel storage systems. This effort will lead to the development of an industry-wide consistent set of practices that will reduce fuel related service calls.

Biodiesel and other crop derived fuels may be reasonable substitute fuels to enable the industry to deal with supply problems on an emergency or on-going basis. Such fuels could be blended with petroleum. There are a number of concerns with the long term reliability of these blended fuels. We propose to address these issues, and strive to come up with a blended fuel strategy that will work.

BCHP, Buildings- Cooling, Heat, and Power Oil Combustion Application Study

The goals of this study are to identify where oil can best be used to alleviate the energy crisis, beyond converting inefficient electric residential space and water heaters to oil powered appliances. On-site integrated oil powered heating, cooling, and electric generation appliances using advanced oil combustion technologies developed by this plan have the potential for huge increases in total system efficiency and dramatic reductions in electricity demanded from our overworked electric power grid. Since oil powered space and water heating is already very efficient, the big benefits of this system will be in converting cooling from electric to oil, as well as generating electricity at the point of consumption-eliminating the huge electric transmission losses we currently suffer. We propose to evaluate the current state of BCHP technologies to see if oil can be used as the fuel, and evaluate how new space and water heating technologies developed by this program can apply to cooling, and electric generation.

Venting- Field Studies and Code Support

Venting systems remove the products of combustion from the building. The goal of this part of the plan is to provide the industry with the information needed to deploy higher efficiency equipment without concern about venting system issues. We must perform a field study with the cooperation of heating service providers to create a database of information on the performance of existing chimneys, as well as other venting technologies. This will help validate computerized venting design models. The second step will be to build an instrument lab test stand. This will be critical for validation or correction of models upon which venting system codes are built. An important and directly linked issue is combustion air. Within the context of the venting program research on combustion air supply and air/exhaust balancing will be conducted.

Technology Transfer

Critical to the success of the program is the transfer of information, technology, and results. We must reach out to a wide range of Oilheat stakeholders: marketers, technicians, manufacturers, code and standards organizations, architects, builders, Realtors, and consumers. We plan to expand the successful annual DOE/BNL National Oilheat Research Alliance Technology Conference, expand the DOE/BNL Oilheat Research Technical Advisory Group, conduct an ongoing survey and analysis of international developments in Oilheat technology, provide liaisons with codes and standards groups like ASHRAE, ASTM, NFPA, and BOCA, and create and maintain an Oilheat Research Internet Resource Center.

Note: For those who wish to read more of the details, the complete NORA/DOE/BNL Oilheat Research Strategic Plan FY 2002 – FY 2007 (revision: February 27, 2001) is presented on the next several pages as developed by the NORA/DOE/BNL Research Committee chaired by Mr. Douglas Woosnam.

Oilheat Strategic Plan

FY 2002 – 2006

BROOKHAVEN
NATIONAL LABORATORY

Department of Energy Science and Technology
Division of Energy Resources
Oilheat Research

NORA
NATIONAL OILHEAT RESEARCH ALLIANCE

U.S. DEPARTMENT OF ENERGY

OFFICE OF POWER TECHNOLOGIES
CLEAN POWER FOR THE 21ST CENTURY

Revision Date: February 27, 2001

The Issues

- In the U.S. there are more than 10 million homes that are heated with oil. Oilheat continues to be an excellent value. Oilheat has been and continues to be an economical choice for home heating for the vast majority of the consumers in those markets where oilheat is commonly used. Oilheat is a free market commodity. This assures customers that they can choose the oilheat supplier with the best home heating comfort product, inclusive of service, reliability, supply and price. Even in this day of utility deregulation most consumers have little or no choice as to who supplies their energy needs. Oilheat enhances the energy supply diversity of the United States and provides the customer with an opportunity to choose.
- Traditionally the price of oil has been a driver for consumers, particularly in the Northeast. Over the past few years volatility in oil price has increased concerns over the security of heating oil supply. Recently the price of natural gas has risen at a much faster rate than oil, raising concerns also. Many commercial natural gas-fired boilers are switched to heating oil during high use periods or during periods of high gas price. Under the current climate it would be most prudent to keep heating energy supply options as open as possible and to promote reduced energy use in general to provide to consumers the greatest assurance of reliable supply.
- Oilheat technology has not received as much R&D attention over the past 20 years as have other technologies. Technical advances in oil heat technology have been deployed in the market place at a much higher rate in Europe than they have in the U.S. There is great potential for an increase in the technical level of oil heating.
- The oilheat industry, comprised of many small businesses, were unable to cooperatively support research in the past due to anti-trust regulations. In passing the National Oilheat Research Alliance (NORA) Act of 2000, the Congress has authorized new opportunities for the oilheat industry in consumer education, research and development, and industry education. Recognizing the need for and benefits of increased R&D in the oil heat area, the industry has supported passage of the recent NORA regulations. Under this program fuel oil distributors will be collecting funds based on sales for research, development, and education. This will meet only part of the need and enable only part of the potential to be realized. A DOE-Industry research partnership is needed to accelerate the development and deployment of advanced oil heat technologies.
- The US Department of Energy, oilheat marketers and oilheat equipment manufactures can be justly proud of the environmental record of improvements that oilheat research has accomplished over the years. The development of currently available efficient clean burning oil equipment has contributed significantly to enhanced air quality along with a safer environment thanks to improvements in fuel transportation and storage systems. Important issues remain that can make oilheat even more environmentally friendly. One area is the nature of the fuel itself, by improving the characteristics of the fuel we can make additional improvements to the air quality, by introducing the use of bio-fuels as a blending agent we can make oilheat renewable, and with new research in fuel systems we can make it even more safe for the environment.

The Challenges

- The oilheat industry is comprised of roughly 7,000 oil marketers, the vast majority are small businesses which sell oil and service equipment in the homes of their customers and many small equipment and or component manufacturers who do not have large research departments. While these companies are innovative and very interested in advanced technology they are reluctant to divert their limited technical staff or to add a large number of staff for a limited time R&D effort.
- Service cost is a high priority for the industry. Fuel quality, which impacts both service cost and efficiency is the top priority subject.
- Service organization's technical staff are well trained with traditional and at times outdated equipment and tools. Any equipment change requires investment on their part in terms of training and equipment. This leads to a barrier to change which must be overcome by clear benefits of advanced technology, training support, consideration of service issues of advanced technologies and market demand.
- New technologies are needed to provide higher efficiency, reduced service cost, lower and modulating firing rates, reduced NOx, appliance configuration options and integration with BCHP concepts. Application studies in the field are need to document the advantages and issues based on actual experience in using combining space, water heating systems and other functions and to see that reflected accurately in rating systems.
- All of the available oilheat equipment choices are over-sized, larger in capacity than they need be, relative to the heating loads found in many modern energy efficient homes, apartments and condominiums. This over sizing results in much lower efficiency than would otherwise be possible. Current technology is limited in its ability to fire oil at lower capacities. Alternative possibilities exist but require research and development for use in the oilheat industry.
- There is a lack of information available on in-use efficiency and usage patterns which could help define new configurations, opportunities and potential efficiency gains.
- Advanced technologies developed in Europe are not directly applicable to the U.S. context because of different regulatory environment, industry practices, service practices, hardware configurations and consumer preferences.
- Current products on the market are reliable and inexpensive, presenting somewhat of a challenge to the developers of any advanced concept. Indeed system designs have evolved relatively slowly so that many components have gravitated towards standardization over the years. A new and innovative product design that departs from the norm radically is at a disadvantage in terms of market acceptability. Issues include training service technicians on new designs and repair parts availability for a new system. The answer so far has been to keep the old technology running if it was built in 1940.
- A systems focus is required looking at how advances in control technology can be applied, investigating possible thermal storage options, and resolving issues on distribution versus efficiency.

The Results

Energy Savings - Current energy use for residential heating is about 1.0 quads. It is estimated that deployment of advanced configurations has the potential to save 0.25 quads annually. This does not include benefits of BCHP integration.

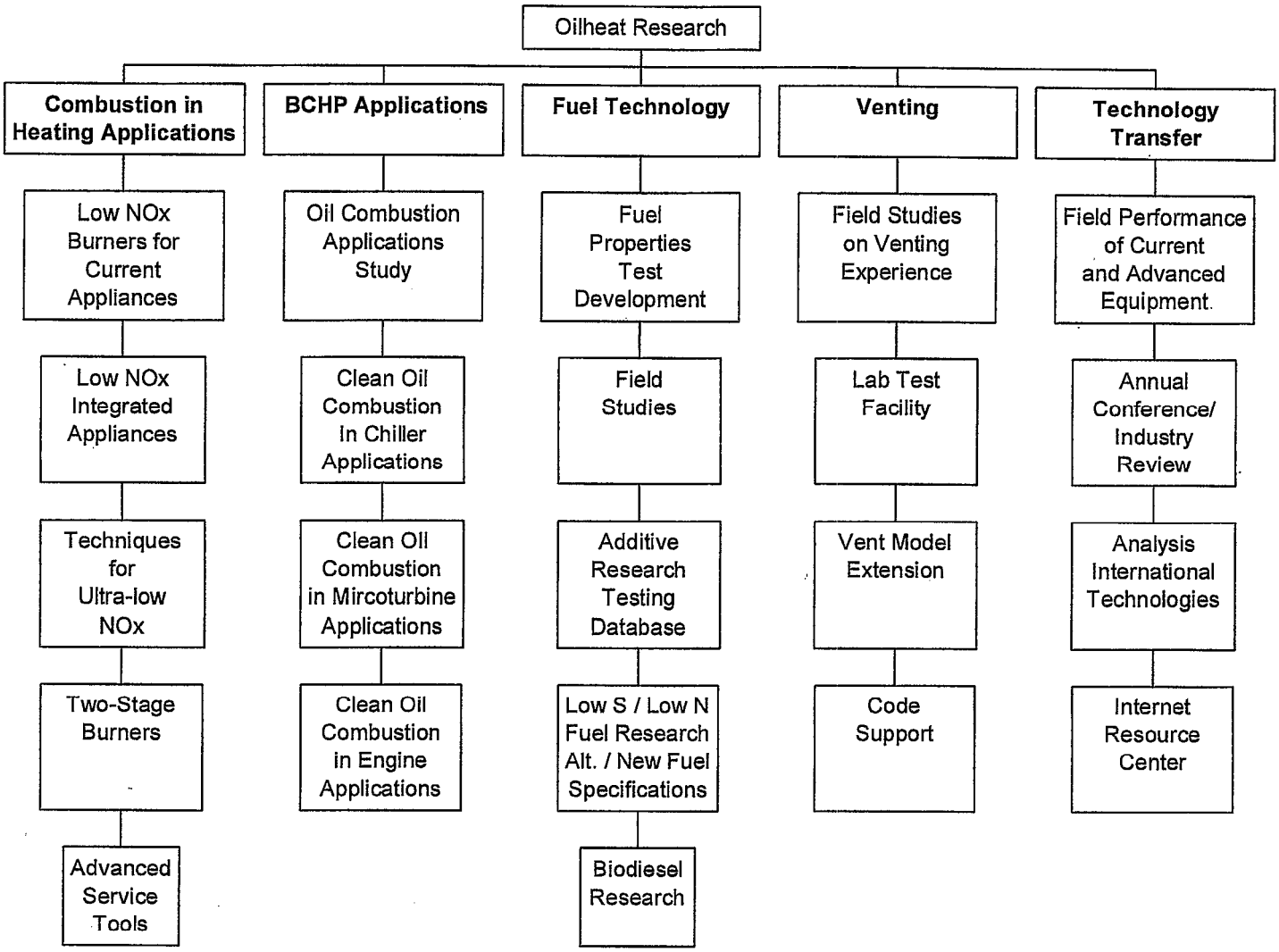
Emissions Reduction - The currently accepted NOX emission factor for residential oil burners is .13 to .15 pounds per million BTU and this translates to 100-115 ppm in flue gas. A practically achievable NOX emission level, based on European experience is 50-60 ppm. Achieving this represents a 50 % reduction or a annual emission reduction of 38,000 tons. This program also seeks to achieve technologies for much lower NOx emissions - on the order of 10 ppm. This would present a reduction of 90% from current levels.

Increased Reliability – The program will result in systems that are more reliable, that require less maintenance, and that are more resilient to power interruptions. More reliable systems will have a benefit for homeowners in reduced maintenance costs. It will reduce operating costs for fuel oil marketers. Including the option of oil fired cogeneration systems, electric power and heating functions, will result in systems capable of running without the need for the power grid either part time or full time depending on system design. It has the potential to make winter time power outages much easier on the consumer.

Energy Security - The combination of efficiency gains to be achieved by this program as well as the work on biofuels and other alternatives provides for decreased dependence upon imported oil and improved energy security.

Competition and Choice - This program seeks not only to identify new technologies but to also prove the benefits of this technology through field performance. This will provide consumers with new technology options and accurate information which they can use to make the best energy decisions.

The Program


Oilheat Research
Combustion in Heating Applications
BCHP Applications
Fuel Technology
Venting
Technology Transfer
Low NOx Burners for Current Appliances
Low NOx Integrated Appliances
Techniques for Ultra-low NOx
Two-Stage Burners
Advanced Service Tools
Oil Combustion Applications Study
Clean Oil Combustion In Chiller Applications
Clean Oil Combustion in Mircoturbine Applications
Clean Oil Combustion in Engine Applications
Fuel Properties Test Development
Field Studies
Additive Research Testing Database
Low S / Low N Fuel Research Alt. / New Fuel Specifications
Biodiesel Research
Field Studies on Venting Experience
Lab Test Facility
Vent Model Extension
Code Support
Field Performance of Current and Advanced Equipment
Annual Conference/ Industry Review
Analysis International Technologies
Internet Resource Center

The Oil Heat Research Program

The oilheat industry feels that there is enormous potential to make available advanced technology to the 10+ million U.S. homes which use this fuel. There are three main aspects of this: 1) improved reliability and increased in-use efficiency with reduced service costs and 2) the availability of new appliance concepts which provide dramatic reductions in NOx emissions and higher efficiency for both heat and hot water delivery and 3) new configuration and installation options which may provide heating cooling and electric power. The program which is outlined in this strategic plan will provide a solid technical foundation for the development of a new generation of equipment and provide to the oil marketers, equipment installers and consumers improved knowledge of how best to install, maintain and operate such equipment for maximum performance and minimum fuel use and environmental impact.

This strategic plan is the result of the efforts of the BNL research team, the oilheat equipment manufacturers, the petroleum marketers and the service industry. Its implementation will involve participation of researchers, manufacturers, marketers and service professionals. The current form of this plan was developed from a 10 year plan outlined in a 1996 report which was developed over a 1 year period with a great deal of review and industry input.

On the following pages, a brief description of the work planned in each of 5 main areas is presented.

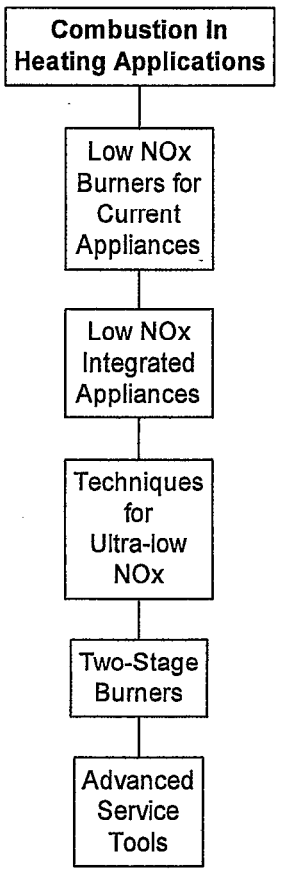
The Overall Program

	2002	2003	2004	2005	2006
Combustion	1.9	2.4	2.8	2.4	1.1
BCHP	1.7	1.7	1.8	1.5	1.5
Fuel Tech.	1.2	1.8	2.0	1.2	1.0
Venting	.8	.75	.2	.1	0
Tech Transfer	.6	.85	.6	.6	.3
Total	**6.2**	**7.5**	**7.4**	**5.8**	**3.9**

Program Budget in Millions of Dollars

Total 5 Year Budget = $30.8 million

The Program – Combustion in Heating Applications



At present all U.S. oil burners are of the pressure atomized, yellow flame type. While this economical technology has developed an excellent reputation for reliability, advanced technologies will be needed to achieve specific goals of this program.

Over the past 15-20 years NOx emissions have been an important issue in Europe and a series of voluntary standards and laws have evolved over the years with decreasing allowed limits. In response, European manufacturers have put a considerable amount of effort into the development of low-NOx concepts. While some of these have proven quite impractical others have realized significant market penetrations. The dominant approach involves burners with high internal recirculation rates in combination with chamber geometries which avoid direct impingement of the longer blue flames on steel walls. This technology, which was originally developed in the U.S., presents challenges in terms of increased potential for CO production, higher safety control costs, more complex and costly burner heads, and flame stability problems under cold start conditions. The U.S. appliance market is significantly different from the European market. The U.S. market for example is about 50% warm air furnaces. In Europe, heating appliances are essentially 100% boilers. European low-NOx burners cannot be used in most U.S. furnaces.

Current burners operate only at one firing rate and cannot be operated reliably at rates below about 0.6 gallons per hour. For most applications this rate is well above the home heat demands even at the design outdoor conditions. The higher rates are generally justified by the domestic hot water demand. The result is a situation where many combined appliance configurations have developed. Burner oversizing is very severe and cycling rates and cycling losses are unreasonably high. What is needed is low cost, practical technical options to achieve low firing rates, two stage, and possibly modulating operation. These have been long-standing industry desires.

The combustion research program has been developed to accomplish several things. Industry participants will work to develop and commercialize moderate NOx burners which can be used with existing cast iron and steel boiler designs as well as warm air furnaces. The NOx target for this effort is 70 ppm @ 3% O_2 although lower targets will be encouraged. The emphasis in this will be designs which have a very strong, near term commercial potential. This target level has been set as one which is achievable with current, yellow flame, short flame tube designs. The second is the development of fully integrated, very low NOx appliances, including a boiler and a warm air furnace. The target NOx emissions here are 55 ppm. By fully integrating the burner and appliance the chamber environment is eliminated as a variable allowing higher recirculation rates and low NOx emissions to be achieved with a high level of reliability. The third effort will involve achieving much lower NOx emission levels with 20 ppm set as a target. This will involve much higher recirculation rates which introduces flame stability challenges. Also required will be fuels with reduced nitrogen content. During this 5 year period the ultralow NOx targets will be reached at the prototype level.

Two stage burners offer the promise of higher efficiency, improved life, reduced cycling rates,

and reduced air pollutant emissions. Under this task the commercial development of two stage burner/ control packages will be completed.

In addition to advanced burner development, the reliability, efficiency, and cleanliness of conventional and future oil heating equipment could be improved and the service costs could be reduced by developing new diagnostic and service tools that can assist oilheat service technicians. The key technical advance needed here is a low cost, practical method of directly measuring smoke level and this will be the primary focus of this project.

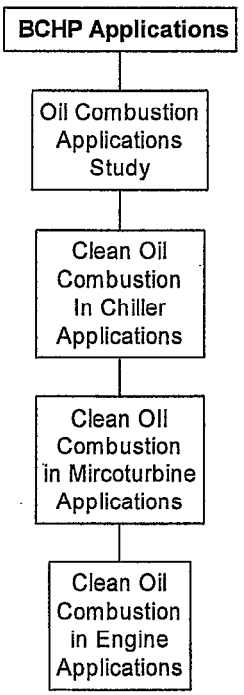
Each of the development targets discussed above will involve three components. The first is involvement of oil heat manufacturers in commercial development. The second is a more generic R&D effort. The fundamental aspects of recirculation, flame stability, flame structure, interaction with cool walls and control options will be studied as an extension of earlier work at BNL. This effort will provide to manufacturers a resource to draw upon in their specific product development efforts and is expected to lead to the ultralow NOx targets. This R&D effort will also address advanced atomization concepts as appropriate to achieve the project targets. The third component of this work involves field tests, completed by service organizations. This effort is intended to provide the opportunity for service organizations to gain experience with low NOx burners, two stage burners and the advanced service tools and to provide feedback to manufacturers on areas where improvements are needed from a service perspective. Service organization acceptance is seen as critical to the success of any new technology in this industry.

Combustion in Heating Applications Budget Summary

	2002	2003	2004	2005	2006
Low-NOx Conventional	.6	.7	.5	.3	.3
Low-NOx Integrated	.5	.5	1.2	.8	.5
Ultra-Low NOx	.5	.5	.5	.6	.3
Two-Stage	0	.4	.4	.4	0
Advanced Service Tools	.3	.3	.2	.2	0
Total	**1.9**	**2.4**	**2.8**	**2.4**	**1.1**

Program Budget in Millions of Dollars

The Program – BCHP Applications



The local integration of building heat sources with power generation, absorption cooling, and desiccant cooling offers the potential for huge increases in system energy efficiency, and solutions for national needs for increased power capacity. Termed Building Cooling Heating and Power (BCHP) this general area is now receiving a great amount of national attention. Much of the potential growth in this area will involve oil as the fuel of choice. The work in this area of the program will involve the development, testing, and demonstration of oil combustion technologies for these applications which will provide substantial improvements in emissions and efficiency.

The work in the area of applications studies will include an evaluation of the current state of technologies which can be used with oil as a fuel and provide, in an integrated way, heat, cooling and power at the residential and commercial scales. System integrated performance and economics will be included. Results of the microturbine and engine parts of this program will provide important inputs. An issue which has always faced the oilheat industry is the seasonal nature of their product. One option to resolve this while providing economic growth in this sector, and improved overall energy efficiency is to consider the possibility of providing oilheat technology which can satisfy building cooling loads. This is one of the major goals of this oilheat research plan. Recent advancements in thermally driven heat pumps and absorption cooling have been packaged with gas burners but have not yet tapped into the possible use of oil.

In chiller applications, work done under the heating applications part of this program on low NOx burner development will be extended to the commercial development of such burners specifically for absorption and desiccant cooling systems. Some of these applications may required high air preheat levels and quite novel combustion approaches. Technologies such as the Fan Atomized Burner (FAB) concept, which has been deployed with air preheat temperatures to 1600 F will be considered. The FAB concept, developed at BNL, involves low pressure air atomization as an alternative to conventional pressure atomization. It offers excellent combustion performance, low firing rate potential, and low NOx emissions.

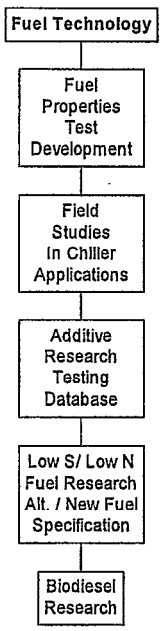
The processes of combustion in turbine and engine applications are subjects of a great deal of research work aimed at larger and transportation applications. Under this program all emphasis will be placed on systems specific to BCHP applications at the residential and commercial scales. The work will involve evaluation of low emissions technologies suitable to this application with oil firing, assembly and testing of candidate systems. Performance testing will involve installation in specific load conditions and measurements of efficiency, energy balance, emissions, and power quality under steady and load following conditions. This effort will serve to provide critical information on performance and ways in which these technologies can be integrated into building systems.

BCHP Applications Budget Summary

	2002	2003	2004	2005	2006
Application Studies	.3	.3	.3	0	0
Clean Oil Microturbines	.5	.5	.5	.5	.5
Clean Oil Engines	.4	.4	.5	.5	.5
Clean Oil Chillers	.5	.5	.5	.5	.5
Total	**1.7**	**1.7**	**1.8**	**1.5**	**1.5**

Program Budget in Millions of Dollars

The Program – Fuel Technology



Fuel Quality

Based on a survey of members of the heating oil industry the top two priorities in research objectives are improved reliability and reduced equipment service costs. Fuel oil marketers and equipment service groups have indicated that problems associated with maintaining fuel quality and the accumulation of contaminates in fuel storage tanks account for up to one-half the service calls made to homes. The objectives of the fuel quality program are (1) to ascertain the leading causes of fuel degradation, (2) to measure the effects of changes in fuel characteristics on the operations and emissions of heating equipment, (3) to develop methods that will improve fuel oil quality and extend the shelf life (stability) of fuels used in the oilheat industry, and (4) to investigate alternative fuel storage systems. This effort will lead to the development of industry-wide, consistent set of practices that can be used by marketers and consumers to reduce equipment down-time and minimize service-related costs.

Marked changes can occur to fuel quality during transportation and storage of fuel oil. Exposure to heat, water, contamination with debris and biological organisms all contribute to the accumulation of gums, sludge and water. A field survey of fuel characteristics, supported by industry participants, is needed to assess the changes in fuel quality from the source to the end user. Participation of fuel producers is considered a critical part of this effort. This task would involve selected, large-scale sampling, field and laboratory testing for specific fuel quality indicators. Required will be the development of field test procedures, coordination of data collection, analyses and reporting. This effort will be coordinated by Brookhaven's Oilheat Research Program and will support the development of a database available on a web-based site. The product will include an evaluation of fuel quality on a regional, local and distribution level (ie. pipeline, terminal, retail, and homeowner tank). Existing current specifications for heating oil will be evaluated and through standards organizations (ASTM), proposed changes will be considered.

Fuel oil additives are commonly used to improve the fuel's handling characteristics and storage stability. For example, some of these additives improve the cold-flow properties, disperse solids or slow down the degradation of fuel. They can be cost effective in comparison to the performance issues they correct. However, depending on the additive product, conditions of the fuel and environmental factors, the use of some products do not necessarily improve fuel quality or reduce the frequency of service calls experienced. The oil heat industry supports the testing, development of field test procedures and documentation of the effectiveness of additives available on the market. In parallel, additive research will be done to identify new formulations that meet the specific needs of the oil heat market. This will require oil marketers' participation in additive testing and reporting of service records which would be reported in a format like "consumer reports" on product development, product selection, and use.

Fuel storage technology is another area that will be included. Research leading to fuel storage system options that reduce the potential for fuel contamination and provide conditions for enhanced fuel stability will be investigated. This would also include designing systems that have the potential to be more suitable regarding environmental issues, pleasing to the customer visually and still maintain or enhance fuel delivery efficiency and cost effectiveness.

New Fuel Specification Research

One avenue to an enhanced environmental signature for oilheat is to challenge the major fuel suppliers with the need for new fuel specifications. While major reductions in NOx emissions can be accomplished through new burner designs applying advanced techniques for combustion. In the end a certain amount of the NOx is fuel related, around 25-30 PPM. To go below this level a new fuel with reduced nitrogen content is required. The same is true for sulfur content in the fuel and its impact on heat exchanger fouling and sulfur dioxide emissions. This has already been studied in the laboratory with regard to lower sulfur fuels and is currently the subject of a limited marketing and environmental benefit demonstration in New York State under NYSERDA funding. An effort to expand this study on a national basis would provide a much stronger basis for the future use of this low sulfur fuel across the country.

In looking at oilheat equipment and the potential for improvement, the range of possibilities expands when new fuel formulations are added to the matrix. To provide the industry with the ammunition required to change or add new fuel specifications requires hard technical data. This research will provide that data along with the effort to support the industry in this endeavor. The research must include investigations into both the benefits as well as any potential problems associated with these changes. Included are issues related to emissions, wear and tear on equipment, control issues and equipment costs.

Bio-diesel Use

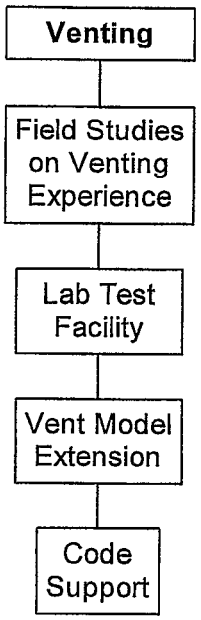
During recent winters, low heating oil inventories, weather, and natural gas supply conditions have led to short tem increases in demand and price. Biodiesel or other crop derived fuels, may be reasonable substitute fuels to enable the industry to deal with supply problems on an emergency or ongoing basis. Such fuels could be used alone but, more likely, would be blended with distillate oil. At present there is considerable interest in this and several field trials are underway with some specific fuel blends. Studies done to date at BNL and elsewhere have indicated that combustion performance may be acceptable for widespread use. Certainly the low sulfur content of these fuels is attractive. However, issues of long term performance, thermal stability (head coking), materials compatibility, lubricity, storage stability, biodegradation, and additive compatibility have not been addressed in a rigorous way. This issues will be addressed in this program.

Fuel Technology Budget Summary

	2002	2003	2004	2005	2006
Properties Test Development	.2	.1	.1	0	0
Field tests	.3	.5	.5	0	0
Additive Research Testing Database	.2	.5	.5	.5	.5
Low-S / Low-N Fuel Specification	.3	.4	.5	.5	.5
Bio-diesel Research	.2	.3	.4	.2	0
Total	**1.2**	**1.8**	**2.0**	**1.2**	**1.0**

Program Budget in Millions of Dollars

The Program - Venting



Venting systems remove the products of combustion from houses and buildings and have a direct impact on safety, reliability, efficiency, and cost of residential heating systems. Chimneys continue to be the most common method for venting oil heating equipment, but they produce several important disadvantages. These include safety concerns for deteriorated chimneys, performance variation as outdoor air temperature changes, increased off-cycle heat losses and lower efficiency. The traditional chimney vent system is an impediment to high efficiency. Low exhaust temperatures with high efficiency equipment lead to poor draft, condensation of water vapor in the chimney, failure of liner materials, and chimney blockage. The work in this area has been planned to provide the industry with information needed to deploy higher efficiency equipment without concern about venting system issues.

The planned work includes a field study, to be conducted in cooperation with the industry, to provide a database of information on the conditions of existing chimneys, field experience with sidewall venting and also performance data which will help with the validation of design models.

A well instrumented lab test stand will be built and used in a research program to allow direct measurement of liner wall temperatures and condensation under realistic transient conditions. This is critical for validation and correction of models upon which venting system codes are built. In addition to traditional chimney venting systems this will include forced and sidewall vented systems.

Existing chimney simulation models will be improved to include a broader range of cases, and improved heat transfer and condensation submodels.

These results when appropriate will be integrated into building code and standards through participation in NFPA and other organizations.

An area closely related to the venting of exhaust products is that of the combustion air supply. In fact in many directly vented systems and also power vented systems this is often an integral to the design. In all cases it is an important and directly linked issue. Within the context of the venting program basic research on combustion air supply and air / exhaust balancing will be conducted. Related issues of concern include the effects on efficiency and reliability.

Venting Budget Summary

	2002	2003	2004	2005	2006
Field Studies	.2	.2	0	0	0
Lab Tests	.35	.3	0	0	0
Vent Model	.25	.25	.1	0	0
Code Support	0	0	.1	.1	0
Total	**.8**	**.75**	**.2**	**.1**	**0**

Program Budget in Millions of Dollars

The Program - Technology Transfer, Regulatory & Industry Liaison

The success of the program will be measured by improvements in the environmental signature associated with oilheat, enhanced energy security, increased economic activity related to oilheat industry, and ultimately the energy and cost savings produced for oilheat consumers. Critical to the success of the program is the transfer of information, technology and results. The results and resources from the program and the advances in oilheat technology need to be disseminated to a wide range of oilheat stake holders including: marketers, equipment manufacturers, service technicians, code and standards organizations, architects, home builders/contractors, real estate companies and homeowners. The information transfer process is essential for success in each of the research areas included in the plan.

The approach in this activity is to provide technology transfer and engineering guidance for oilheat equipment manufacturers; technical information, diagnostic tools, and guidelines to oilheat marketers and service technicians; and more generic information to the public, all through a variety of mechanisms. These include cost shared development of new products with industry, oilheat technology conferences, workshops, and other activities which include initiating an Internet based resource center for oilheat technology. This task will be closely coordinated with the National Oilheat Research Alliance (NORA) plans for both direct consumer education and industry education/training program.

Oilheat Research Technology Transfer, Regulatory & Industry Liaison Elements:

Field studies - An important first activity planned under this area is field studies to update existing information on usage patterns. This includes current oversize factors, distribution system capacity, cycling frequency, domestic hot water usage and draw patterns and in-service efficiency. This information will provide the baseline of information needed to define the benefits of future advanced systems. This will be extended to tests of advanced concepts to provide high quality, field test performance data on selected advanced systems. These results will help the industry and homeowners make well founded, rational decisions about which technologies to promote and use. The field study program will include a limited number of well instrumented sites to document operating patterns and system efficiency. Specific technologies to be examined will evolve over the course of the project but are expected to include: purging systems, setback controls, two stage burners and control concepts.

Involve and incorporate NORA and BCHP in continuing the successful series of DoE/BNL oilheat technology conferences designed for oilheat industry audiences ranging from oilheat marketers, equipment manufacturers, service managers and technicians, to other government agencies, code groups and building inspectors.

Involve and further incorporate members of NORA in continuing the DoE/BNL Oilheat Research Technical Advisory Group (TAG) in the ongoing annual research review and planning process. Invite key members of the Buildings: Cooling, Heating and Power (BCHP) Initiative to join the Oilheat TAG to further the concept of fuel oil use in BCHP programs while providing oil research results for BCHP applications.

Conduct an on going survey and analysis of international developments in oilheat technology. Advance an international exchange

of information and build potential partnerships for future collaboration on new ideas for improvements in oilheat technology.

Provide for industry liaisons through technical presentations and participate in standards committees at engineering association meetings (for example ASHRAE) regarding new oil heating technologies and equipment. Develop new construction guidelines for using oilheat *systems* for the building industry by working with code organizations, NFPA and BOCA.

Create and maintain an Oilheat Research -- Internet Resource Center as a mechanism for the open publication of BNL/NORA information with a searchable database. Technical notes, engineering bulletins, topical reports for technicians and engineers regarding advances in oilheat technology research would be included on the site. Information would also include burner and heat exchanger design guidance for equipment manufacturers that would summarize key results from the research program. Data sharing on non-proprietary or proprietary basis would be an additional option. Provide technical support to oilheat outreach programs to national, state and regional oilheat associations to architects and engineers, real estate companies, builders, building contractors, heating contractors, consumer groups and others indicating the benefits of advanced oilheat equipment. Provide technical information and support for consumer education programs that inform homeowners about the advances in oil heat technology and the benefits that are produced by installing new equipment.

Technology Transfer Budget Summary

	2002	2003	2004	2005	2006
Field Performance	.3	.4	.3	.3	.2
Conference/ Ind. Review	.15	.15	.15	.15	.15
International Analysis	.05	.15	0	0	0
Internet Resource	.1	.15	.15	.15	.15
Total	**.6**	**.85**	**.6**	**.6**	**.5**

Program Budget in Millions of Dollars

Paper No. 01-04

The US Department of Energy's Cooling Heating and Power for Buildings Program

Richard Sweetser
President
EXERGY Partners Corp.
12020 Meadowville Court
Herndon, VA 20170
(703) 707-0293
rsweetser@exergypartners.com

The US Department of Energy's

Cooling Heating and Power

for Buildings Program

2001

NORA

NATIONAL OILHEAT RESEARCH ALLIANCE

TECHNOLOGY CONFERENCE

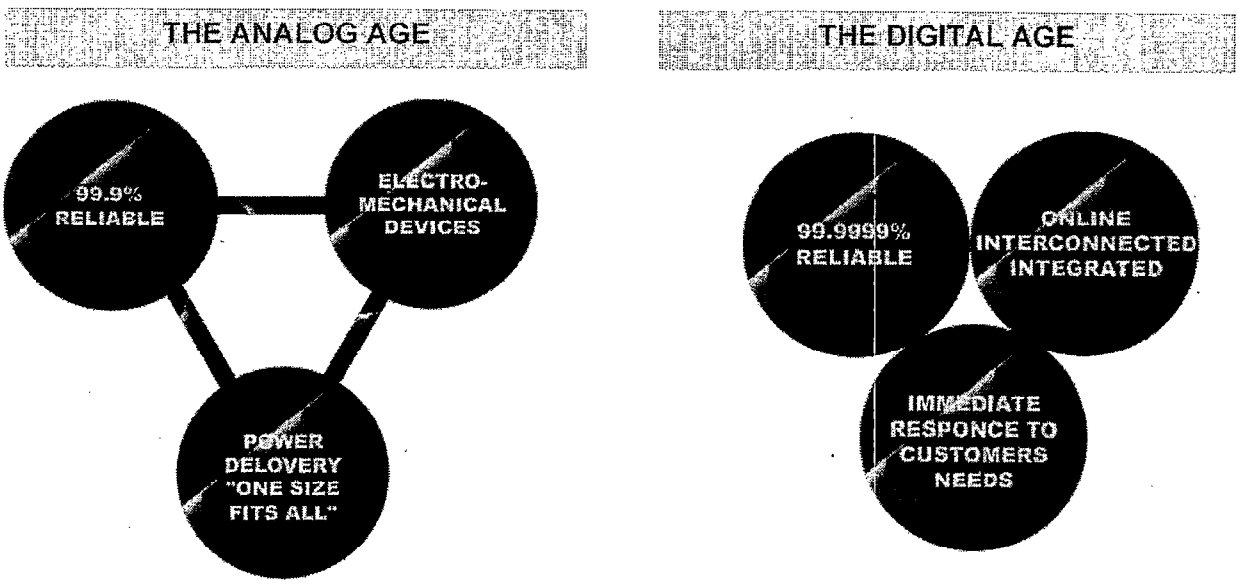
BROOKHAVEN

NATIONAL LABORATORY

Richard Sweetser, President, EXERGY Partners Corp.

Economic Transformation

America's electric grid infrastructure was developed – and served well – business and industry largely based on analog devices. The dominance of the PC and the Internet during the 1990's ushered in the digital age. Digital commerce has a new set of requirements for reliable power that requires fundamental change in energy supply and the creation of a portfolio of solutions that provide high reliability (99.9999%), seamless connectivity and instantaneous response. The distributed energy resources (DER), in general, and cooling, heating and power for buildings, in particular, are essential elements in achieving this economic transformation.



Situation Analysis

Energy price spikes, power outages, power quality problems, dirty air, customer choice. The time to act to address these problems is now. America's economy is in the midst of the longest economic boom in history. At the same time, significant progress has been made in cleaning up the environment.[i]

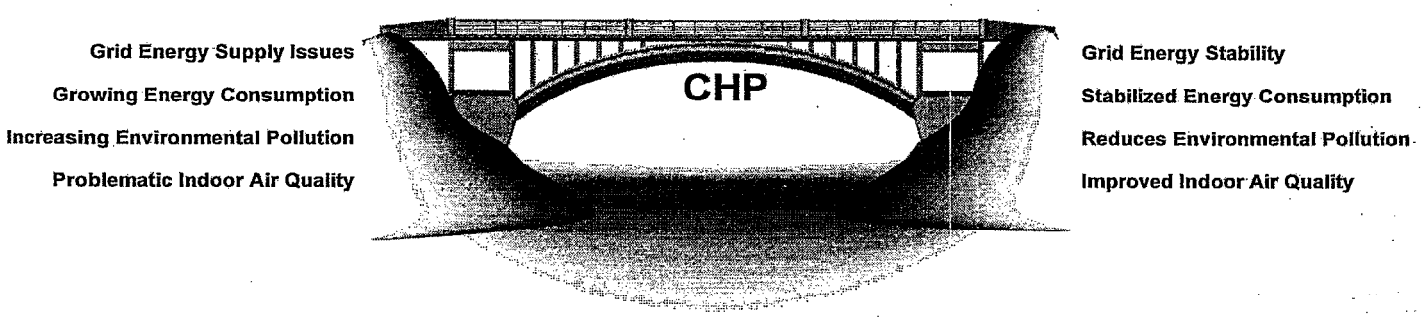
Perhaps it can be said that the robust economy has become a victim of its own success. Rising incomes and business expansion has led to a surge in energy demand, particularly in the demand for electricity to power our transformation into the digital economy. This has put the nation's energy supply sector under pressure to respond. So far, the response in certain regions has been inadequate. California, for example, has experienced unprecedented price increases and power supply constraints, including rolling blackouts and brownouts. Other regions, including the Pacific Northwest, New York, New England, and portions of the Midwest face the possibility of similar problems. Natural gas prices are on the rise and supplies of home heating fuel are expected to be tight.

These problems threaten the underlying strength of America's economy and environmental quality. Both near and long-term actions are needed urgently. In the near term, practical actions to increase supply and reduce demand can lessen the upward pressures on energy prices and supplies. In the long term, actions are needed in the policy arena to provide a robust and competitive marketplace for bulk electric power and natural gas and Oilheat or CleanOil and retail energy services. Also needed is a focused research, development, and demonstration (RD&D) plan of action to accelerate the pace of moving advanced clean energy technologies from the laboratory to the marketplace.

The U.S. Department of Energy (DOE) directs a broad portfolio of RD&D programs aimed at increasing the efficiency of energy generation, delivery, and use, while boosting economic productivity, and protecting the environment. One of the areas in the portfolio in need of greater emphasis is distributed energy resources (DER). DER consists of a suite of clean, modular, and small-scale, energy generation and delivery technologies and techniques. These include, for example, fuel cells, advanced turbines and microturbines, reciprocating engines, thermally activated heating, cooling, and humidity control systems, cooling, heat and power (CHP) systems, energy storage devices, and power transmission and distribution systems. The promise of DER is in having customers make their own energy choices – including an optimal mix utility and on-site generation - to customize and control the "*can't do without*" services energy provides the nation's factories, farms, commercial buildings, and homes.

CHP for Buildings

Cooling Heating and Power is an essential element in the distributed generation portfolio often making the economic and environmental difference between success and failure of a project. It has been called a bridge to a sustainable future.



The elements of this program plan come together and combine with other important distributed energy resources programs to provide the nation with:

- Unleashed energy market forces
- A portfolio of energy choices
- Strategic reliability where e-commerce sites and homeowners are equally satisfied with price and performance
- Optimized resource utilization
- Improved air quality and productivity

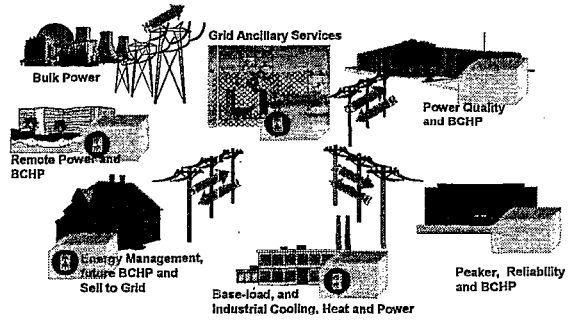
The goal the Cooling Heating and Power for Buildings program plan is to develop the technology, application knowledge and educational infrastructure necessary to enable CHP systems to provide at least 8 GW of onsite electrical power and an additional 10 GW of thermal energy.[ii] This effectively contributes a total of 18 GW of affordable efficient energy to the Nation's energy network.

CHP for Buildings National Potential

Depending on the choices we make, innovations made possible by this effort can help America improve the world we live in and continue to expand our economy over the next 20 years:

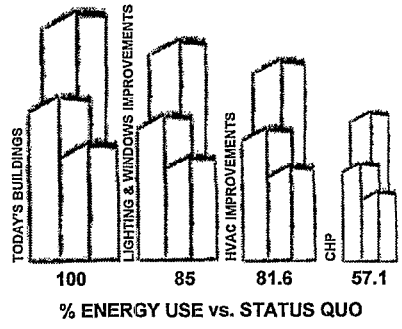
Significantly Improve Energy Grid Supply

Increase reliability of energy supply networks, improve power quality, ensure energy security and ensure long-term price stability through strategic peak demand management and grid support planning.



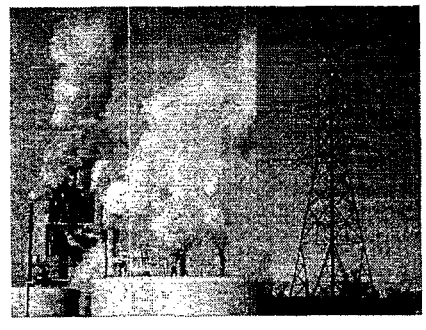
Significantly Improve Building Resource-based Energy Efficiency

Improve Efficiency through the use of recovered energy, would yield about a 30% natural resource saving.



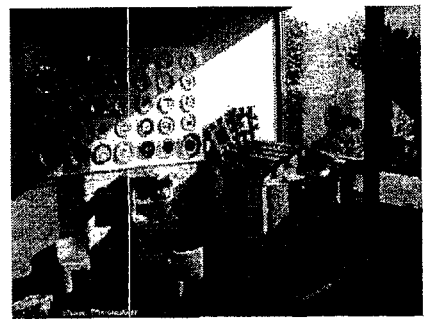
Significantly Reduce Local, Regional and Global Emissions

Through efficiency improvements, CHP systems operation offers up to a 50% reduction in major air pollutants.



Significantly improve Indoor Air Quality (IAQ)

Effective integration of humidity control with onsite power will dramatically accelerate their use in buildings and thereby improve moisture levels and IAQ.



The Issues

Energy price – electricity, natural gas and oil prices have increased substantially in several parts of the country due to constrained supplies and uncertainty about future market structures and regulations.

Dirty air – most major metropolitan areas in the country are in "non-attainment" with the requirements of the Clean Air Act, according to the U.S. Environmental Protection Agency. Adding new energy capacity to meet growing needs must be done in a way that protects the quality of the environment.

Global Warming – the emissions of global warming gases continues to be one of the most important atmospheric environmental issues worldwide. Power plant emissions of carbon dioxide are a major source of CO_2 emissions.

Indoor Air Quality – today's buildings (residential, commercial and institutional)

Reliability – electricity disruptions over the past several years are well-documented and future demand of global competition and e-commerce will increase customer need for high reliability.

Power quality – voltage spikes and sags are becoming commonplace as grid reserve margins tighten. Even minor power anomalies can permanently damage digital equipment and appliances.

Energy demand growth – e-commerce is creating a new level of electricity demand with high-energy requirements to service digital transactions, which creates high power requirements on feeder cables usually in urban centers that do not have sufficient capacity.

Grid congestion – constrained transmission and distribution capacity coupled with siting difficulties in expanding capacity limits electricity availability in certain areas, at certain times of the year, and increases line efficiency losses.

Aging infrastructure – much of the nation's energy delivery infrastructure (electricity and natural gas), particularly within urban centers, is over one-half century old. This leads to increased risk of failure, poor power quality and high replacement cost.

The Goal

The goal of this program plan is to develop the technology, application knowledge and educational infrastructure necessary to enable CHP systems to provide at least 8 GW of onsite electrical power and an additional 10 GW of thermal energy.[iii] This effectively contributes a total of 18 GW of affordable efficient energy to the Nation's energy network.

To achieve this goal, accelerated research, development and demonstration (RD&D) of CHP systems is required and certain policy and regulatory barriers must be removed. A joint industry-government partnership is needed to accomplish this goal.

Deployment

Financial Risk - the financial risks to undertake the breadth and diversity of this CHP endeavor will not be borne by industry alone as most consumers have not factored into their buying decisions environmental impact and energy stability issues.

Utility Restructuring - there are many facets of utility restructuring that impact programs like CHP, however, the most significant impact is the virtual cessation of research, development and demonstration (RD&D) funding and technical support from utilities and energy industry originations like the Gas Research Institute

(GRI)[1] and the Electric Power Research Institute (EPRI). The addition of new RD&D funds from the states in the form of Public Benefits Funds has not come close to equaling the amount the utilities provided in the past.

Bridge to the Future

Partnership - the CHP program proposes an important industry-government partnership that reaches across the private sector to create a new industry that integrates major equipment from different companies with intelligent control systems and then further integrates these new systems into buildings and industrial processes. Because of the decline in utility RD&D spending, it is critical for the U.S. DOE to play a larger role and become an important partner for bridging the technology gap, particularly in the areas of systems integration for which there is no current industry leader.

Technology - the U.S. Department of Energy is already working in the field of microturbines, fuel cells and certain thermally activated technologies. However, the efficiency and environmental challenges of the New Economy require a new level of engineering focus. CHP technology is ready to support business, industry and our communities today. However, we have been a nation that has created very good "stand-alone" products. The future requires that our energy consuming products become far more intelligent and integrated. It is only by integrating electric and thermal equipment together with power generation equipment and intelligent control systems and further integrating these systems with buildings and industry that the results stated above can be achieved. However, this requires a new approach to equipment design, new controls, new integrated systems, and even cleaner small-scale power technology.

- Controls are yet to be developed to fully integrate CHP equipment, CHP systems to building loads and CHP systems to the grid. The level of control integration needs to take place far earlier that natural market forces will encourage as there is no market value places upon emissions, indoor air quality or energy consumption. By the time market forces come to bare, far too much damage will have occurred to the nation's economy, the environment and manufacturer's ability to globally compete from a US manufacturing base.
- Integration is the only way to achieve a significant change in energy efficiency. Integration between onsite power generation and thermal energy use equipment, systems to load (i.e. buildings and potential district energy users) and to the grid must begin today to become effective by the middle of the decade.

Regulatory Issues - regulatory and institutional barriers, based on the regulated monopoly model of the past interferes with market development. For example:

- The existing regulatory framework for energy generation, delivery, and use favors incumbent suppliers;
  - Stranded cost charges
  - Unfair standby charges
- Environmental siting and permitting requirements are different from state-to-state;
- Input-based emissions standards prevail, rather than the more comprehensive output-based emissions standards
- Lack of pre-certification of smaller-scale CHP systems has meant that many profitable small projects have not been implemented.
- Lack uniform and streamlined siting processes has meant higher than needed installation costs.
- Lack of uniform interconnection standards has also driven up the costs of installation beyond what is really needed.

Education - There was a clear CHP Initiative consensus that for market transformation to take place during early stages of the technology development, engineering risk reduction is essential. Education is the cornerstone that will assist in risk reduction by providing reliable CHP design options for commercial and institutional building applications. The goal is to accelerate CHP verification and integration into the building

[1] The Gas Research Institute recently merged with the Institute for Gas Technology (IGT) and formed the Gas Technology Institute (GTI)

trades in order to offset growing electric demand, improving electric grid reliability, improving power quality, increasing energy efficiency and lowering air emissions.

The Results

Price stability – greater use of distributed energy and CHP systems will lead to lower costs of delivered energy compared with the costs of grid-connected energy because of improved energy efficiency and the elimination of line losses. Higher energy efficiency also yields less peak demand for electricity, cleanoil and natural gas.

Energy savings – significant reduction in foreign oil imports can be achieved utilizing CleanOil technologies in place of oil fueled simple cycle and combined cycle power plants could save a similar amount of energy.

Emissions reduction – based on energy produced (power and thermal), CHP systems outperform the best available combined cycle power plants by 33% by recovering more energy and eliminating line losses. On this basis, CHP systems are already among the cleanest in the nation.

Grid support – CHP systems can provide grid support through on peak electric power saving to prevent brownouts and blackouts.

Dependence on Foreign Oil – conserving natural gas and cleanoil and efficiently using it for clean power reduces American dependence on foreign oil.

Competition and choice – clean, efficient, reliable, and affordable alternative energy solutions are the best way to assure competition among suppliers, that consumers have choices, and thus that energy prices remain as low as possible.

CleanOil

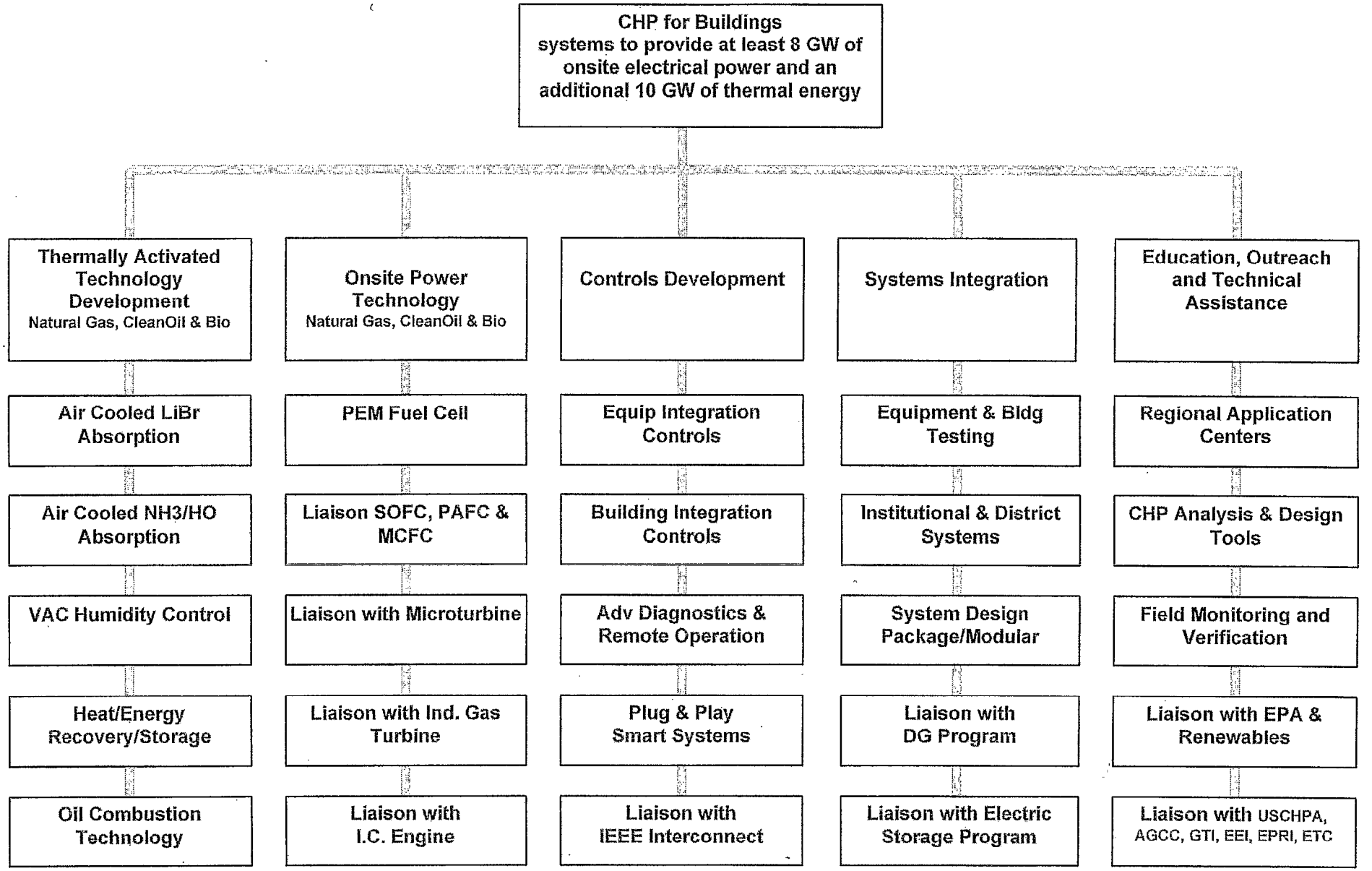
The strength of our nation was built on the efficient and effective use of fossil fuels. Oil, in particular, has made the nation an economic powerhouse. Today there are more than 10 million homes that are heated with oil. Oilheat™ continues to be an excellent value[iv]. Oilheat™ is a free market commodity. This assures customers that they can choose the Oilheat™ supplier with the best home heating comfort product, inclusive of service, reliability, supply and price.

The fuel oil industry is largely made up of 8,000 small business that service households and commercial customers in specific regions of America where oil remains a very strong economic value. Many of these customers live and work in the northeast where the electric grid is under severe restriction, natural gas transmission infrastructure is not adequate for the transition to the digital economy and where 6,000 Oilheat™ suppliers and marketers are ready to rapidly deploy CleanOil technology for heating, cooling, onsite power and Cooling, Heating and Power (CHP) systems.

Fuel oil is already an important source of standby energy when natural gas supply is scarce or uneconomical. In fact, the winter of 2001 saw many natural gas generators switch for natural gas to oil for solid economic dispatch reasons. Therefore, it is essential to understand that a viable CleanOil™ needs to be developed for those states where fuel oil is an important energy source and can become a valuable part of the energy solution as we move toward a fully digital economy.

The Oilheat™ industry is coming forward today to invest and help the nation solve one of its most pressing problems as it ventures to expand its horizons in partnership with Brookhaven, DOE and manufacturing partners to move beyond heating to include cooling, power and CHP for buildings.

The Program


CHP for Buildings systems to provide at least 8 GW of onsite electrical power and an additional 10 GW of thermal energy
Thermally Activated Technology Development Natural Gas, CleanOil & Bio
Air Cooled LiBr Absorption
Air Cooled NH3/HO Absorption
VAC Humidity Control
Heat/Energy Recovery/Storage
Oil Combustion Technology
Onsite Power Technology Natural Gas, CleanOil & Bio
PEM Fuel Cell
Liaison SOFC, PAFC & MCFC
Liaison with Microturbine
Liaison with Ind. Gas Turbine
Liaison with I.C. Engine
Controls Development
Equip Integration Controls
Building Integration Controls
Adv Diagnostics & Remote Operation
Plug & Play Smart Systems
Liaison with IEEE Interconnect
Systems Integration
Equipment & Bldg Testing
Institutional & District Systems
System Design Package/Modular
Liaison with DG Program
Liaison with Electric Storage Program
Education, Outreach and Technical Assistance
Regional Application Centers
CHP Analysis & Design Tools
Field Monitoring and Verification
Liaison with EPA & Renewables
Liaison with USCHPA, AGCC, GTI, EEI, EPRI, ETC

i U.S. EPA National Air Pollutant Emissions Trends 1990-1998, August 2000

ii 3.4% represents the direct buildings portion of the 46 GW CHP Challenge recognized by the U.S. Department Of Energy "Energy Accomplishments, Investments, Challenges POWERING THE NEW ECONOMY", dated September 27, 2000

iii 3.4% represents the direct buildings portion of the 46 GW CHP Challenge recognized by the U.S. Department Of Energy "Energy Accomplishments, Investments, Challenges POWERING THE NEW ECONOMY", dated September 27, 2000

iv The Issues

- In the U.S. there are more than 10 million homes that are heated with oil. Oilheat continues to be an excellent value. Oilheat is a free market commodity. This assures customers that they can choose the oilheat supplier with the best home heating comfort product, inclusive of service, reliability, supply and price. Even in this day of utility deregulation most consumers have little or no choice as to who supplies their energy needs. Oilheat enhances the energy supply diversity of the United States and provides the customer with an opportunity to choose.
- Traditionally the price of oil has been a driver for consumers, particularly in the Northeast. Over the past few years volatility in oil price has increased concerns over the security of heating oil supply. Recently the price of natural gas has risen at a much faster rate than oil, raising concerns also. Many commercial natural gas-fired boilers are switched to heating oil during high use periods or during periods of high gas price. Under the current climate it would be most prudent to keep heating energy supply options as open as possible and to promote reduced energy use in general to provide to consumers the greatest assurance of reliable supply.
- Oilheat technology has not received as much R&D attention over the past 20 years as have other technologies. Technical advances in oil heat technology have been deployed in the market place at a much higher rate in Europe than they have in the U.S. There is great potential for an increase in the technical level of oil heating.
- The oilheat industry, comprised of many small businesses, were unable to cooperatively support research in the past due to anti-trust regulations. In passing the National Oilheat Research Alliance (NORA) Act of 2000, the Congress has authorized new opportunities for the oilheat industry in consumer education, research and development, and industry education. Recognizing the need for and benefits of increased R&D in the oil heat area, the industry has supported passage of the recent NORA regulations. Under this program fuel oil distributors will be collecting funds based on sales for research, development, and education. This will meet only part of the need and enable only part of the potential to be realized. A DOE-Industry research partnership is needed to accelerate the development and deployment of advanced oil heat technologies.
- The US Department of Energy, oilheat marketers and oilheat equipment manufactures can be justly proud of the environmental record of improvements that oilheat research has accomplished over the years. The development of currently available efficient clean burning oil equipment has contributed significantly to enhanced air quality along with a safer environment thanks to

improvements in fuel transportation and storage systems. Important issues remain that can make oilheat even more environmentally friendly. One area is the nature of the fuel itself, by improving the characteristics of the fuel we can make additional improvements to the air quality, by introducing the use of bio-fuels as a blending agent we can make oilheat renewable, and with new research in fuel systems we can make it even more safe for the environment.

- The Challenges
  - The oilheat industry is comprised of roughly 7,000 oil marketers, the vast majority are small businesses which sell oil and service equipment in the homes of their customers and many small equipment and or component manufacturers who do not have large research departments. While these companies are innovative and very interested in advanced technology they are reluctant to divert their limited technical staff or to add a large number of staff for a limited time R&D effort.
  - Service cost is a high priority for the industry. Fuel quality, which impacts both service cost and efficiency is the top priority subject.
  - Service organization's technical staff are well trained with traditional and at times outdated equipment and tools. Any equipment change requires investment on their part in terms of training and equipment. This leads to a barrier to change which must be overcome by clear benefits of advanced technology, training support, consideration of service issues of advanced technologies and market demand.
  - New technologies are needed to provide higher efficiency, reduced service cost, lower and modulating firing rates, reduced NOx, appliance configuration options and integration with BCHP concepts. Application studies in the field are need to document the advantages and issues based on actual experience in using combining space, water heating systems and other functions and to see that reflected accurately in rating systems.
  - All of the available oilheat equipment choices are over-sized, larger in capacity than they need be, relative to the heating loads found in many modern energy efficient homes, apartments and condominiums. This over sizing results in much lower efficiency than would otherwise be possible. Current technology is limited in its ability to fire oil at lower capacities. Alternative possibilities exist but require research and development for use in the oilheat industry.
  - There is a lack of information available on in-use efficiency and usage patterns, which could help, define new configurations, opportunities and potential efficiency gains.
  - Advanced technologies developed in Europe are not directly applicable to the U.S. context because of different regulatory environment, industry practices, service practices, hardware configurations and consumer preferences.
  - Current products on the market are reliable and inexpensive, presenting somewhat of a challenge to the developers of any advanced concept. Indeed system designs have evolved relatively slowly so that many components have gravitated towards standardization over the years. A new and innovative product design that departs from the norm radically is at a disadvantage in terms

of market acceptability. Issues include training service technicians on new designs and repair parts availability for a new system. The answer so far has been to keep the old technology running if it was built in 1940. A systems focus is required looking at how advances in control technology can be applied, investigating possible thermal storage options, and resolving issues on distribution versus efficiency.

Paper No. 01-05

NORA Education Committee Report

Robert Hedden
The Hedden Company
3125 Lilly Hill Rd.
Pawlet, VT 05761
802-325-3509
bhedden@sover.net

NORA Education Committee Report
Robert Hedden, The Hedden Company

The NORA Education Committee held its first meeting on March 15, 2001 at the New England Fuel Institute Headquarters. Thirty-seven people including twelve manufacturers, seven NORA state associations, three trade publications, six professional trainers, and representatives from NAOHSM, PMAA, OMA, and NEFI attended the meeting.

NORA's President, John Huber started the meeting with a NORA Update. He told the group that NORA is like a three legged stool. The legs are Research and Development, Consumer Education, and Industry Education and Training. NORA's renewal in four years depends on our being successful in all three areas within the next two years. In order to accomplish this we need to start to deliver value to the Oilheat Industry this summer. The goal of the committee is to identify and prioritize early deliverables for education and training.

Meeting discussions centered upon how we can best invest the portion of NORA money earmarked for education. Four percent (4%) of the NORA national budget will be for education, $480,000 in 2001 $720,000 in 2002, the states will also probably invest part of their 85% of the NORA budget on education. We talked about how much of the education budget should be for technician education and what other education should we be doing.

We first focused upon the state of Oilheat Education today including the PMAA Technician Certification Program. We identified Industry weaknesses Education should address and how we can better organize our Industry Education effort. We decided the committee must not only concern itself with technician training, we also must work to improve driver, CSR, management, sales, marketing, and customer relations training. We talked about creating suggested career paths and a corresponding training plan. We worked on ways to avoid duplication of programs, as well as a plan to identify what programs already exist and promote them to the industry so that all can benefit. A big area of concern is educating management to the need to make money in the Service Department and show them how to do it. Once we see the Service Department as a profit center, then recruiting and educating our people becomes easier. So we must educate management on how to succeed, to invest in education, to reprioritize their focus on service, and to increase equipment sales. We also concluded that Cooperative Training Programs like Carlin University are successful and should be expanded. We need better basic training, for example: how to use tools, soldering, making a flare joint, and how to properly join two wires with a wire nut. We need more and better electrical and combustion training. Once we have highlighted all the weaknesses in our offerings, we should solicit manufacturers, free lance educators, and associations to create them in a cooperative fashion to reduce overhead and maximize distribution to the industry.

Next we discussed the challenges for the future and what should be our priorities. The biggest problem seems to be how do we attract bright young people to our industry? We must go to the schools, and reach out to parents since they have a strong influence on kids' career decisions. We must expand our recruiting focus to include women, and the underemployed in other fields. We will work with NAOHSM on the Benefits of a Career in Oilheat Program they already have underway.

There are HVAC trainers and programs like NATE that do not understand oil, yet are claiming to teach it. Do we need to explore the idea of certifying trainers? Should we develop train the trainer programs, with lesson plans and core curriculum?

How do we educate technicians in remote areas and parts of the country where independent contractors rather than oil companies service the equipment? Over two million oil burners in the U.S. are not serviced by oilheat companies. If they are being serviced at all, it is plumbers and air conditioning contractors who are doing the job. How do we insure that they are doing it right? Conventional wisdom has it that technicians learn best with tactile, hands-on training. If this is true, how do we economically take hands-on training on the road?

We must do Education Needs Analysis. How can we best accomplish this? Curriculum, once we have established educational needs, must we survey what is already available and create the programs that do not currently exist?

We must explore all the high and low technology options and packages our educational offerings in all the appropriate delivery technologies. How can we best exploit the new information sharing technology to get our message out to the front lines?

We seem to be covering basic training pretty well. The problem is with advanced and refresher training. How can we better link R&D and Education? It seems that our technological advances are outrunning our education. We have so much great new information, new products, and improvements on old products, but they are not getting to the front lines.

At least half of the oilheating equipment out in the field is outdated and/or oversized. The problem is this stuff is not as clean burning, efficient, economical, and reliable as it could be. Our customers are not experiencing the comfort of state of the art oilheat. The results are conversions to other fuels, new homes not being built with oilheat, and a poor reputation. Is this an Education problem? If it is, what can we do about it?

Over 30 people is too many for a working committee, so we decided to create several action committees to get things done. The Action Committees are: The Deliverables Committee, The Education Delivery Technologies Committee, The Technician Certification Committee, The Management Training Committee, The Technician Recruiting Committee, and The Brave New World Committee.

Prioritized Action Items- NORA deliverables, we will create a package of proposals for the NORA Board of Directors to consider at their meeting on June 12. The proposed deliverables are:

- Do a study of the number of technicians in the field, the current demand for technicians, the average age of the technicians in the field, and their amount of experience. We will also ask how many technicians would be let go if we only had any alternatives. This will help us determine the extent of the technician shortage. If the current technicians need more training, and experience, how many replacements will we need, and when will we need them. Bob Hedden will write the proposal.
- To give the industry an idea of how they work, we propose to create a CD/ROM on oil burner combustion. John Batey will write up the proposal.

- We identified a need for a catalog of Oilheat Education resources. The catalog will include a list of the industry trainers and the courses they offer. It will list all the manufacturer's trainers and the courses they offer. It will also include a listing of all the books, videos, CD/ROM's, "seminars in a box," and oilheat websites as well as a listing of all the training facilities, labs, and scholarships. We will also create an Oilheat Training Master Calendar. Lee Yaffa and Judy Garber will write up this proposal
- We will create an introduction to the Oilheat Industry that can serve as a new employee orientation program, as well as a recruiting tool and a basis for industry outreach and consumer education programs. It will be a combination of MOC's program and OMA's Benefits of Oilheat Program. Michael Ferrante and Bob Hedden will write up this proposal.
- Technician Certification Program- NORA should take over the program from PMAA. We are rewriting the Silver Book. We need to proof read the book and test the tests, then print it, create the teaching guide and market the program to the industry and to consumers. We decided that the loose leaf note book is still the way to go. We also decided it is time to rewrite the Gold Book and extend the scope from just conservation to also include heating systems, improved reliability, performance, and comfort. The Continuing Education Program needs work, we need to track credits, get a better handle on certified courses, and explore the idea of increasing the number of CEU credits required (currently 24 hours in 5 years). Bob Hedden and Mike Markarian will write this proposal.
- We should create a generic Oilheat "seminar in a box" for Building Inspectors, and Code Officials. Mike Markarian will write this proposal.
- Thanks to the referendum process we now have the best Oilheat Industry mailing list we have ever had. We propose to create an Education Needs Analysis survey to send to the list. Peter Cullen will write up this proposal.
- There could be significant Public Relations benefits to creating NORA scholarships to train disadvantaged people for careers in the Oilheat Industry. John Huber will write up this proposal.
- Technician recruiting is a major challenge for us. We will create a poster to displayed in class rooms about the advantages of a career in the Oilheat Industry. Al Little will write up this proposal.
- One of the problems we identified is the reluctance of managers to invest in education for their people. We decided the place to start to solve this problem would be to do an economic analysis of the cost of a call back, in monetary terms, and in lost customer confidence and satisfaction. We will ask John Nardozzi if his Fuel Track Program can help us with this. Peter Cullen will write this proposal.
- Some areas in oilheat country currently have no education programs. We felt it would be worthwhile to create a "how to start a training, and Oilheat Promotion Program" instruction manual. Judy Miller will write up this proposal.

The next NORA Education and Training Committee meeting will be at the NAOHSM Convention on Monday May 14, 2001 in the afternoon.

Paper No. 01-06

Marketing Oil Heat in Europe: A Study in Contrasts

Ralf Kühnemund
Market Manager
Testo, Inc.
36 Ironia Rd.
Flanders, NJ 07836
800-227-0729, Ext. 134
ralf@testo.com

Marketing Oil Heat in Europe: A Study in Contrasts

By Ralf Kühnemund, Market Manager, Testo, Inc., 35 Ironia Rd., Flanders, NJ 07836
Phone: 1-800-227-0729 ext. 134, Fax: 973-252-1729, Mail to: Ralf@testo.com

1. **Introduction**
2. **Technical Differences**
3. **Legal Aspects**
4. **Oilheat Numbers and Facts**
5. **Marketing: Why it comes down to efficiency...**

1. Introduction

Besides the good beer and tasty food, it is more than just light switches, doorknobs, windows and toilet bowls that make homes so different in Europe. There is also a very fundamental difference in the reasons why people build or buy their own homes, and how they are designed, in order to keep a desired level of comfort. Therefore, the heating system plays a very important role in homes in Europe.

When I say Europe, I am basically talking about my home country Germany, because that's where I spent 30 years of my life and that is where the biggest part of my experience comes from. The presentation is also focused on residential 1 or 2 family homes.

Many people in Germany build their own one family home to stay there for the rest of their life and to be able to give their children a home, once they pass away. These houses are built to last for a very long period of time, very often for several generations. This is why they build them on concrete foundations and with brick walls, usually up to 1 foot thick, including a very effective insulation and Thermopane ® windows. Roofs are usually tiled and also very well insulated.

This type of sealed house prevents losing heat in the winter, and it also prevents heat from getting in during the summer months. Because of these differences in

construction and because of the cooler climate, air conditioning cooling systems are not necessary and are very unusual in residential homes in Germany. The heating systems in Europe typically have a very important dual function: To supply both the heat and the domestic hot water!

2. Technical Differences

Whereas here in the **U.S.** people most likely have a **separate hot water heater** and use **forced hot air** to heat their homes (if necessary at all), the most common type of heating systems in **Europe** is the **hydronic heating** system. Today, it usually **combines the heat supply as well as of domestic hot water**. Therefore, a typical hydronic heating system in Germany has two circulation systems, one for the supply of hydronic heat and the other one for the supply of the domestic hot water.

The circulation for the water as the transfer fluid (heat carrier) is usually controlled by an outside temperature sensor, and heat kicks in, as required according to the outside temperature and the settings of the controls of the radiators in the various rooms. This type of control allows for effective thermal zoning. In the U.S. thermal zoning in the residential market is a growing trend.

The rooms in the house usually have radiators (size and/or quantity depending on room size), which have an integrated thermostat and control. This thermostat allows for a much greater degree of control than the control valves typically found in the U.S.. It gives people the possibility to set the desired level of heat for each room. Bathrooms and livingrooms nowadays are equipped increasingly with radiant floor heating, primarily because it is so comfortable.

There are building guidelines that outline the volume of circulated water necessary in a heating system based upon the size of the radiators and the distance from the furnace.

A second circulation system for the domestic hot water is usually connected to a hot water reservoir (corresponding to the hot water heaters in the U.S.). In a

single family home the size of the tank is about 55 gallons. These tanks are well insulated to minimize heat loss. They are connected to a thermostat and usually kept at a temperature of at least 130-140°F.

Basically there are two variations of how the water for the hydronic heat and for the domestic hot water is supplied:

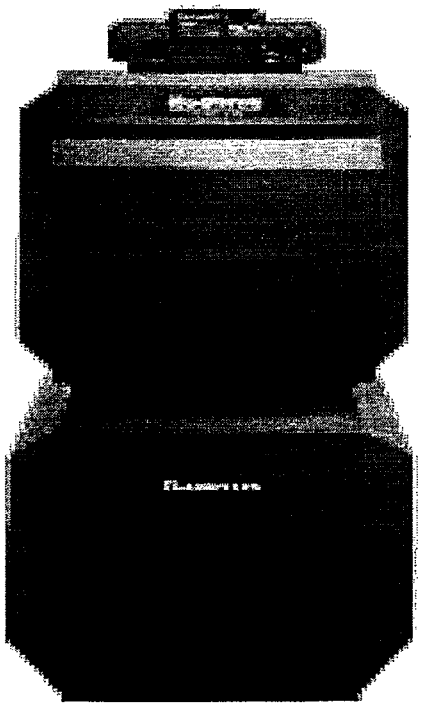
a) Internal to the heating system itself, on top of the furnace. This is chosen most frequently, where space is very limited. This internal tank usually holds just a very limited amount of domestic hot water. The hydronic heat carrier (system water) is limited to the system volume and passes through the heat exchanger as needed by means of a pump.
b) In a separate hot water reservoir, usually located in a large, well insulated tank adjacent to the furnace. For a one to two family home it holds about 300 to 350 gallon of water, which includes approximately 50 to 80 gallon of domestic hot water in a seperate internal tank. This tank is located in the top of the reservoir. This solution is very comfortable, because there is always a sufficient amount of hot water available, even if there are peaks in the use of domestic hot water.

   It is also better from a technical point of view, because the burner is heating bigger amounts of water and thus running on higher capacity and for longer cycles, instead of many short cycles at a lower capacity.

By now it is obvious that European heating systems, no matter if oil or gas fired, are more complex than the majority of the ones in the U.S.. It gets even more complicated, when people combine these systems with other forms of alternative energy sources, such as solar heating. This is actually quite typical as during the summertime, the alternative energies can often keep the domestic hot water at the required temperature and additionally people get financial rebates from the government.

Operating and servicing this kind of equipment (see Fig. 1) with LCD computer controls requires a high level of training. Therefore the requirements, to become a heating technician in Germany – a journeyman, not a foreman - include 3 years education, with at least one day of technical school per week. To get his certificate, the student has to pass a final test at the local "Chamber of Industry and Commerce". In order to run your own business, it is required to go to a technical school for another year (usually on own expense) and to graduate as a heating contractor master one must pass a final test on a federal level. Compared to the U.S., this is quite a difference!

system with separated water tank



Combined system

Fig.1: Examples of European style oil heating systems

3. Legal Aspects

Germany has a law, the "1. Bundes Immissionsschutz Verordnung" (1. Federal Imission Control Act), that determines the minimum efficiency a heating system must reach depending on its capacity.

Residential 1 to 2 family homes would fall under the first category of up to 25 kW or 85000 BTU. The maximum allowed flue gas loss for heating systems in this category, which were installed after January 1st, 1998, is 11%, which means, they must have an efficiency of at least 89 %.

In the U.S. federal law requires manufacturers of furnaces to use AFUE (Annual Fuel Utilization Efficiency) to rate efficiency. Effective January 1, 1992, all furnaces produced have a minimum AFUE level or 78%. AFUE is obtained from an empirical equation, which accounts for losses of exhausted latent and sensible heat, cyclic effects, infiltration and standing pilot losses yearround.

The AFUE rating is a design control that the U.S. Government places on manufacturers. However, who checks the heating system after it has been installed? What regulations are there to ensure continued efficiency?

In Germany the Chimneysweep Guild (besides many other functions) is charged to take official measurements once a year on every oil or gas heating system above 4 kW (13650 BTU).

If the system does not have the required efficiency, the responsible chimneysweeper will give the homeowner a limited period of time to have the equipment serviced and adjusted. If after this period the heating system still does not have the required efficiency, the chimneysweeper is entitled to shut it down! The chimneysweep is not authorized to make the changes to the system, this way there is reduced possibility of fraud from the service industry.

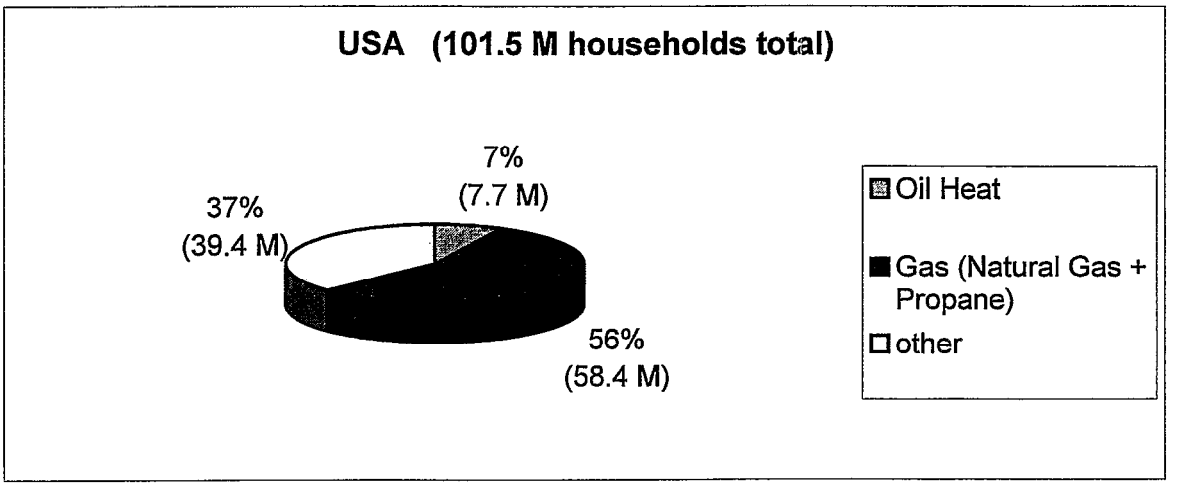
Again, to become a chimneysweeper it requires three years of education from a special technical school. After a couple of years as a journeyman one is able to take further education to become a certified master with a final test on federal level. This will entitle a chimneysweeper to take over responsibility for a dedicated district.

The Central Chimneysweep Guild Association ("ZIV" approx. 8,000 members and 25000 employees) is member of the European Chimneysweep Federation ("ESCHFOE"), and the President of the German ZIV (Eugen Steichele) is also the President of the ESCHFOE. The U.S. National Chimney Sweep Guild (see www.ncsg.org) is a guest member of ESCHFOE.

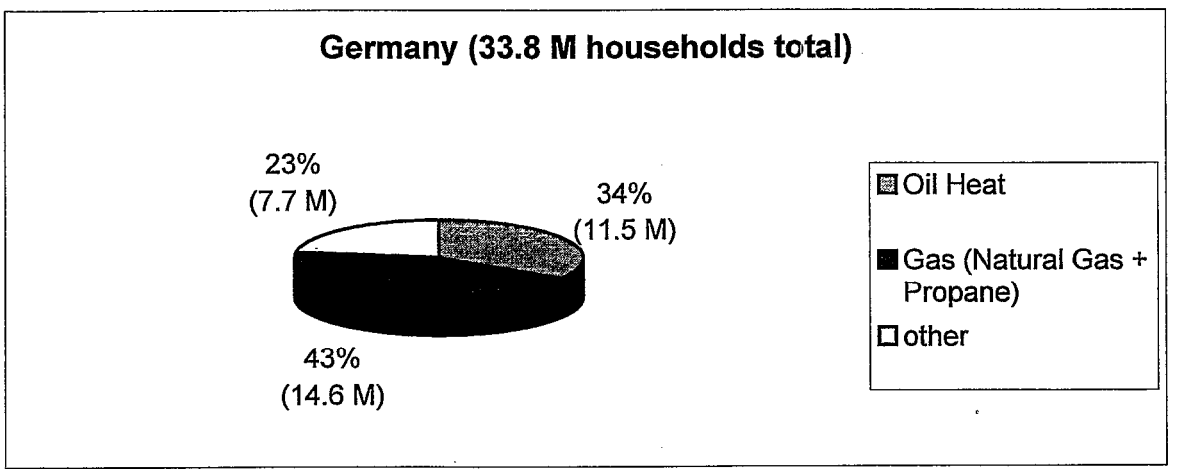
Since the requirements for heating systems are so tough, the German government offers financial support to homeowners, who replace heating systems, that were built prior to 1984 (lower interest rates on loans through federal credit agency), and to customers who combine a new heating system with alternative energies (cash allowance).

4. Oil Heat numbers and facts

4.1 Coverage



Source: Energy Information Administration, USA



Source: Federal Agency for Statistics, Germany

With 11.5 Million systems, Germany actually has more oil heated households than the United States with only 7.7 Million!

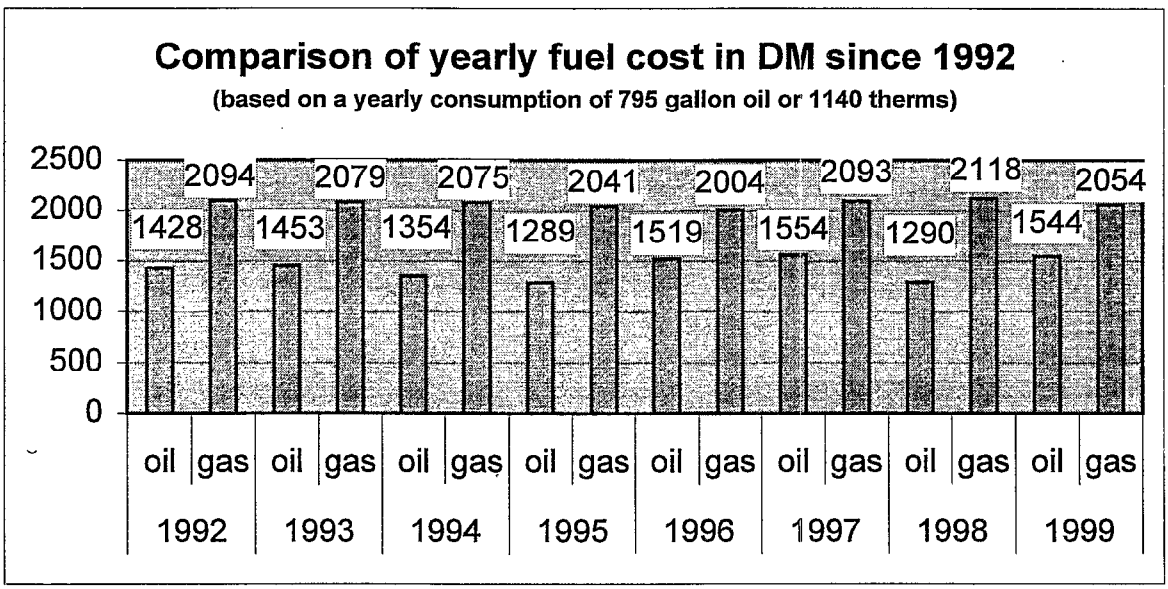
4.2 Fuel Cost

Following table shows average fuel cost prices as per January 2001:

	Germany	USA
Average Price Heating Oil (1 Gallon)	1.35 US$	1.53 US$
Average Price Natural Gas (1 Therm)	1.25 US$	0.96 US$
Compareable Price for Gas compared to Oil (Based on 140,000 BTU/ Gal. or 1.4 Therm)	1.75 US$	1.38 US$

Source: Institute for Economic Oilheating (IWO), Germany, Federal Agency for Statistics, Germany, Energy Information Administration, USA

An interesting thing to look at is also the development of fuel prices in Germany since 1992:



Source: IWO, Germany

5. Marketing: Why it comes down to efficiency...

We have seen that from a perspective of fuel prices, heating oil has historically been in a better position in the German market. However, when fuel oil prices rose sharply last fall, they were nearly as high or even higher, than natural gas. Following the previous OPEC decisions, to sell effectively the oil heating industry needs to push other factors as well.

Another issue is safety... There have been tragic gas explosions including several deaths in Austria and Germany in the last couple of years. As a result, concerns about the safety of residential heating systems have increased.

Similar to the U.S., the German oil heat industry makes a big point of the fact, that people can buy heating oil when they want and from whom they want and thus can profit through the freedom of choice.

It is important to know, that in Germany the "Green Party" is currently powerful in the government. It is obvious that CO_2 emissions and the whole topic of global warming are handled more seriously. As a result, the efficiency of heating systems is also taken seriously.

In Germany there is an association called " Institut für wirtschaftliche Ölheizung e.V." (IWO), the institute for economic oilheating. The members and associates are representatives of the oil and heating appliance business and include companies like BP, Shell, Conoco, Buderus, Vaillant and Danfoss. They actively support the development of the oil heating market in Germany by generating and accumulating basic knowledge through technical articles and advertising in technical magazines. They also contact customers directly at industry specific seminars and at regional and national trade shows. At the shows and seminars they distribute brochures that inform about the advantages of oil heat, about oil heating systems, the fuel "oil" itself and about fuel storage. These brochures are free of charge and distributed to contractors as well as homeowners. (See also www.iwo.de)

But the most important message from the oil heat industry is, that oil heating systems today are almost as efficient as natural gas fueled systems. Thanks to the research and development efforts of the oil heat industry, there are low temperature oil heating systems available on the market that show efficiencies up to 96%. Considering the fact, that the "efficiency gap" between oil heat and natural gas is decreasing, investors can amortize the higher installation cost of an oil heating system faster than in the past, because their variable cost is lower. So, in summary – the people in Germany build things to last forever – the investment is calculated over a longer period of time. And therefore again, with higher efficiency and thus decreasing variable cost, today oil heating systems show a higher profitability for the consumer than in the past.

There is certainly a lot of work to do, to convince people all over the U.S. that on the longterm they will save money with an oil heating system. But as already said: It is not just an issue of money (even if it is very often the first thing that we look at)! Environmental responsibility, especially towards our children and following generations, durability, reliability, freedom of choice, independence and safety are additional facts that need to be considered to make up a decision for what kind of heating system a homeowner should chose.

Paper No. 01-07

Diagnosing Burner Problems with Recorded Data
"The solution to any problem is obvious...once it is found"

John E. Bunting
OnWatch Electronics Inc.
PO Box 448
New Boston, NH 03070-0448
603-487-3400
jb@onwatchinc.com

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"The solution to any problem is obvious...once it is found."

by John E. Bunting
OnWatch Electronics Inc.

BACKGROUND

Thank you very much for the opportunity to address you today.

If it is true that Necessity is the Mother of Invention, then perhaps it is equally true that Frustration is the Father. More than 20 years ago this speaker was frustrated by the recurring, intermittent failure of his oil burner. These safety lockouts had no pattern other than that they seemed to occur during the day when no one was home or during the night when no one was aware.

While it was a source of frustration for this speaker, the ongoing problem was an even greater source of frustration for the oil burner service company. After trying various logical 'fixes', the company was faced with the undesirable and expensive route of changing parts "until the problem went away." Keep in mind that each service call required about 20 miles of travel, so the expense to the company became very significant.

The frustration led to the question, "Why can't there be a 'black box' for oil burners?"

Service companies in every industry are plagued with intermittent equipment malfunctions and the oil burner service industry is no different. Automotive repair technicians face similar challenges but have the benefit of both on-board computers and portable data loggers that can be attached to the car and will record while the customer is driving. The need in the oil burner service world was for a similar piece of equipment that could be attached to a problem oil burner and would record until the failure next occurred.

Because of this speaker's frustration more than 20 years ago, OnWatch Electronics developed the OnWatch Burner Monitor. The logic is very simple: To record important operational data until the intermittent problem reoccurs, then allow the customer to reset the burner, and have the device save the data until the technician can return.

To use previously recorded data to diagnose a burner problem was new to the oil burner service industry. We wondered if it was possible to diagnose the cause of a failing oil burner with data that had been previously recorded when no one is present. And, just as important, what data needed to be recorded? Our research led to the development of a proprietary, patented system to record the operational data of an oil burner.

PROBLEM TO THE INDUSTRY

Intermittent burner problems cause repeat service calls which result in several significant issues impacting the burner service industry. Some of these include loss of income, increased parts expense, decreased perceived professionalism, decreased customer goodwill, potential loss of customers, and lowered service technician morale. At OnWatch we believe that recorded data can successfully address the problem of diagnosing intermittent oil burner problems.

For a burner service company, when a service technician makes a repeat service call for the same customer complaint, there is very little chance of recouping any of the cost. In the customer's mind, this is simply a continuation of the first service call. The customer's perception is that the only reason the service company is back is that the first technician was unable to diagnose the problem correctly. Customers do not expect a second bill. Unfortunately the costs continue for the company. All of the overhead expenses keep ticking away. All of the compensation and other direct expenses keep adding up. And none of these expenses is offset by any income for the hour or two that the technician spends trying to diagnose the problem.

While the monetary loss is well known, one impact that this speaker feels is not sufficiently recognized, is what repeat calls can do to a technician's morale. After all, it is the tech who is in the uncomfortable position of having to face the dubious customer. It is the tech who has to provide all the smooth talk to explain that intermittent problems are tough to catch and that the technician who was there last time is a good technician, and that this time it should be different. All the while the technician is praying that some part on the burner will fail so that it won't be just an intelligent guessing game. This puts stress on technicians and no tech wants to leave a customer's house with the nagging feeling that, "I just know we're going to be back there soon."

Additionally, repeat calls hurt the oilheat industry, as a whole. As we all know, the oilheat industry is in competition with other heat sources that claim to be less trouble-prone. Each time a homeowner changes to a different heat source, he/she has to have a reason. The homeowner has to be able to state a perceived reason for switching. To a customer, perception is reality, facts are not. If the customer perceives that their heating system has been unreliable because of an intermittent problem resulting in multiple service calls, then that will be the reason they give to their friends and neighbors. Or it may simply be a reason they switch from one service company to another.

PRODUCT DEVELOPMENT

The basic design of the OnWatch Burner Monitor was established by common sense. The monitor had to be portable so it could be used over and over again, it had to be

quick to install (in less than one-half hour) and its job would be to record until the problem reoccurred regardless of how long that might be.

Such a diagnostic tool had to work entirely in the background. It couldn't make demands on the customer. Likewise, it had to be convenient for the service company. It turned out that both needs were met with the same aspect of the recording algorithm. This portion of the software involves detecting when the burner system has failed and lockout has occurred. Detection of a lockout condition is done by monitoring the call for heat and the output voltage of the burner primary controller. If after five minutes of a steady call for heat power does not go to the burner motor, then it is deemed that safety lockout has occurred. At that point the device will stop recording. It is "frozen."

The importance of this is that it would permit the customer to reset the burner. If the burner did restart, as they so often do, then heat would be restored. And it meant that the service company could return at its convenience to examine the data.

For the next step in developing the product, which was first introduced in 1994, OnWatch Electronics spent a great deal of time talking with many service managers, technicians and vocational school instructors. The discussions with industry professionals gave us information on what were the significant causes of intermittent problems that they encountered. Interestingly, the list included every part of an oil burner system as well as some external factors such as line voltage, boiler controls, and wiring.

Taking all this, we had to decide what information to record. One objective was to make sure the product could be universally used. That dictated that the installation had to be universal. It also dictated that the operational parameters that were recorded had to be generic in nature. For example, it was discovered that, depending on the method and frequency of recording, something as simple as voltage output could not only provide the line voltage, but also would permit diagnosing virtually all motor problems. Our method of determining voltage is to take a low average of a collection of samples. As you will see later in this paper, by using the low average, diagnoses of faulty start switch assemblies can be made confidently.

During our research it became apparent that other subtle problems could be diagnosed through the proper interpretation of recorded, generic data. In the worst case, the data would point to the specific area that was causing the problem, but that, in and of itself, was a great step towards correctly diagnosing the cause of an intermittent failure.

Attachment #1, titled "Recording Sequence", shows what the device records and when it is recorded. Please note that some items have been added since the original product was introduced. The parameters we record are:

- Calls for heat
- Line voltage
- Power venter proving
- Voltage potential across the cad cell circuit terminals

- Stack temperature
- Nozzle line pressure
- Fuel line vacuum
- Amperage

The data saved in the device's memory includes not only that from the failure run but also several sets of data from previous successful burner runs. This historic data, as you will see, is very important in interpreting the cause of the failure. Interpreting the data and thereby diagnosing the cause of the failure consists mainly of comparing the data from the faulty run with that from previous runs when the oil burner system operated correctly. A particular oil burner will sequence very consistently. One burner may differ dramatically from another but a specific burner evidences similar characteristics time after time after time. The question then becomes, "Where did the sequence of events in the failure run deviate from the normal pattern and how did it differ?"

RECORDING SEQUENCE

Looking at the same Attachment #1, the chart shows the frequency of recorded data. You will note that there are two primary sections to the software. The first section, titled Detailed Recording, encompasses the first 50 or so seconds of the burner operation, and is a step by step record of the start up phase of the burner. After the first 50 seconds, the software goes into Monitor Mode.

Monitor Mode continues for the remainder of the burner run. During this phase, the device looks for any significant change in the operation and then makes a new record of all of the parameters. This recording phase could last for an hour or more if the burner operated that long. From a design point of view, the important point is that the unit does not record any more data until something significant happens. This means that the memory in the device could be smaller, which would help keep costs down, and the technician would not have to wade though great quantities of irrelevant data.

When the burner motor is shut down, whether from achieving a high limit condition or the end of the call for heat, that data set ends and the monitor waits for the next call for burner operation. That new operation will then trigger another Detailed Recording sequence followed by another Monitor Mode sequence.

The device retains data from at least 15 of the most recent burner operations, providing historical data which is critical for correct interpretation.

INTERPRETING DATA

By looking at a few scenarios, the reader will see how the recorded data can be used to diagnose intermittent problems.

Attachment #2 is sample data from a "normal" burner run. Good operational data provides a baseline to compare to failure sets. [NOTE: These data sets come from several different burners, so it may not be valid to compare one intimately with another, but there are enough consistencies to make a comfortable diagnosis.]

SHORT CYCLING

One piece of data recorded is the number of calls for burner operation, or calls for heat. This is a sequential count. Turn, please, to the data set labeled "SHORT CYCLING," Attachment #3.

In this data the reader will see a series of rapid Thermostat On, Thermostat Off readings. This data came from a boiler. The OnWatch Monitor records every call for heat as a Thermostat On, whether initiated by a thermostat on a furnace or a boiler control on a boiler. If this short cycling had happened in front of the technician, diagnosis would be easy but burners don't always misbehave when they are supposed to.

The number of calls for heat can be dramatic. To the our knowledge, the highest number of calls for burner operation was recorded by a company in Rhode Island. The OnWatch was installed on a furnace which went to lockout after just three days. The data showed that there had been 7463 calls for heat. The service manager checked the thermostat and saw that it appeared to be in good condition. He then examined the thermostat circuit wiring. While not finding any loose connections or broken wires, he did notice a little bit of dried calcium on one of the "T" terminals. He looked directly above and there was a valve with a leaking valve stem. Once in a while a drop of water would land on the "T-T" terminals causing chattering of this circuit. This probably should be categorized as one of the external factors that can impact the operation of a burner.

LINE VOLTAGE PROBLEMS

The cause for the intermittent lockouts at the speaker's house, mentioned at the beginning of this paper, was simply low line voltage. Even though it went on for two months and it was very difficult to determine, the most aggravating part was that the repair took all of five minutes. The power company simply changed the tap on the pole-mounted transformer, increasing the voltage to the house.

MOTOR PROBLEMS

Burner motors, generally speaking, do three things. They run like they are supposed to, they have faulty starting switch assemblies, or they are physically prevented from spinning. As it turns out, if the voltage is recorded in a certain way and according to a certain pattern, it is very easy to determine any of the three. Compare Attachment #2, the so-called normal burner run, with Attachment #4.

Attachment #2 indicates that the motor did start. Our first voltage reading at 00:00:00 elapsed time is 108 volts. Two seconds later it has risen to 118 volts. This voltage

increase is typical and is a prime example of using recorded data to reconstruct history. The initial low voltage is a reflection of the high amperage draw of the starting windings of the motor. Once the motor gets up to speed and the starting switch disconnects, the amperage draw drops significantly and the voltage increases. Certainly in this case we can see that the fuel pressure has also been established, which confirms the fact that the motor started. But if in another situation the fuel pressure stayed at zero and the same voltage increase occurred, the data would point to a fuel problem and not a motor problem. The data confirms that the motor did start.

The OnWatch monitor is like the high speed camera. It samples the voltage very quickly, calculates a low average and records it. The OnWatch starts its recording cycle 1/30 of a second after it detects meaningful voltage coming out of the burner primary controller. Like the high speed camera, it records quickly.

A faulty starting switch assembly is a specific term for a number of problems, any of which can be intermittent. This is often called "a dead spot" but that is a misnomer. The condition can be caused by the starting switch linkage hanging up, or perhaps there is dirt on the starting switch contactor ring, or there is a bad section of the starting windings, or for some other reason that there is no voltage going through the starting windings of the motor. Any of these situations can spontaneously clear up between the time the burner locks out and someone presses reset, and that is the problem.

By looking at Attachment #4, the voltage pattern recorded by the OnWatch Monitor is significantly different from that of the normal burner run. The data shows no significant voltage increase at start up and it is confirmed by zero pump pressure.

CONCLUSION

The reader has seen a few examples of how recorded data can be used to diagnose vexing problems in an oil burner system. If a burner fails in front of the technician, the repair is obvious. With an intermittently faulty component, the tricky part is to get it to fail. Space does not permit more examples of malfunctions, but suffice to say that in almost all cases the defective component can be pinpointed. There are a couple of situations, however, where the cause is narrowed down to one of two components.

We are working on products in the future which will have this type of recording capability embedded into one of the regularly installed components, such as the primary controller, so that the information will be there when the technician first arrives.

At OnWatch Electronics, it is our intention to lift the level of service of the entire oilheat industry by providing a diagnostic tool that will address the problems of economic loss, customer dissatisfaction, damaged industry image and lowered technician morale caused by intermittent oil burner failures.

As a wizened, old service manager once said, "Son, the solution to any problem is obvious...once it is found."

ATTACHMENT #1 **Recording Sequence**

MODEL 51 RECORDING SEQUENCE - OIL

Version 1.23

ATTACHMENT #2 **Normal Burner Run**

SET: 28 Start Time: 18:38:41 Start Date: 02/07/2001
Recording Mode: Oil

Elapsed	TT	VOLT	CAD	TEMP	PSI	VAC	PV	AMP	EVENT
18:38:41	02/07/2001								Thermostat On
00:00:00	ON	104	6.1	103	0	0	N		Sample
00:00:02	ON	118	5.8	103	142	0	N		Sample
00:00:04	ON	118	2.1	103	142	0	N		Sample
00:00:06	ON	117	1.8	103	142	0	N		Sample
00:00:08	ON	118	1.8	103	142	0	N		Sample
00:00:10	ON	118	1.8	103	142	0	N		Sample
00:00:13	ON	118	1.8	105	142	0	N		Sample
00:00:18	ON	118	1.8	109	142	0	N		Sample
00:00:23	ON	118	1.8	113	142	0	N		Sample
00:00:28	ON	118	1.8	118	142	0	N		Sample
00:00:33	ON	118	1.8	122	142	0	N		Sample
00:00:38	ON	118	1.8	127	142	0	N		Sample
00:00:43	ON	118	1.9	132	142	0	N		Sample
00:00:48	ON	118	1.8	137	142	0	N		Sample
00:00:53	ON	118	1.8	142	142	0	N		Stack Temp Change
00:00:59	ON	118	1.8	147	142	0	N		Stack Temp Change
00:01:05	ON	118	1.8	152	142	0	N		Stack Temp Change
00:01:11	ON	118	1.8	157	142	0	N		Stack Temp Change
00:01:16	ON	118	1.9	162	142	0	N		Stack Temp Change
00:01:22	ON	118	1.8	167	142	0	N		Stack Temp Change
00:01:28	ON	118	1.8	172	142	0	N		Stack Temp Change
00:01:33	ON	118	1.8	177	142	0	N		Stack Temp Change
00:01:39	ON	118	1.8	182	142	0	N		Stack Temp Change
00:01:45	ON	118	1.8	187	142	0	N		Stack Temp Change
00:01:51	ON	118	1.8	192	142	0	N		Stack Temp Change
.	.	.	.	.	.	.	.		.
00:03:17	OFF	OFF	<1.0	266	0	0	N		Thermostat off

ATTACHMENT # 3 **Short Cycling**

SET: 1412 Start Time: 05:12:20 Start Date: 12/14/2000
Recording Mode: Oil

Elapsed	TT	VOLT	CAD	TEMP	PSI	VAC	PV	AMP	EVENT
05:12:20	12/14/2000								Thermostat On
00:00:00	ON	OFF	<1.0	82	0	0	N		Sample
00:00:01	OFF	OFF	<1.0	82	0	0	N		Thermostat Off

SET: 1413 Start Time: 05:12:21 Start Date: 12/14/2000
Recording Mode: Oil

Elapsed	TT	VOLT	CAD	TEMP	PSI	VAC	PV	AMP	EVENT
05:12:21	12/14/2000								Thermostat On
00:00:00	ON	OFF	<1.0	82	0	0	N		Sample
00:00:00	OFF	OFF	<1.0	82	0	0	N		Thermostat Off

SET: 1414 Start Time: 05:12:22 Start Date: 12/14/2000
Recording Mode: Oil

Elapsed	TT	VOLT	CAD	TEMP	PSI	VAC	PV	AMP	EVENT
05:12:22	12/14/2000								Thermostat On
00:00:00	ON	OFF	<1.0	82	0	0	N		Sample
00:00:01	OFF	OFF	<1.0	82	0	0	N		Thermostat Off

SET: 1415 Start Time: 05:12:23 Start Date: 12/14/2000
Recording Mode: Oil

Elapsed	TT	VOLT	CAD	TEMP	PSI	VAC	PV	AMP	EVENT
05:12:23	12/14/2000								Thermostat On
00:00:00	ON	OFF	<1.0	82	0	0	N		Sample
00:00:00	OFF	OFF	<1.0	82	0	0	N		Thermostat Off

SET: 1416 Start Time: 05:12:23 Start Date: 12/14/2000
Recording Mode: Oil

Elapsed	TT	VOLT	CAD	TEMP	PSI	VAC	PV	AMP	EVENT
05:12:23	12/14/2000								Thermostat On
00:00:00	ON	OFF	<1.0	82	0	0	N		Sample
00:00:01	OFF	OFF	<1.0	82	0	0	N		Thermostat Off

SET: 1417 Start Time: 05:12:24 Start Date: 12/14/2000
Recording Mode: Oil

Elapsed	TT	VOLT	CAD	TEMP	PSI	VAC	PV	AMP	EVENT
05:12:24	12/14/2000								Thermostat On
00:00:00	ON	OFF	<1.0	82	0	0	N		Sample
00:00:00	OFF	OFF	<1.0	82	0	0	N		Thermostat Off

SET: 1418 Start Time: 05:12:25 Start Date: 12/14/2000
Recording Mode: Oil

Elapsed	TT	VOLT	CAD	TEMP	PSI	VAC	PV	AMP	EVENT
05:12:25	12/14/2000								Thermostat On
00:00:00	ON	OFF	<1.0	82	0	0	N		Sample
00:00:00	OFF	OFF	<1.0	82	0	0	N		Thermostat Off

ATTACHMENT #4 **Faulty Starting Switch Assembly**

SET: 106 Start Time: 12:49:39 Start Date: 01/22/2001
Recording Mode: Oil

Elapsed	TT	VOLT	CAD	TEMP	PSI	VAC	PV	AMP	EVENT
12:49:39	01/22/2001								Thermostat On
00:00:00	ON	121	6.0	141	0	0	N		Sample
00:00:02	ON	121	6.0	141	0	0	N		Sample
00:00:04	ON	121	6.0	141	0	0	N		Sample
00:00:06	ON	120	6.0	141	0	0	N		Sample
00:00:09	ON	121	6.0	141	0	0	N		Sample
00:00:11	ON	121	6.0	141	0	0	N		Sample
00:00:13	ON	121	6.0	141	0	0	N		Sample
00:00:18	ON	121	6.0	141	0	0	N		Sample
00:00:23	ON	121	6.0	141	0	0	N		Sample
00:00:28	ON	121	6.0	141	0	0	N		Sample
00:00:33	ON	121	6.0	141	0	0	N		Sample
00:00:38	ON	121	6.0	141	0	0	N		Sample
00:00:43	ON	120	6.0	141	0	0	N		Sample
00:00:48	ON	OFF	<2.3	141	0	0	N		Sample
00:00:53	ON	OFF	<1.0	141	0	0	N		Sample
00:05:48									Fault Detected

Paper No. 01-08

Variable Firing Rate Oil Burner Using Pulse Fuel Flow Control

C.R. Krishna

Brookhaven National Laboratory
Department of Energy Sciences and Technology
Energy Resources Division
Oilheat Research
12 North Sixth St.
Upton, NY 11973
631-344-4025
krishna@bnl.gov

and

Michael Curtis
The Lee Company
55 Bokum Rd.
Essex, CT 06425-1506
860-399-6281, Ext. 3264
curtism@theleecompany.com

Variable Firing Rate Oil Burner Using Pulse Fuel Flow Control

C.R. Krishna, BNL and M. Curtis, The Lee Company

1.0 Introduction

1.1 Background

The residential oil burner market is currently dominated by the pressure-atomized retention head burner, which has an excellent reputation for reliability and efficiency. In this burner, oil is delivered to a fuel nozzle at pressures from 100 to 150 psi. In addition to atomizing the fuel, the small, carefully controlled size of the nozzle exit orifice serves to control the burner firing rate. Burners of this type are currently available at firing rates of more than 0.5 gallons-per-hour (70,000 Btu/hr). Nozzles have been made for lower firing rates, but experience has shown that such nozzles suffer rapid fouling of the necessarily small passages, leading to bad spray patterns and poor combustion performance. Also, traditionally burners and the nozzles are oversized to exceed the maximum demand. Typically, this is figured as follows. The heating load of the house on the coldest day for the location is considered to define the maximum heat load. The contractor or installer adds to this to provide a safety margin and for future expansion of the house. If the unit is a boiler that provides domestic hot water through the use of a tankless heating coil, the burner capacity is further increased. On the contrary, for a majority of the time, the heating system is satisfying a much smaller load, as only rarely do all these demands add up. Consequently, the average output of the heating system has to be much less than the design capacity and this is accomplished by start and stop cycling operation of the system so that the time-averaged output equals the demand. However, this has been demonstrated to lead to overall efficiencies lower than the steady-state efficiency. Therefore, the two main reasons for the current practice of using oil burners much larger than necessary for space heating are the unavailability of reliable, low firing rate oil burners and the desire to assure adequate input rate for short duration, high draw domestic hot water loads.

One approach to solve this problem is to develop a burner, which can operate at two firing rates, with the lower rate being significantly lower than 0.5 gallons per hour. This paper describes the initial results of adopting this approach through a pulsed flow nozzle.

1.2 Pulsed Flow Concept

The two-stage burner operation is to be achieved thus. At the high firing rate, the flow of oil to the conventional pressure atomized burner nozzle will be continuous. The low firing rate is achieved by the cycling of the flow on and off at a high frequency, so that the average flow rate corresponds to it. Ideally, under low-fire operation the fuel will arrive at the atomizer in sharp, high-pressure pulses as illustrated in Figure 1. The fuel pulses must be sharp, as the atomization of fuel at lower pressures, which would occur with "blurred" pulses, would result in large fuel drops and poor combustion. The high operating frequency ensures that the flame is not 'quenched' and hence the operation is fundamentally different from on-off cycling. The low firing rate can be adjusted by changing the pulse widths, called pulse width modulation (PWM).

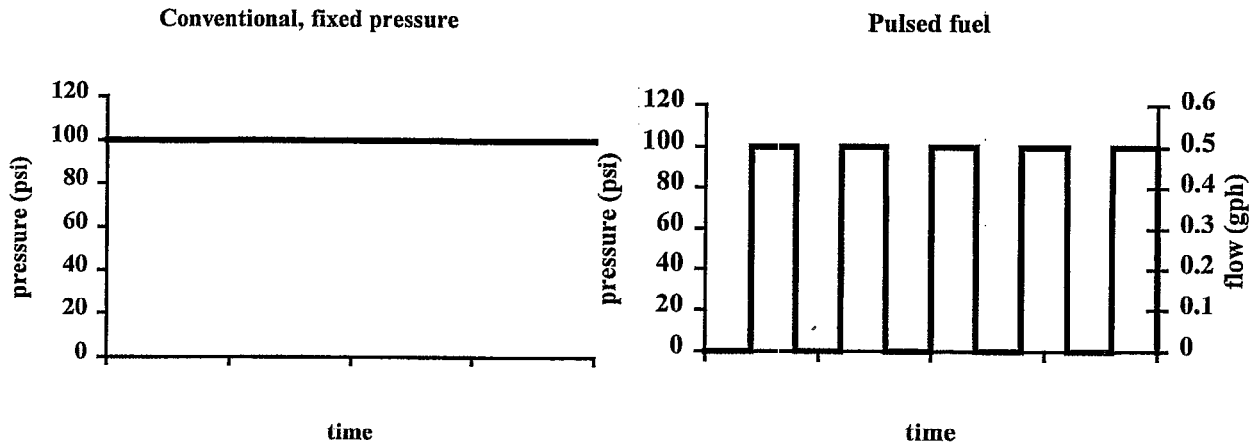
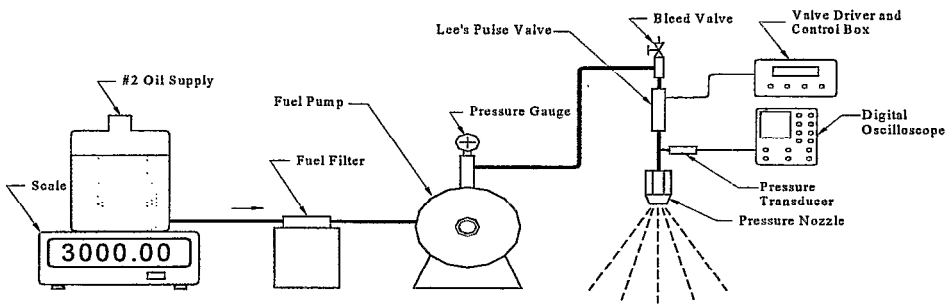


Figure 1. Ideal Normal and Pulsed Fuel Flow through a Pressure Atomizer.

Prior U.S. work has been done in this area in which the fuel flow pulses were achieved by a specially designed fuel pump [1,2]. That system has not been commercialized.
The pulse width modulation approach was implemented by the cycling operation of a solenoid valve in the fuel supply line. The valve and the drive circuit were supplied by the Lee Company. The valve was customized to fit our requirements and uses a complex circuitry to drive the low mass valve's solenoid. The packaged control circuit provided by the manufacturer supplies the normal operating voltage of 12 volts DC for a short period to open the valve and then drops it to an average holding voltage of about 3 volts. This helps to prevent overheating of the low mass valve.

2.0 Cold flow Tests

Initial tests with the valve were cold flow tests to determine the range of flow modulation possible while cycling at high enough frequencies. Figure 2 is a schematic of the experimental set-up used for the cold flow tests.
The importance of sharp pressure pulses was emphasized above. In order to measure these pressure pulses, a fast response pressure transducer was installed in the test system just before the nozzle. The transducer has a small and thin diaphragm that flexes in response to the transient fuel pressures. This flexing is converted to electrical voltages by strain gauges. This voltage output was measured by a storage digital oscilloscope, which can store the data internally and on magnetic media. The oscilloscope can also be used to perform a Fourier analysis using a Fast Fourier Transform feature. The characteristic of the nozzle spray under pulsing operation was determined using the Malvern Spray Analyzer.



The Lee's Pulse Valve Testing System Diagram

Figure 2. Schematic of Cold Flow Test set-up.

Results of cold flow testing

The Lee solenoid valve was tested in combination with a 0.5 gallons per hour nozzle at a cycling rate of about 58 Hz. The valve functioned well and in combination with the 0.5 gph nozzle gave a reasonable modulation in the fuel flow. The results of the flow modulation tests are given below in Figure 3.

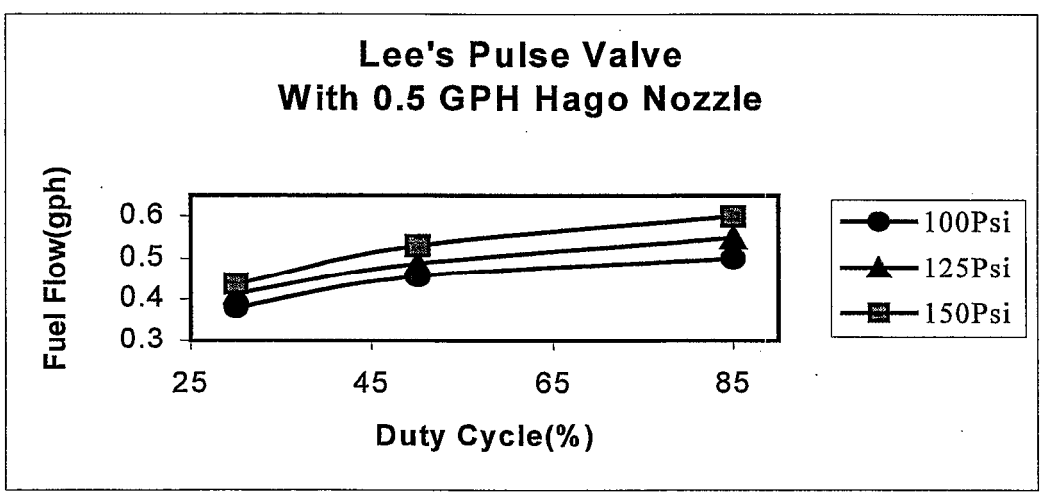


Figure 3. Fuel Flow Modulation with Lee valve.

Figure 4 below shows the volume mean diameters obtained from the Malvern spray analyzer data. As would be expected, the mean drop sizes become smaller with increase in pump pressure. As any increase in drop sizes at the lower firing rates will add to the difficulty of achieving good combustion performance, this would suggest that operating at 150 psi is especially beneficial at low duty cycles, meaning low firing rates.

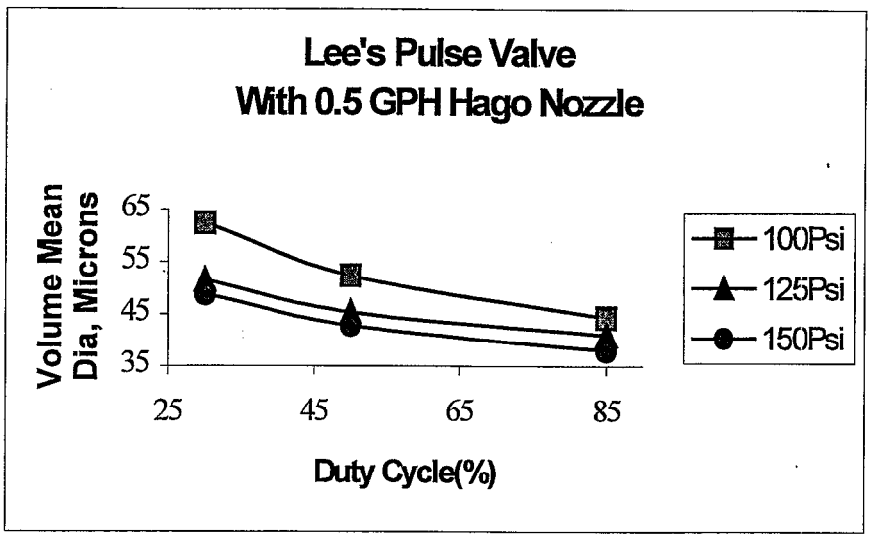


Figure 4. Volume Mean Diameters with Lee valve.

Figure 5 below is one set of data from the pressure transducer and is an example of the pressure transients measured in the cold flow tests with the Lee valve. They exhibit reasonably sharp rise and fall and the Fourier analysis indicates the primary component is at the operating frequency of ~58 Hz.

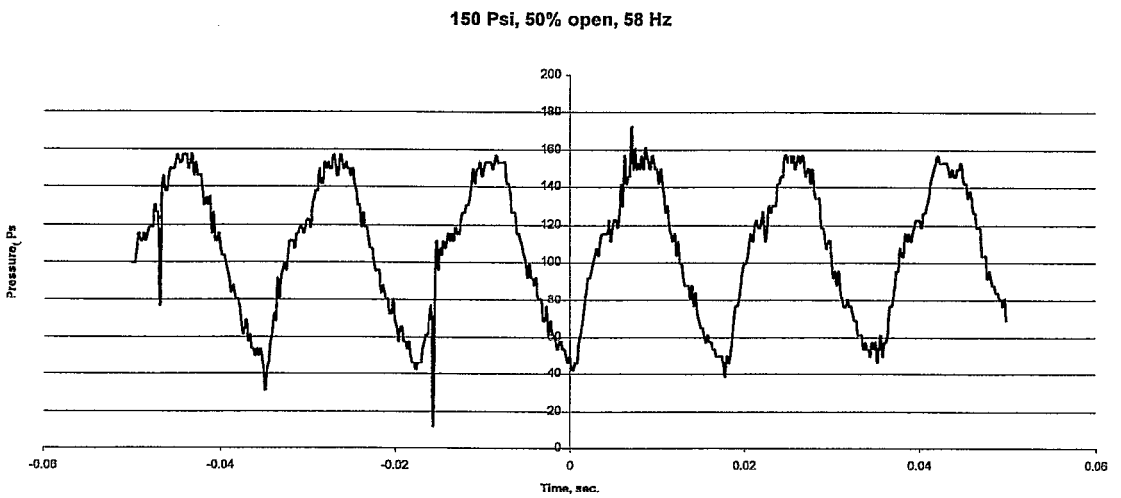


Figure 5. Pressure Transients in Lee valve tests.

Burner tests were carried out using the same nozzle in a modern retention head burner and a wet base boiler. The tests were carried out at the maximum flow rate and at the minimum flow rate attainable. Figures 6 and 7 show the effect of excess air on the smoke numbers at the low and high firing rates. It seems that the performance is worse at the lower firing rate. However, no attempts were made to optimize the system, as these were only preliminary tests and were only intended to demonstrate that such a pulsed flow system could be made to work in a residential boiler.

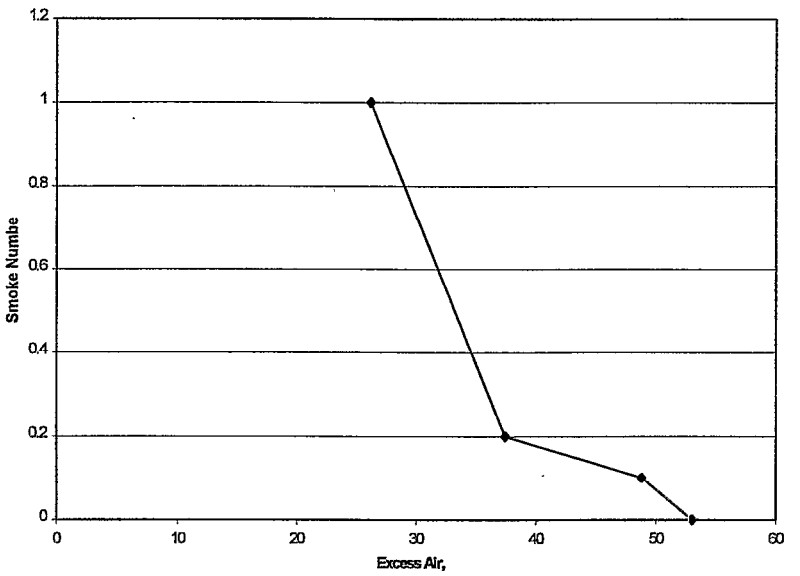


Figure 6. Lee valve burner test results at low firing rate.

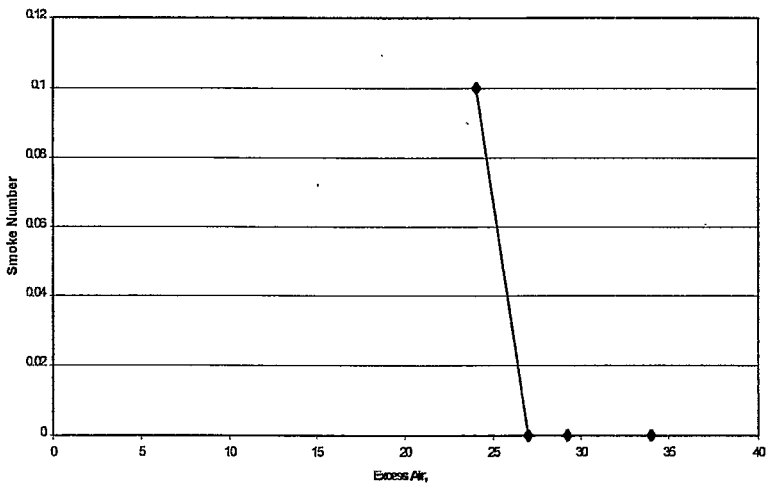


Figure 7. Lee valve Burner Tests at High firing rate.

3.0 Conclusions

Preliminary success has been achieved in showing that the proposed approach of using a cyclically actuated solenoid valve to control the flow to a conventional pressure atomizer is feasible. Preliminary results indicate that successful combustion performance can be achieved with minimal changes in a conventional retention head burner. However, the projected flow modulation of two to one has not been achieved despite a satisfactory modulation ratio in the solenoid valve. Modifications to improve the dynamic range through improvements to the valve and the system dynamics will be made and further tests will be carried out.

4.0 Acknowledgements

George Wei and Yusuf Celebi gave substantial help in the assembly and operation of the equipment. Narinder Tutu offered significant help in the choice and testing of the pressure transducer system.

5.0 References

1. Hunsberger, D., Suntec Industries, personal communication with T. Butcher.
2. U.S. Patent 4391580, Liquid Fuel Supply for an Atomization Burner Nozzle, Assigned to Sundstrand Corporation. (1980).

Paper No. 01-09

Oil-Fired, Hydronic Heating Appliances with Reduced Electric Power Consumption and Battery Backup

Richard A. Oman, Sc.D.
Insight Technologies, Inc.
1150 Walnut Avenue
P.O. Box 525
Bohemia, NY 11716
800-424-3484
roman1@optonline.net

Thomas A. Butcher, Ph.D.
Brookhaven National Laboratory
12 North Sixth St.
Upton, NY 11973
631-344-7916
butcher@bnl.gov

Bola Kamath, Ph.D,
Heat Wise, Inc.
PO Box 662
Ridge, NY 11961
631-345-0447
bkamath106@aol.com

Sponsored by: NYS Energy Research & Development Authority & US Dept of Energy

Oil-Fired, Hydronic Heating Appliances with Reduced Electric Power Consumption and Battery Backup

Richard A. Oman, ScD, Insight Technologies, Inc., Bohemia, NY
Thomas A. Butcher, PhD, Brookhaven National Laboratory, Upton, NY
Bola Kamath, PhD, Heat Wise, Inc. Ridge, NY

Abstract

This paper describes a simple system that significantly reduces electrical power consumption of residential oil heat appliances. It is based on a 12 vdc internal power paradigm, the centerpiece of which is an oil burner that operates on 35 Watts after ignition. The system uses available technology and components and introduces some innovative strategies for preserving battery power, so that heat can be supplied at emergency levels for several days through periods of power outage. During normal operation on utility power, the system consumption of electrical power is an order of magnitude less than is the current norm for residential oil heat appliances.

Acknowledgements

A number of people besides the authors made significant contributions to the work described here. Roger McDonald, Yusuf Celebi and George Wei of BNL, contributed many ideas, measurements and analysis. Doug Davis, Andrew Rudin, Vince Calia and Michael Rossi of Insight Technologies, Inc. made major contributions. Manjunath Kamath of Heat Wise, Inc. contributed to the burner development and testing.

Introduction

There is an increasing awareness of a nationwide shortfall in electrical energy supply, driven home by the reality of rolling blackouts in hard-hit areas of the country This has stimulated a new concern for electrical power conservation in the Northeast, where much of the US oil heat industry is concentrated. NYSERDA (New York State Energy Research and Development Authority) has sponsored a research program, also supported in part by the Department of Energy and corporate cost sharing, to explore the feasibility of substantially reducing the electrical power consumption of conventional residential oil heat appliances. A significant objective of this investigation is to enable emergency heating of the residence in the event of extended power outages. These outages are most likely a result of a severe winter storm accompanied by heavy coatings of ice responsible for downed power lines that can take several days to restore.

The objective of this project is to develop a practical system that would sustain minimal comfort levels for a typical residence for up to 3 days in a power outage. Brookhaven National Laboratories was selected as the prime contractor for this study, with Insight Technologies, Inc. and Heat Wise, Inc. providing additional technical support as subcontractors.

Development of the Concept

The Objectives of the Project are:

- Create a practical oil-fired system that significantly reduces electrical power consumption from the level of currently available appliances
- Provide minimal comfort level for extended periods during line power outages
- Achieve this capability at a unit cost < 1.5kW standalone generator (<< $600)

A brief review of the incentives for these objectives reveals that the Northeastern US & Europe have most of the oil heat installations and high electrical power costs (up to $0.18/kWH). Figure 1 presents a very rough evaluation of the financial incentives for the individual consumer and the nation as a whole. While electrical energy conservation is a worthwhile goal from the perspective of the National Good, the average consumer will have difficulty recognizing the subtle value of a saving in electrical power that is some percentage of $48 per year. Similarly, the national energy economy has many leaks that are much larger than the $200M per year we can attribute to the electrical consumption of oil heat appliances.

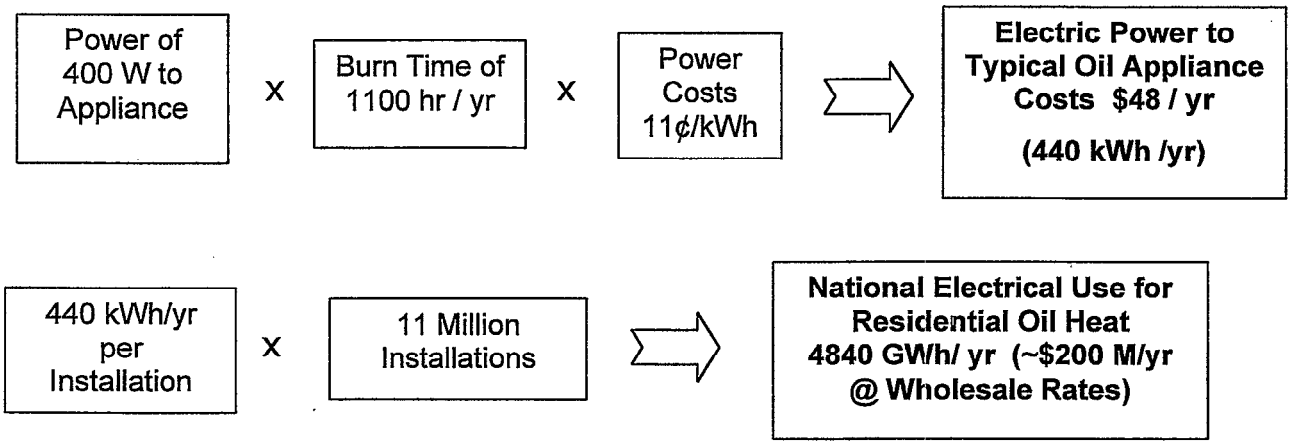


Figure 1 - A Rough Valuation Model for Energy Savings:

If we try to measure the value of the ability to sustain marginal levels of habitability during protracted power outages, we find that quantification is more difficult. One measure of this value is the cost of repair of frozen plumbing, which might reasonably be estimated at $400 per incident. Another way to measure such value is the cost of an alternative remedy, such as motel accommodations for 3 days for a family (perhaps $300 to $500, if available), or the cost of a portable generator capable of running the heating plant; perhaps $600. Complicating these value judgments, and also affecting the character of

our solution, is the reality that very few families possess the capability to manage even the simplest technical operations to convert to an emergency power mode, such as switching over to an auxiliary generator and disconnecting the utility feed to ensure line-worker's safety. We decided that an exact figure for the value of standalone operation was impossible to derive, but that setting a budget goal of much less than $600 for the incremental cost of our low-power system was probably a marketing necessity.

Power Requirements of Current Oil Appliances:

Table 1 presents power ratings of the typical components of residential oil heat appliances as they appear in the US market today. It is apparent that there has been little concern for the conservation of electrical power in the development of these components. One of the most significant consumers of power is the conventional oil pump. Because it is a positive displacement gear pump that must provide a significant suction capability to lift oil from underground tanks, is has very small clearances, and consequently very high friction losses. Another high consumption component is the conventional igniter, which operates whenever the burner is on. Conventional AC motors and fans, and the conventional circulator pumps and zone valves are also very far above the theoretically required energy consumption.

Table 1 - Component Power Usage (Watts) in Conventional Boilers and Furnaces

Component	Hydronic System	Min. Theoretical	Warm Air System
Fuel pump & fan	350	5	350
Igniter	250	0*	250
Control	10		10
Circulating pump	75	19	-
Furnace blower	NA	70	500
Total	685	← 24 / 94 →	1110

*Steady-state value ignores starting period

The fact that conventional hydronic systems are operating at < 5% efficiency indicates that there is a significant opportunity for improvement in electrical power consumption. Warm air furnaces, which are not discussed further here, are somewhat higher in efficiency; about 10%.

Energy Storage Alternatives:

Although there are many types of energy storage that are used in special situations, at this time the best candidate for maintaining the operation of a residential oil heat appliance in backup mode is the conventional lead-acid storage battery. This judgment is driven primarily by the cost limits discussed earlier, and the fact that lead-acid battery technology has benefited from the maturity provided by

many years of automotive applications, and more recently, by use in uninterruptible power supplies for computing equipment. The extractable energy content of fully-charged automotive-type lead-acid batteries start at about 500 Watt-hours (class 24) and are available in a selection of sizes up to about twice that level. The greatest advantage of this type of battery lies in their ubiquitous supply, where modestly priced charged batteries and recharging services are available at any time, any place in the US. This fact alone opens up a variety of means for extending the duration of any emergency system when rare prolonged outages occur.

System Components:

Our approach began with a search for off-the-shelf components that would provide the required functions of an oil appliance. Discovery of a solenoid-driven piston oil pump and a permanent-magnet DC motor with a very efficient integral fan; two key elements that were remarkably efficient, yet available in quantity at a reasonable cost, soon drove us toward 12 vdc power for the central components of the oil burner. Battery chargers are commercially available in any desired power output at very reasonable prices and have built-in controls that ensure that batteries will not be overcharged when left permanently connected to the charger. Tests demonstrated that these chargers run the other DC components quite effectively, whether directly connected, or in parallel with a battery. Therefore, the decision was made to develop a burner based on the 12 vdc oil pump and motor-fan combination. A conventional pressure-atomized approach was selected based on the operating characteristics of the selected components.

Tests were run to determine that operating characteristics of these components were acceptable in these roles, with the results described later in this paper. A burner was assembled based on these components, and after some evolutionary development, the present design (shown in Figure 2) was found to operate very satisfactorily at a power drain of 35 Watts. (Recall that this is approximately 10% of the requirement of a typical burner on the market today.) The motor-fan combination is more than twice the efficiency of conventional AC units. The igniter is shut off a short time after ignition is confirmed by the cad cell.

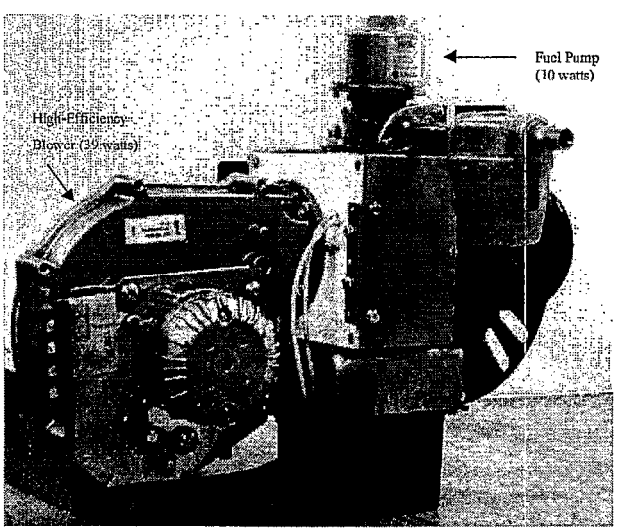


Figure 2 – A Working Prototype of the 12 vdc Burner Developed for this Project by BNL and Heat Wise. – This burner operates continuously on 35 Watts after a brief ignition period.

Figure 3 shows a typical flame from the 12 vdc burner prototype. Operating characteristics will be shown later in this paper. The success of the burner opened up the possibility of a practical system that could operate for useful periods from one or two conventional auto batteries.

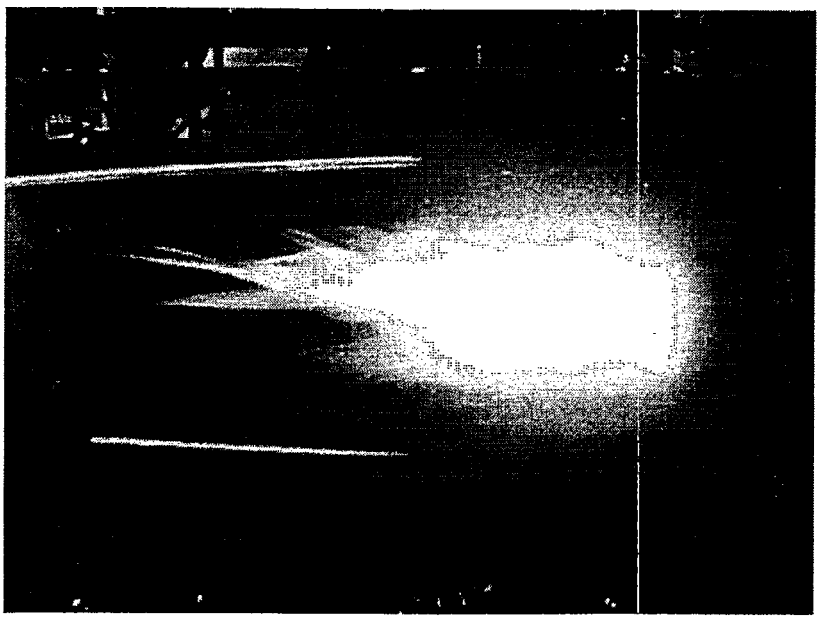


Figure 3 – View of Flame from 12 vdc Pressure-Atomizing Burner – It produces a compact, efficient flame, requires lower pressure in oil supply, and terminates gracefully at low battery voltage

The cost of developing alternatives to conventional burner controls that would operate at 12 vdc was immediately recognized as prohibitively high. Furthermore, we wanted to include both new heating installations and retrofits of existing installations in our market scope. This approach evolved with an appliance configuration that employs commercially available inverters to convert the 12 vdc battery power to nominally 120 vac, 60 Hz power specifically to run the existing peripherals of conventional boilers; aquastats, relays, zone valves, thermostats, and circulator pumps.

In the system configuration we have selected, all of the AC components except the 12 vdc power supply ("battery charger") are permanently disconnected from utility line power. The battery bank (we recommend two batteries in parallel) is permanently connected across the power supply output, which is sized to handle the simultaneous power demands of all system components. Also connected in parallel to the power supply output are relays that provide power to a DC to AC Inverter, the DC burner and the custom controller that manages the system. The controller employs proprietary technologies to conserve power in both normal (utility power) mode and in standalone mode.

Operating Modes and Characteristics:

Because the AC components of the system are completely isolated from the utility power line, there is no need to be concerned about the safety hazard associated with local power sources "back-powering" the line during outages; a factor that presents a potential hazard to lie workers. Furthermore, there is no need for an active switch to convert from normal to standalone mode, as the battery charger contains diodes that automatically isolate the DC from the AC when the AC supply fails. The battery, which functions as a short-term power source in normal mode, then automatically becomes the sole power source until utility power is available again. The controller has sensors that detect the absence of AC

power and the controller invokes severe energy conservation modes whenever in standalone state. There are also measures that are incorporated in the controller to minimize energy consumption in the entire system during normal operation.

The battery continuously powers the custom controller, whether in normal or standalone mode. The controller can shut down any or all of the other components according to the availability of power and the internal algorithms of the controller. When empowered, the inverter in turn powers the AC components, all of which operate in the conventional way whenever activated to provide regulation of the burner and heat distribution system. In the next section of this paper we present data on component operation and show results of some early testing of the burner and prototype peripherals in a residential installation.

The AC components of the heating system receive all of their power from the inverter. While the power requirements of the control elements are very small, the circulators and zone valve (if any) become the dominant power consumers in the new system. While there are proprietary control techniques for minimizing power consumption in standalone modes, we show in this paper that a hydronic system can be remarkably effective in a natural convection mode, even in a single-story dwelling.

Test Results

Battery Performance:

We conducted run-down tests of a small automotive battery to establish the minimum energy supply in standalone mode. Several different load configurations were tested, with a sample of the results shown in Figure 4.

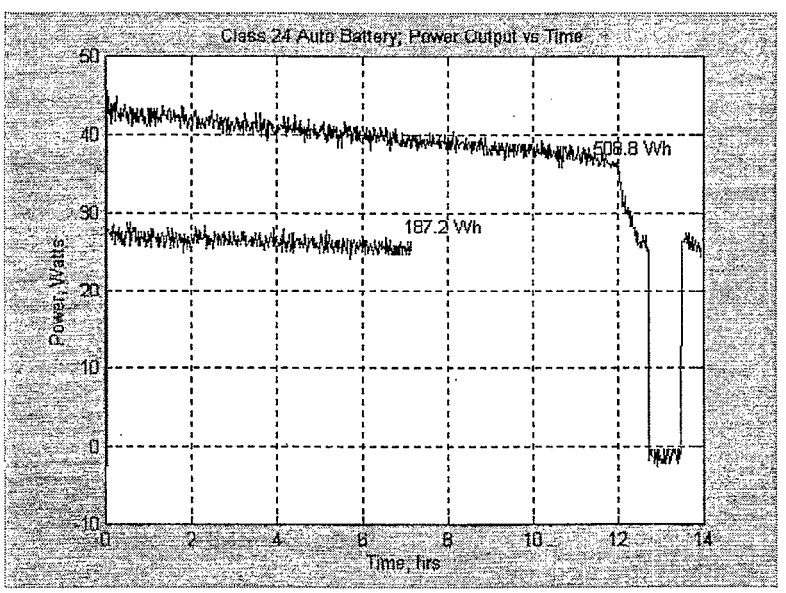


Figure 4 – Run-Down Tests of a Class 24 Auto Battery – The upper curve shows a complete discharge at a very high, continuous rate. This produces the lowest total energy. The lower curve is a partial discharge at a lower, more efficient rate.

Figure 4 establishes the minimum level of total energy that can be expected from a minimum size automotive battery in good condition. In actual use, considerably more that 500 W-Hr can be expected, because usage will be intermittent, and at a much lower rate of extraction, both of which are helpful in increasing the cycle efficiency of such batteries. The rapid drop in output at 12 hours in Figure 4 on the upper curve was tested after a rest period, and as can be seen, the battery was not capable of significant further power delivery. Since inverters will shut down if input voltage drops below about 10.5 volts and burner motor speed will drop markedly, this marks the end of use for standalone application. Multiple batteries offer the possibility of strategies such as recharging by owner's auto or at a remote site with available power, or simply purchasing an additional battery or two to extend duration to cover long outage periods.

Burner Operation from Battery in Standalone:

The next step in testing was to operate the prototype burner for an extended period from one battery from full charge to exhaustion. For the results shown in Figure 5, the burner was operated against a dummy hydronic load with a timer that switched it on for 3 minutes, then off for 7 minutes.

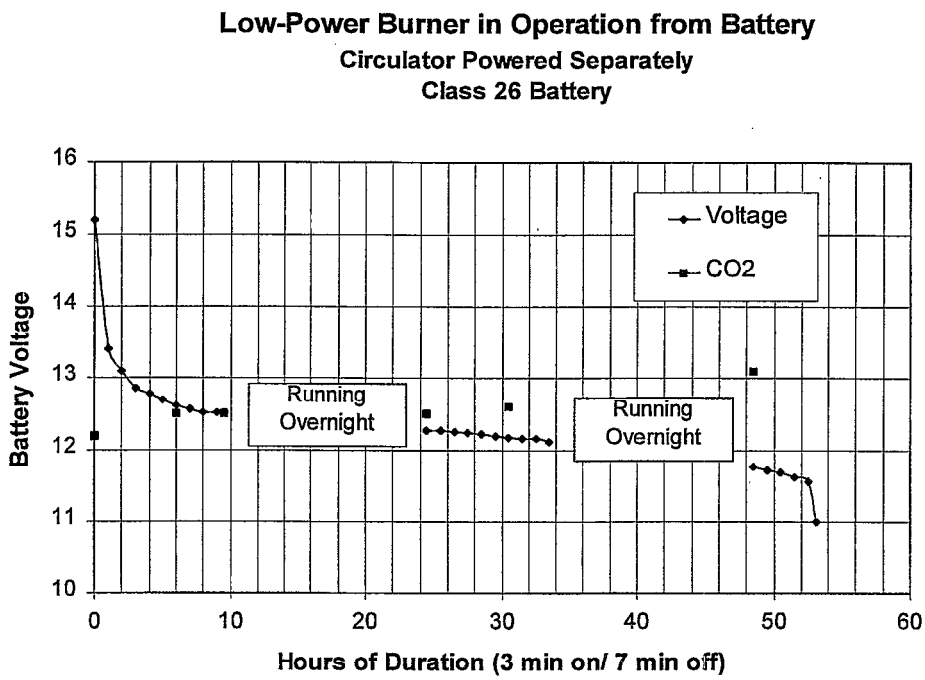


Figure 5 – Run-Down History of Prototype DC Burner Operating from Class 26 Battery – This demonstrated endurance is the basis of a practical stand-alone oil heat system.

The data shown in Figure 5 are taken with no battery drain for peripheral equipment, but they are extremely encouraging for the performance of a standalone oil burner system. The operation was quite normal during the run-down period, and when the battery finally crashed, the burner shut down cleanly.

Peripheral Component Performance:

Table II presents the data from a series of component performance measurements together with representative retail cost for some of the items specific to the current design.

Table II – Results of Component Performance Measurements

	Measured Peripheral Component Characteristics			
Component	Pow er/Energy	No-Load W	Efficiency (%)	Retail $
10A Charger	250W	55W	65%	$40
300W Inverter	<450W	2W	90%*	$55
Passive Aquastat	0	0	-	-
Aquastat Relay	6W	0	-	-
Circulator	75W	0	25%	-
Zone Valve	8W	0	-	-
Standalone Control	1W	-	NA	TBD
Class 24 Battery	500 W-hr	-	~ 50%	$40
* For Inductive Loads; 70% typical for Resistive loads				

Note that the standalone control production cost is not yet determined. The battery cycle efficiency is only estimated from industry general experience. The efficiency of 65%, which is typical of commercial chargers, applies to all of the energy consumed by the entire heating system. Switching Power Supplies have somewhat greater efficiency (~85-90%) at corresponding increase in cost over the ordinary battery charger, which employs a simple rectifying array of diodes behind a step-down transformer. The consumption of the AC components (circulators, zone valves, aquastats) is further taxed by the efficiency of the inverter. Measured efficiencies of inverters tested so far have been strongly dependent on the power factor of the load, delivering typically 90% to inductive loads like the ones listed here, but only about 65 – 70% to purely resistive loads. Note that in the presence of an oil burner that consumes a mere 35 Watts, the load of a circulator pump (e.g., Taco 007) is the dominant electrical load for the appliance system. Clearly limiting the duty cycle of the circulator is critical to achieving long duration in the standalone mode.

Some of the other considerations of a successful design relate to sizing of the components for maximum performance in standalone mode. Typically equipment operated significantly below rated capacity will have substantially reduced efficiency levels, so it is important not to oversize components. On the other hand, the power supply in our design must be capable of delivering the full electrical demand of the system, or the battery will gradually lose charge during extended periods of high duty cycle operation under utility power. The following Figures (6 and 7) show the operating characteristics of some inverters and chargers, respectively.

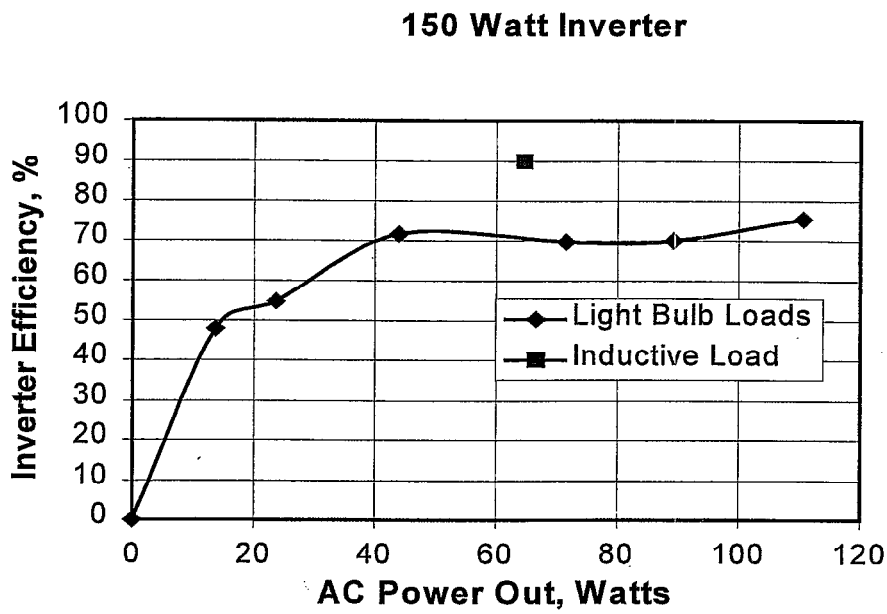


Figure 6 – Typical Inverter Efficiency/Load Characteristics – This model (Vector 023) is typical of a family that is available at a number of sizes. Competitive models behave similarly. Note the improvement in efficiency for the inductive load, which in this case was a Taco 007 circulator pump running filled with blanked flanges.

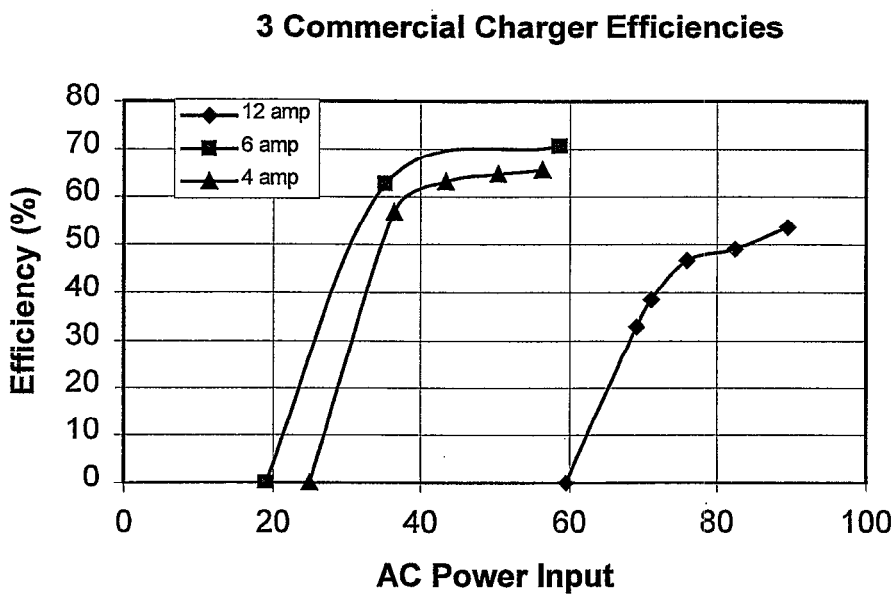


Figure 7 – Efficiency/Load Characteristics of 3 Commercial Battery Chargers – Note that there is considerable power consumed when there is no load on the charger output. It is an important function of our control to minimize this loss throughout the year. When used as a power supply, the charger must not be too large relative to the total power requirement of the heating appliance and its peripherals.

Circulators & Zone Valves

Although there are 12 vdc circulators and zone valves available, and they are generally more efficient that the standard AC models in use in the US, the high labor and material cost of circulator replacement makes replacement of existing components practical in only a few upscale situations. We therefore elected to accept the 10% losses in the inverter on top of the 75 Watts per circulator, and concentrate on minimizing circulator use. Similarly, the ideal standalone system would not use Normally-Closed automatic zone valves because the power cost of maintaining them in open position is an additional loss. Unfortunately, most US zone valves are NC automatic. Whenever possible, homeowners will be instructed to manually open zone valves while standalone service is being provided. In the last section of this paper we will discuss the surprisingly effective results of operating a single-story hydronic system with open flow valves and circulator pumps disabled.

A New Control Pulls it all Together:

Insight Technologies, Inc. is developing a digital control that will manage all of the normal functions of operation on utility power, conserving electrical power by several proprietary techniques in that routine situation. When there is a power failure, the control detects the absence of line power, and reverts to a mode of operation that provides a minimum habitation level as defined for that particular installation, seeking the longest possible duration on battery operation in that mode. To that end additional proprietary techniques and algorithms are employed to conserve battery power. A fully automatic mode that requires no action or awareness by the homeowner is the default condition, but the control can be configured at installation to suit the capabilities of homeowners who have the ability and desire to make such accommodations as manual override of flow or zone valves, or manual introduction of new or recharged batteries to prolong standalone duration in extraordinarily long outages. Finally, the control provides for graceful shutdown of the heating appliance when the battery bank is finally exhausted.

Initial Field Test:

Field tests were run in early January 2001 on Eastern Long Island on a single-story residence. The prototype 12 vdc burner used a class 26 automobile storage battery as its sole power source and the same battery also powered a 300 Watt inverter that provided power to the conventional boiler controls and circulator pump. Two separate runs were made from a fully-charged battery. No energy management was employed, the thermostat and boiler controls functioning in a totally conventional manner.

The first run was with the circulator operating normally as periodically activated by the aquastat. In that mode the battery rundown time was 10 hours. The second run was with the circulator disconnected and the flow valve opened manually. In this mode, which relied entirely on natural convection for distribution throughout the dwelling, the run-down time was greater than 24 hours (the exact termination time was not recorded due to a collection instrument problem). In this mode, the comfort level in spaces near the boiler was reported as normal, and the comfort level in the most remote areas of the dwelling was "cool", but certainly acceptable in an emergency situation. One of the authors has in the past had occasional successful experiences with a similar natural convection mode in storm survival, but with a dwelling in which the living space and the heating systems were on two different levels, giving the natural circulation an operating "head" of approximately 8 feet. To discover that even a marginal distribution is possible completely absent either forced circulation or a

substantial gravitational head is very encouraging. Apparently the density difference within the height of the boiler is sufficient to move the boiler water enough to provide some heat distribution.

Monitoring instrument results from these tests are shown in Figure 8, in which the operating cycle of the burner is indicated by the monitored flue gas temperature, and the circulation system behavior is indicated by the monitored temperature at one of the baseboard radiation units. About 5 hours of the operation are shown for each case, with the circulator active in the left panels, and inactive on the left.

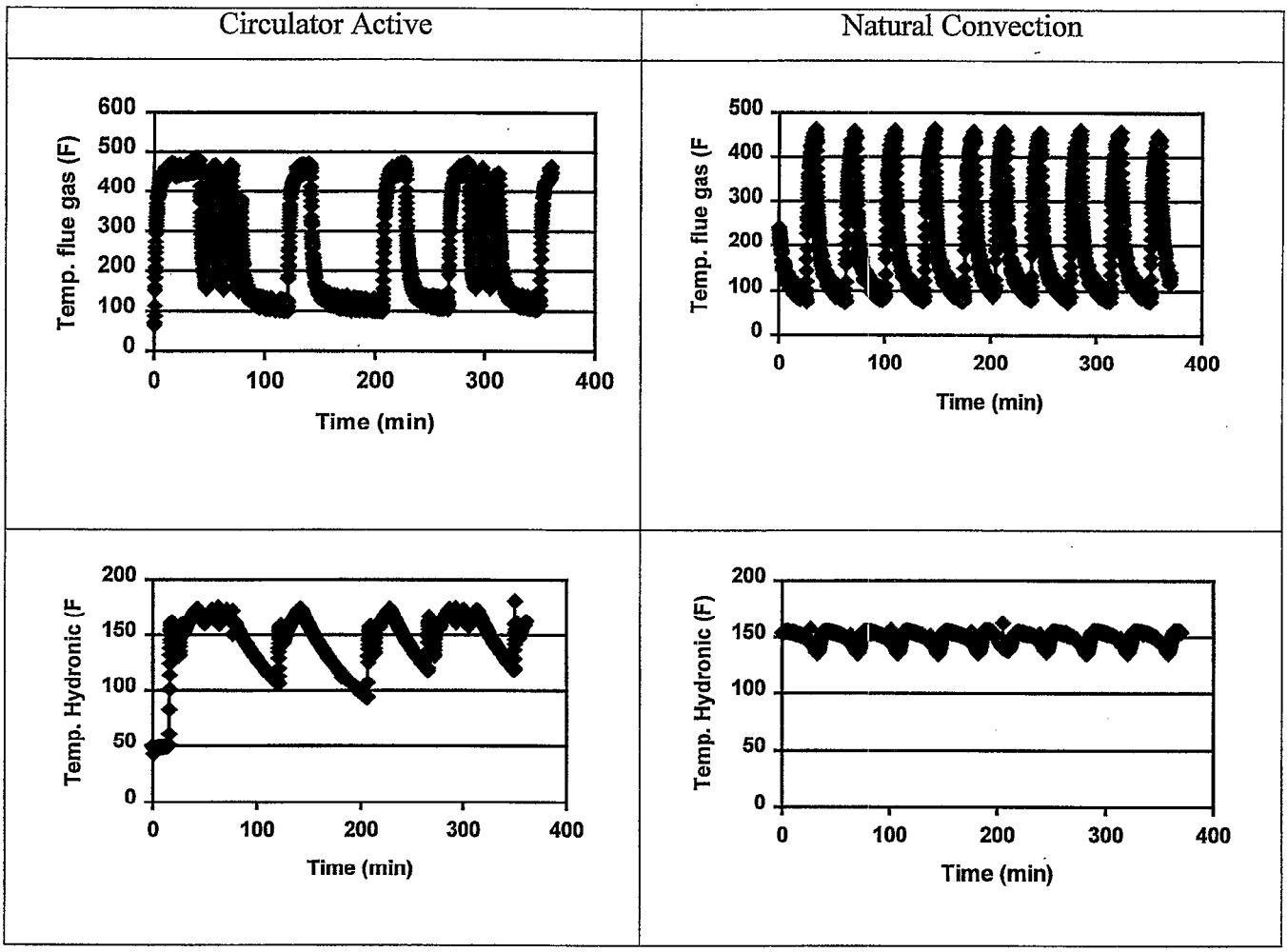


Figure 8 – Monitored Temperatures from the first Field Test of the DC-Powered Prototype Burner in Rundown Mode – Note that the case with circulator inactive on the right exhibits a much more regular pattern than the corresponding period with active circulator.

Concluding Remarks

It is possible to operate an oil burner and hydronic distribution system with about 10% of the electrical power consumption of current models. This has been accomplished utilizing 12vdc components, a mode that also permits standalone operation. A Pressure Atomizing Burner that currently operates at about 35 Watts on 12vdc power is the key element of this system. Survival heating levels of about 24

hours have been demonstrated in Winter in a single-story dwelling with one standard auto battery. This has been accomplished by disabling the circulator pump, and relying on natural convection for distribution.

A complete heating appliance that can be installed in existing dwellings is under development. In that system, existing hydronic components (Aquastat, Thermostats, Circulators, Zone valves) are powered at 120vac by an off-the shelf inverter, enabling retrofit of conventional systems at minimum cost. A 120vac to 12vdc power supply powers the burner and the inverter, isolating appliance and hydronic system from utility grid. The 12vdc power supply also maintains lead-acid storage battery at full charge. Standalone operation from batteries in this system will profit from careful energy management implemented by a Digital Control Unit that is currently under development.

Paper No. 01-10

PEEP INTO THE NOZZLE USING COMPUTATIONAL FLUID DYNAMICS!

Mahesh Panchagnula, Ph.D.
Design R&D Engineer

Delavan Inc.,
(A division of BF Goodrich Co.)
P.O. Box 969
Bamberg SC 29003
803-245-4347
mahesh@delavan.bfg.com

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Mahesh Panchagnula, Ph.D.
Design R&D Engineer
Delavan Inc.,
(A division of BF Goodrich Co.)
P.O. Box 969
Bamberg SC 29003

Introduction

The nozzle is probably the most critical component in an oil burner. The primary function of the nozzle is to atomize the fuel into drops so that they can be evaporated and burnt. It meters the fuel to the burner and also controls the spray pattern. The performance of the nozzle has a direct impact on the efficiency and pollutant emissions from the burner.

The nozzle sprays the fuel into the combustion chamber, where it is mixed with air from the burner to generate a uniform fuel and air mixture. This process is influenced by the spray pattern generated by the nozzle. This fuel/air mixture is then ignited by a high energy spark to cause a fire.

The nozzle essentially converts the potential energy that has been packed into the fuel in the form of pressure energy to kinetic energy, in the form of a swirling and highly turbulent flow. This causes the liquid sheet formed at the exit of the nozzle to break up into drops. The manner in which these drops are dispersed into the air stream determines the spray pattern. The atomization and dispersion processes in turn are governed by the internal fluid dynamics of the nozzle as determined by the nozzle geometry. Therefore, it is important to relate the spray pattern distribution to nozzle geometry and design in order for us to fully understand the performance of the oil burner system.

Introduction to CFD

The flow of fluids in general is governed by a set of nonlinear partial differential equations in three spatial coordinates and in time, called the Navier Stokes equations. The set of equations is complete once the initial boundary conditions for the problem are specified. These equations are generally not solvable analytically. They can however be solved numerically under most conditions. The process of obtaining this numerical solution to the Navier Stokes equations is called Computational Fluid Dynamics (CFD). CFD is therefore an off-shoot of classical fluid mechanics.

"Computational" has to do with mathematics computation and "Fluid Dynamics" is the dynamics of things that flow. This is CFD - a computational technology that enables you to study the dynamics of things that flow. Using CFD, you build a computational model that represents a system or device that you want to study. Then you apply the fluid flow physics to this virtual prototype, and the software outputs a prediction of the fluid dynamics. CFD is a sophisticated analysis technique. It not only predicts fluid flow behavior, but also the transfer of heat, mass (such as spray dispersion), phase change

(such as evaporation), chemical reaction (such as combustion), mechanical movement (such as an impeller turning), and stress or deformation of related solid structures (such as a mast bending in the wind).

Basically, there are three compelling reasons to use CFD:

1. **Insight**
   There are many devices and systems that are very difficult to prototype. Often, CFD analysis shows you parts of the system or phenomena happening within the system that would not otherwise be visible through any other means. CFD gives you a means of visualizing and enhanced understanding of your designs.
2. **Foresight**
   Because CFD is a tool for predicting what will happen under a given set of circumstances, it can answer many 'what if?' questions very quickly. You give it variables. It gives you outcomes. In a short time, you can predict how your design will perform, and test many variations until you arrive at an optimal result. All of this is done before physical prototyping and testing. The foresight you gain from CFD helps you to design better and faster.
3. **Efficiency**
   Better and faster design or analysis leads to shorter design cycles. Time and money are saved. Products get to market faster. Equipment improvements are built and installed with minimal downtime. CFD is a tool for compressing the design and development cycle.

Computational Fluid Dynamics as a field of study has been in existence for over thirty years. Over the last fifteen years however, it has seen a great resurgence with the boom in desktop computing power. CFD is now a feasible solution that can be implemented on most high-end desktop computers. There are a number of commercial products available that deliver CFD analysis and results with varying degrees of accuracy and confidence. FLUENT is one such premier software product that has been in existence for about twelve years. FLUENT has in the past been used to study Oil burner performance and aid in Oil burner design by Tom Butcher (1997).

Nozzle internal flow model

As we discussed earlier, a very important aspect of predicting the burner performance is the knowledge of the spray distribution and its relationship to nozzle geometry. Toward this end, a CFD model was developed in FLUENT to understand this relationship.

There are three essential aspects to a CFD Model.

1. **Geometry:** The CFD model requires the user to input the Geometry of the flow passages. This was achieved by developing a three dimensional model of the swirl volume in GAMBIT. The regions where fluid enters and exits the swirl volume are marked as the boundaries. The pump pressure is therefore the inlet boundary condition to the nozzle and the pressure in the burner is the exit boundary conditions. The flow through the nozzle is now modeled using FLUENT given this set of boundary conditions.

2. **Grid Generation:** The swirl volume in the nozzle thus obtained has to be discretized into a number of sub domains in order to numerically solve for the fluid velocities and pressures at various points in the domain. The choice of the number of grid points in the domain depends on the physical size of the domain, the complexity of flow features and the turbulence levels in the system. In this case, a grid with approximately 500,000 cells was used. In other words, the total swirl chamber volume which is approximately a cylinder about 0.25" in diameter is divided into 500,000 cells to obtain a reliable solution!
3. **Solution procedure:** The solution parameters for the CFD model have to be chosen to obtain a reliable and accurate solution. They will also have to match the physical flow phenomenon. A number of different schemes were tried but it was found that using a second order PISO/ QUICK numerical scheme yielded the best results. The solution thus obtained will contain the pressure and three dimensional fluid velocity at every point in the grid. The system of steady state equations are solved to realize a steady start and then switched over to the temporal scheme to obtain a refined solution. The model is run for about 1000 iterations in the steady state before changing to the temporal mode where it is run for about 10 time steps. The solution is allowed to converge to normalized residuals of about 0.00001 for the steady state and each time step. The solution thus obtained is post processed to solve for the velocity and pressure at each point in the domain.

The pressure and velocity flow field information can then be used to study the general flow features in the nozzle. Figure 1 and 2 show the geometry of the flow path in the nozzle for a couple of different designs. Fuel enters the slots at the rated pump pressure. The slots inject the fluid into the swirl chamber. This swirl chamber is formed by mating the distributor with an orifice disk. The distributor has slots to introduce the fuel to the swirl chamber and the orifice disk has outlet geometry to shape the spray pattern and angle. The fuel swirls in this chamber, as a result, there is a radial pressure gradient generated. This radial pressure gradient causes the fuel to stick to the walls of the swirl chamber and the exit orifice as the fuel flows out of the nozzle. In order for the model to succeed, it must capture this essential physics in the nozzle internal flow.

Results and Discussion

The first exercise in applying the results from CFD to nozzle design was to validate the results. In this case, the nozzle flow rate was used as the validation parameter. A nozzle was manufactured under controlled conditions. All the dimensions in the nozzle were measured carefully and a three-dimensional CAD model of the nozzle was constructed based on these measured dimensions. A CFD analysis was performed using the CAD geometry of the nozzle, the measured fuel properties and flow conditions. The flow rate predictions from this model were then compared against experimentally measured flow rate. Figure 3 is a graph of flow rate versus pressure for this nozzle. As we can observe, the predictions of the CFD agree with the experiments to within about 10% for all cases. Also, the model was able to qualitatively predict the relationship between pressure and flow, while consistently under predicting the flow rate to within 10%. This helped us gain confidence in the predictions of the model.

The next step along the process was to develop a parametric study of the important dimensions in the nozzle in order to study the effect of nozzle geometry on spray performance. Spray performance can thus be related to the film thickness exiting the nozzle. Figures 4 and 5 are representative results from one such simulation.

Figure 4 is a plot of the pressure in the swirl volume. As can be observed, there is a drastic negative pressure generated along the centerline of the nozzle. This is a result of the swirling flow in the nozzle that causes a "tornado" effect along the centerline. The fuel in that region is swirling at about 80 m/s!

Figure 5 is a plot of the velocity field in the nozzle exit. This plot clearly shows the swirling flow of fuel out of the nozzle as the "dark" layer of fuel sticking to the wall. The inner air core is shown by the lighter gray scale in the figure.

The air core that is formed at the exit of the nozzle is an interesting feature that determines the film thickness and therefore the drop size. This air core is characterized by a reversed flow of air into the nozzle, due to the low-pressure region inside the nozzle. Figure 6 shows the air core at the nozzle exit. This air core is responsible for the fuel to exit the nozzle in the form of a swirling film. This swirling film of fuel breaks down into drops downstream. The thickness and swirl velocity of the film determines the spray pattern and drop size in the spray. These parameters are directly linked to performance of the nozzle and thereby to the burner.

Figure 7 is a plot of the streamlines of fuel in the nozzle. This plot shows the path taken by fuel particles from the time they enter the nozzle to when they exit. The entangled streamlines show the level of mixing that is achieved inside the nozzle.

CONCLUSION

This paper describes the potential of CFD as a viable tool for the design and understanding of spray nozzles. A computational model was developed to study the internal flow inside the nozzle. This model was then used to design new simplex nozzles for specific applications.

ACKNOWLEDGEMENTS

The author would like to acknowledge the help of Dr. Daniel Lee at FLUENT Inc. for helping with the modeling and analysis. He would also like to thank Mr. Jeff Stembridge for helping putting together the presentation and parts of the model.

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Patankar, S.V., "Numerical Methods in heat transfer and fluid flow", Hemisphere Publishing Co., NY

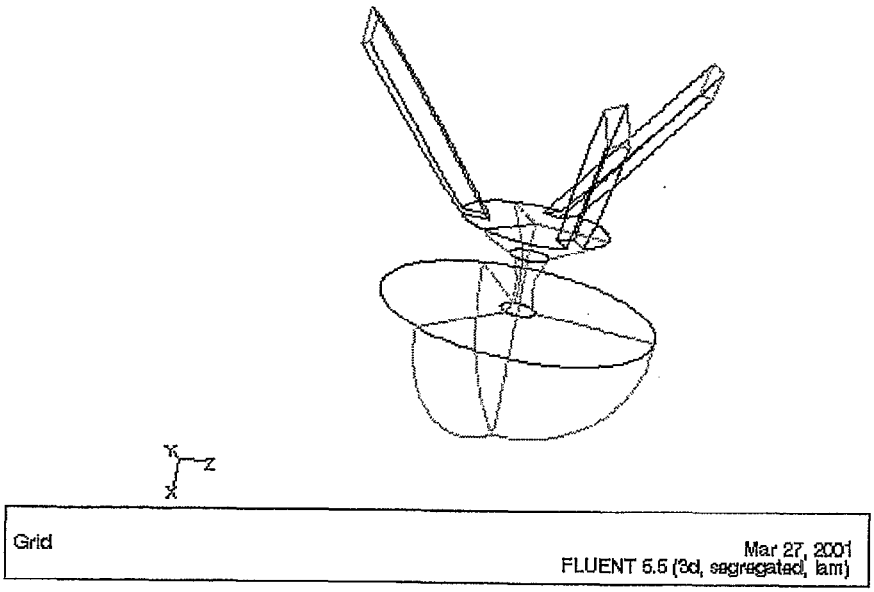


Figure 1: FLUENT Model of a simplex nozzle

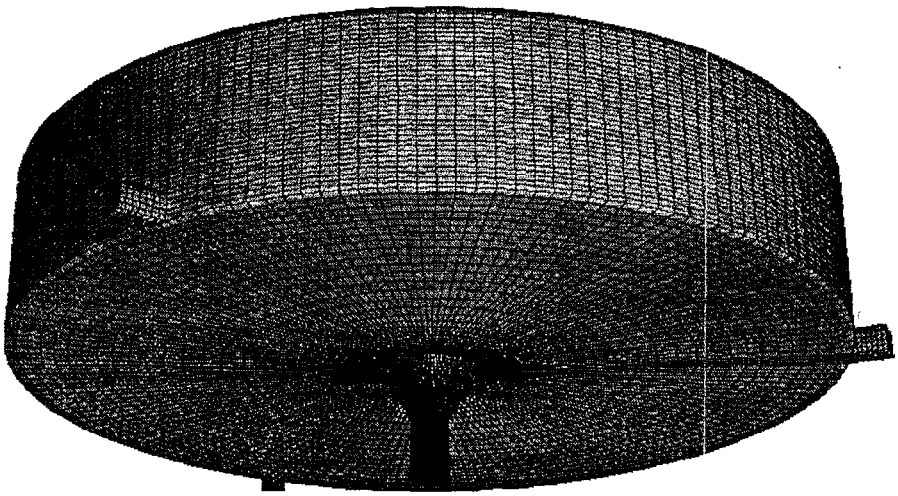


Figure 2: Computational GRID used in the model

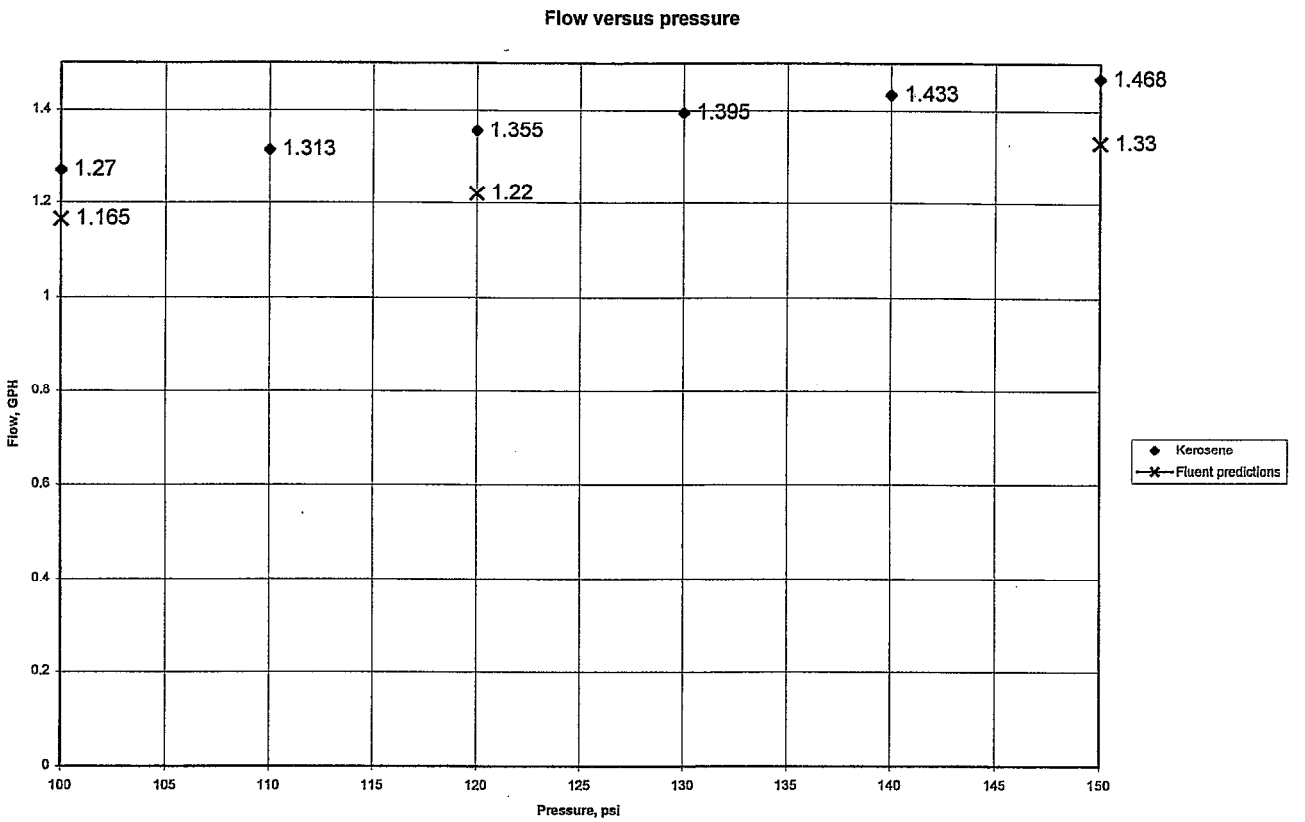


Figure 3: Flow rate versus pressure for the validation nozzle case

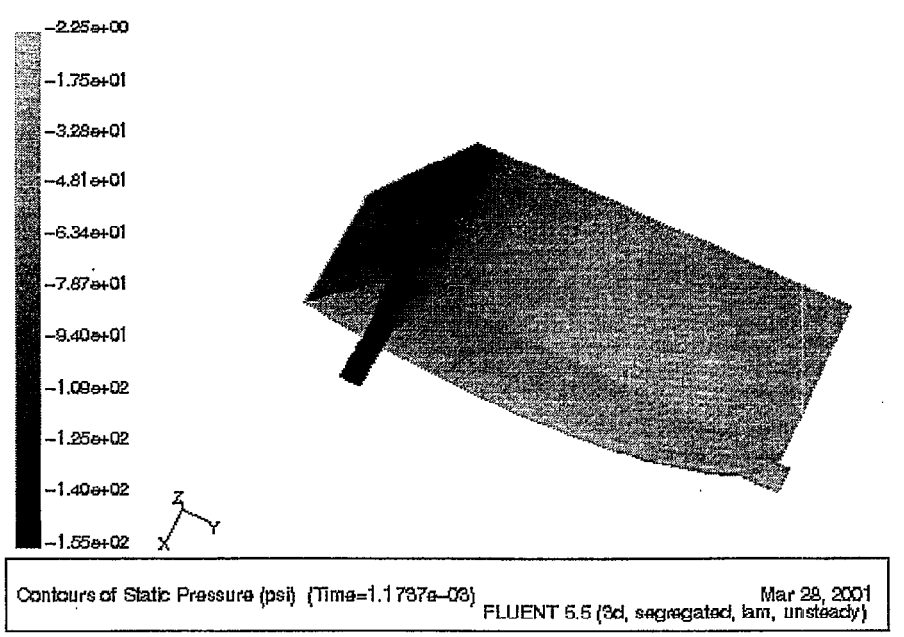


Figure 4: Contours of static pressure showing the negative pressure in the air core region

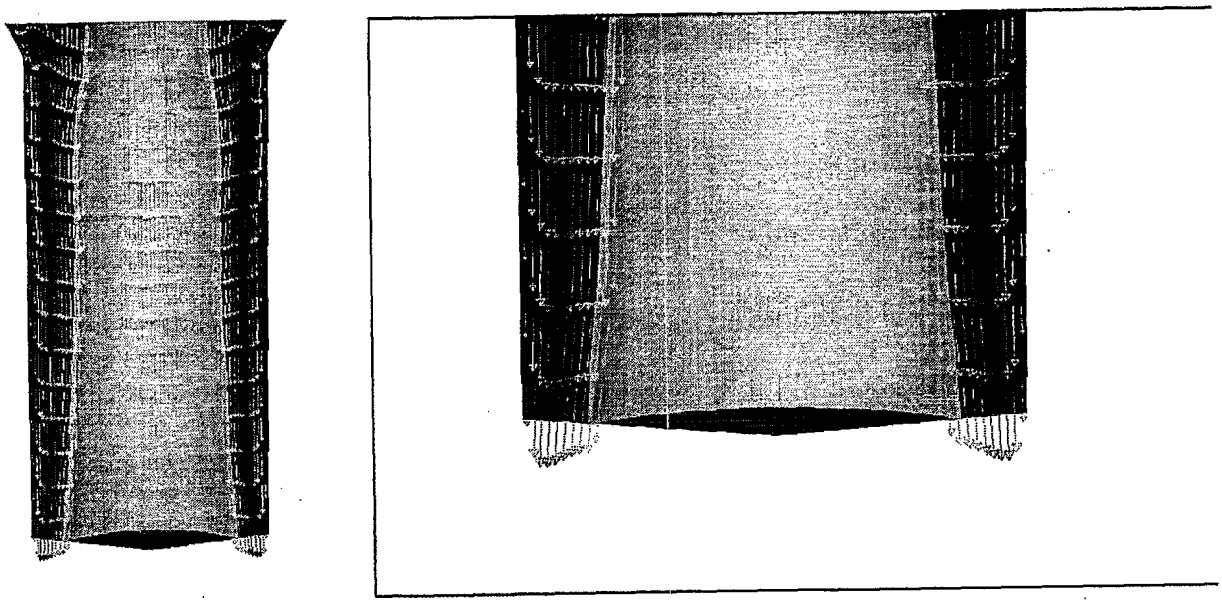


Figure 5: Reversed flow at the exit of the nozzle in the air core.

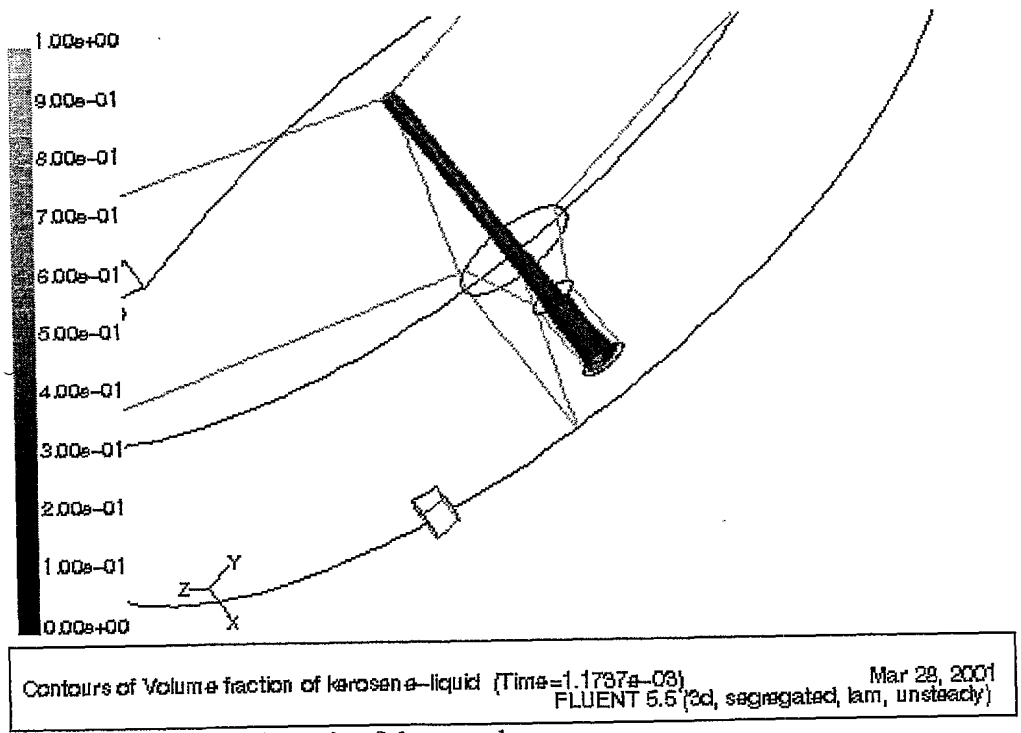


Figure 6: Air core at the exit of the nozzle

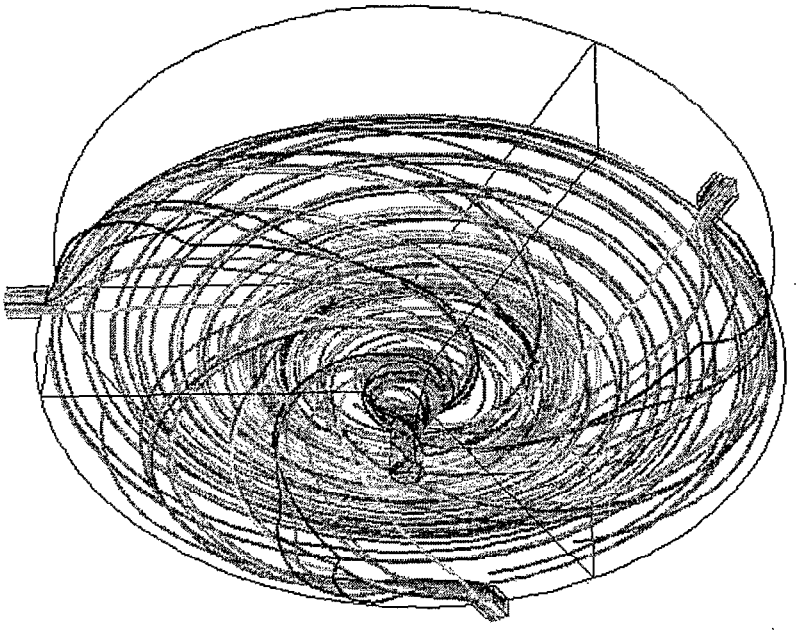


Figure 7: Path line visualization in the nozzle showing the swirling flow

Paper No. 01-11

Results of Parametric Investigation of Spray Characteristics Using Pre-filming Airblast Atomizer (HFAB type)

Richard Theurer and Richard Thiel, Hago and
Michael Eckert and Dr. Thomas Butcher, Ph.D., BNL

Hago Manufacturing
1120 Globe Ave.
Mountainside, NJ 07092
(908) 232-8687
rtheurer@aol.com

Brookhaven National Laboratory
Department of Energy Sciences and Technology
Energy Resources Division
Oilheat Research
12 North Sixth St.
Upton, NY 11973
631-344-7916
butcher@bnl.gov

Results of Parametric Investigation of Spray Characteristics Using Pre-filming Airblast Atomizer (HFAB type)

Richard Theurer and Richard Thiel, Hago Manufacturing. Michael Eckert and Dr. Thomas Butcher, Ph.D., Brookhaven National Laboratory

Introduction

Based on research which has been done at Brookhaven National Laboratory (BNL), the low pressure, air atomization concept appears to hold significant potential for commercial application to oil burners. Advantages of this concept include: low firing rates, modulation, low NOx, and high efficiency. In recent work at BNL the burner head which has been developed involves introducing most of the combustion air through the atomizer, a spray angle near 80 degrees, and the use of a flame tube to control flame zone recirculation rates. Commercial use of this concept, however, could involve different burner head arrangements, depending upon specifics of the application. This may include burners with much lower NOx levels. The work described in this paper was started in response to the recognition that serious commercial use of this concept requires better understanding of the impact that nozzle internal details have on the spray produced. With this type of information, burner designers can tailor nozzle characteristics and head details for new appliances.

With conventional, pressure atomized nozzles the spray is characterized by the flow rate, droplet size distribution, the spray angle, and the spray pattern. In addition to these parameters characterization of the behavior of the low pressure, air-atomizing nozzle also involves measurement of the air velocity field produced by the nozzle. This is particularly important because the flame aerodynamics is so strongly controlled by the nozzle with this technology.

Meaningful study of the effects of internal geometries on nozzle performance is not possible without the availability of components manufactured to tight tolerances. For this reason Hago Manufacturing is producing internal part variants for study with the same precision that would be expected to be used in commercial production, see in Figure 1.

In the basic nozzle geometry being used the airflow is internally divided into two paths. An outer stream flows axially through swirl vanes and then to the exit. An inner stream flows radially inward through four offset holes which also impart swirl and then to the exit. The oil is delivered to a filming surface by a central pin and is atomized by the shear forces from the inner and outer air flows. At the nozzle exit the inner and outer air flows combine to form a divergent, swirling flow pattern.

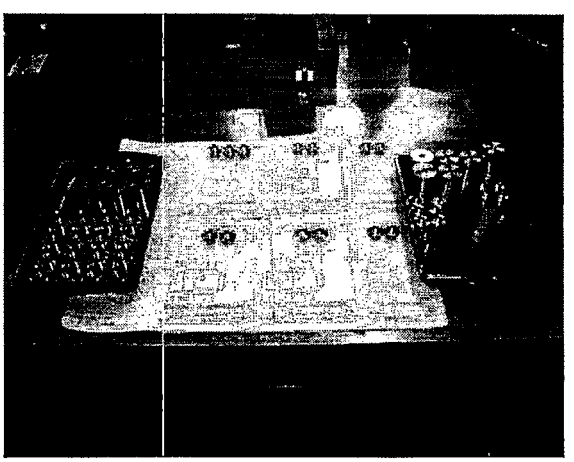


Figure 1. Nozzle internal part variants.

In developing variants to the basic nozzle design there are a large number of parameters which could be adjusted but the most significant ones are expected to include: angle of the outer swirl vanes, open area of the outer swirl vanes, area and offset of the inner air holes, final nozzle hole opening, inner and outer flow areas at the point where the oil film is broken into droplets near the exit hole, oil injection pressure, and axial distance between the oil injection point and the atomizing edge. Some of these parameters will strongly affect the nozzle pressure drop and a decision was made to put less emphasis on those parameters, which would impact the fan selection for a burner.

Measurements

For each variant studied the basic air flow/air pressure relationship was first evaluated without oil flow. For this test air was delivered to the nozzle assembly using a variable speed blower. The inlet of the blower has a long, straight test section and a flow metering orifice, which has been previously calibrated.

The cold air flow pattern produced by the nozzle is being measured at BNL using a mircopitot tube mounted on a precision positioning table in combination with a mircomanometer, see Figure 2. Only axial velocity is currently being measured. This includes axial velocity on the centerline as a function of distance downstream from the nozzle exit, and the radial profile of axial velocity at a fixed distance (two inches) downstream from the nozzle exit. These radial velocity profile measurements enables the angle at which the airflow jet expands after leaving the nozzle to be estimated. Recently a laser Doppler velocity measuring system has been added to the lab and this will be integrated with these efforts in the future. Figure 3 provides an example of the results of measurements of axial velocity as a function of radial position. Figure 4 shows, for the same nozzle, axial velocity measured along the centerline of the flow.

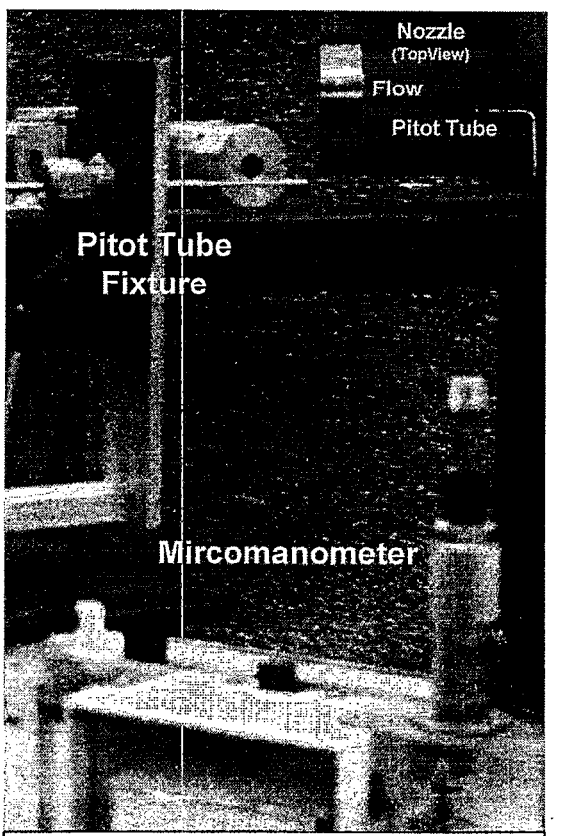


Figure 2. BNL measurement system.

The droplet spray pattern for each variant is being measured at Hago using a patternation test stand. Here the spray is collected in an array of glass containers positioned across the spray field diameter, see Figure 5. After a test period the volume of oil collected in each container is measured and the spray pattern reconstructed from this. Hago will also be doing some flow and viscosity effects studies.

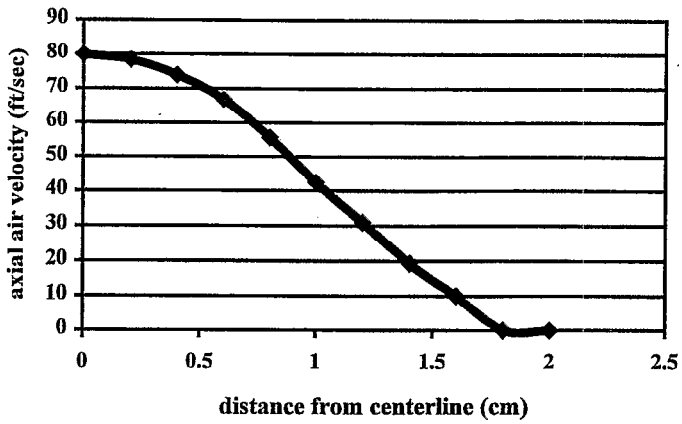


Figure 3. Measurement of the radial profile of axial velocity and example results. Cold conditions (not firing).

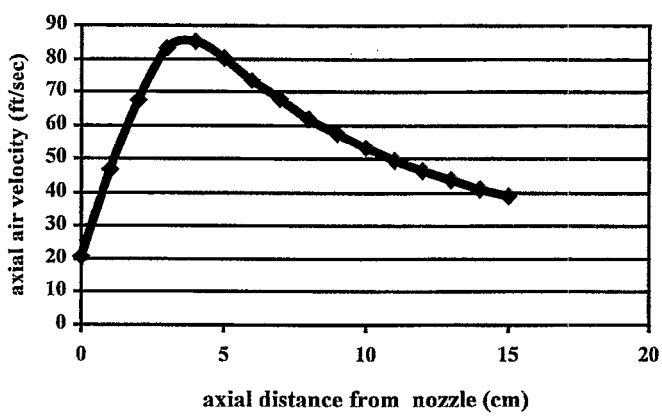


Figure 4. Measurement of axial velocity along the centerline and example results. Cold conditions (not firing).

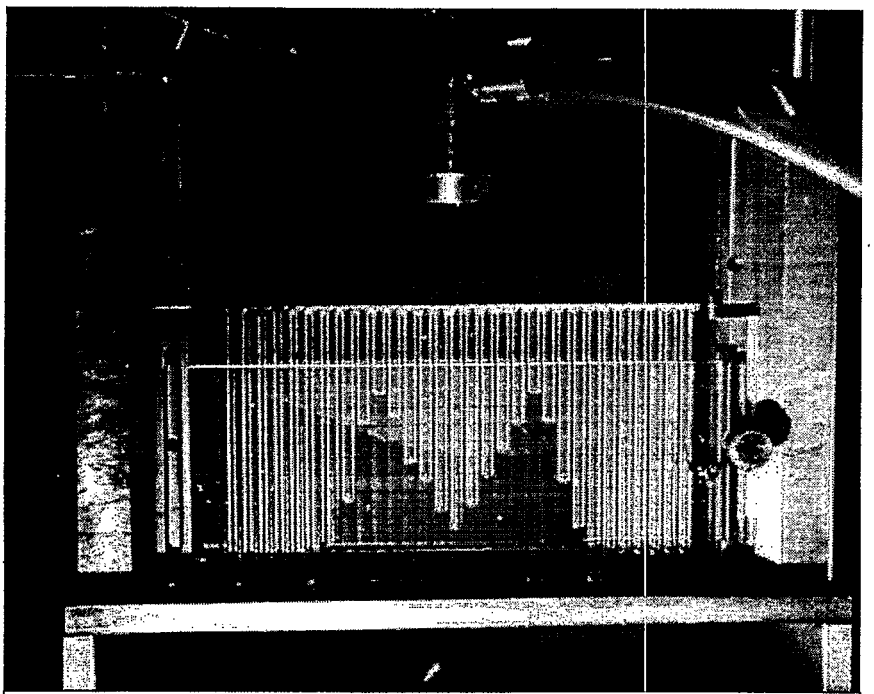


Figure 3 Patternation measurement system at Hago Manufacturing, Inc.

The spray drop size distribution is being measured at BNL using a laser Fraunhoffer diffraction measurement instrument. This provides mean drop size and also details of the droplet size distribution. Some drop size confirmation measurements will also be made at Hago.

Combustion tests are being done to evaluate the impacts, which the nozzle variants have on ignition, flame stability, and basic appearance in the BNL horizontal quartz test chamber. Detailed combustion behavior, including emissions measurements, is being studied in selected test boilers in the BNL lab.

Results to Date

This work is clearly on going and the results of specific variants currently being tested are expected to lead to the definition of new configurations, which may be of interest. These new configurations will then be manufactured and tested. However, some interesting results can be reported from work completed to date.

1. The swirl level produced by the nozzle can be made larger by increasing the angle of the swirl vanes and by increasing the offset of the holes through which air flows into the inner passage. If this is done without decreasing the open area at the swirl vanes or the hole area there is no impact on the nozzle pressure drop but very significant impacts on the air velocity field produced by the nozzle. Increasing swirl leads to an increased divergence angle for the air flow field and lower air velocity in the flame zone.

2. With most of the swirl variants tested to date there is a recirculation zone on the centerline near the nozzle exit, which can contribute to flame stability. Increasing swirl level increases the length and width of this zone.
3. Droplet size is not significantly affected by small changes in swirl level. At the highest swirl levels tested, however, there is a reduction in spray mean drop size from about 40 to about 30 microns.
4. Swirl levels can be increased to a greater degree by decreasing the open area of slots and inner flow holes but with substantial cost in terms of pressure drop. This cost does not provide greater benefits in terms of reduced drop size.

Future Plans

Tests with the first series of nozzle variants are still in progress. Results to date indicate that it may be possible to derive an initial advantage of this work through simplification of the burner flame tube, leading to lower head cost. The work will continue into a second phase of variant manufacture as appropriate.

Paper No. 01-12

Progression and Improvements in the Design of Blue Flame Oil Burners

Bola R. Kamath, Ph.D.

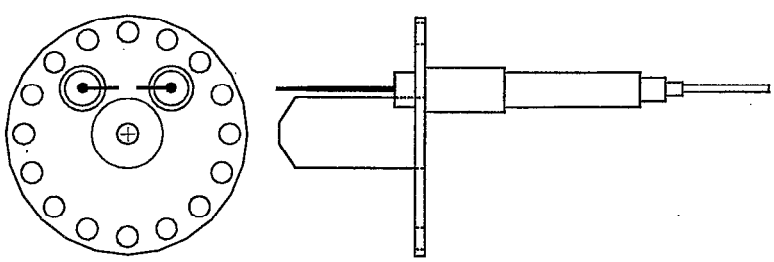
Heat Wise Inc.
PO Box 662
Ridge, NY 11961
631-345-0447
bkamath106@aol.com

Progression and Improvements in the Design of Blue Flame Oil Burners

Bola R. Kamath Ph.D.
Heat Wise Inc.

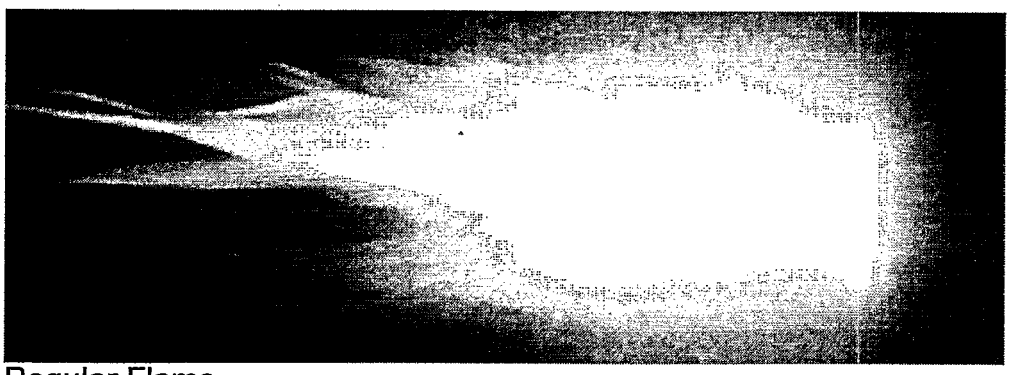
Blue is the color of the clean vast sky, oceans and lakes, blue is also associated with a clean flame. Now we know that a clean flame means that you can expect certain flue products, such as maximum CO_2, low CO, lower NO_x (compared to known NO_x), less particulates or zero smoke numbers. When oil is burning as a blue flame, these levels were obtained compared to so-called yellow flame or regular retention flame colors. It became an obsession of burner designers to come up with this kind of flame. In mid seventies, Blue Flame equipment became the name of game in the oil industry in North America. The first Blue Ray hot air furnace was introduced at this time.

Blue Ray Burner Head

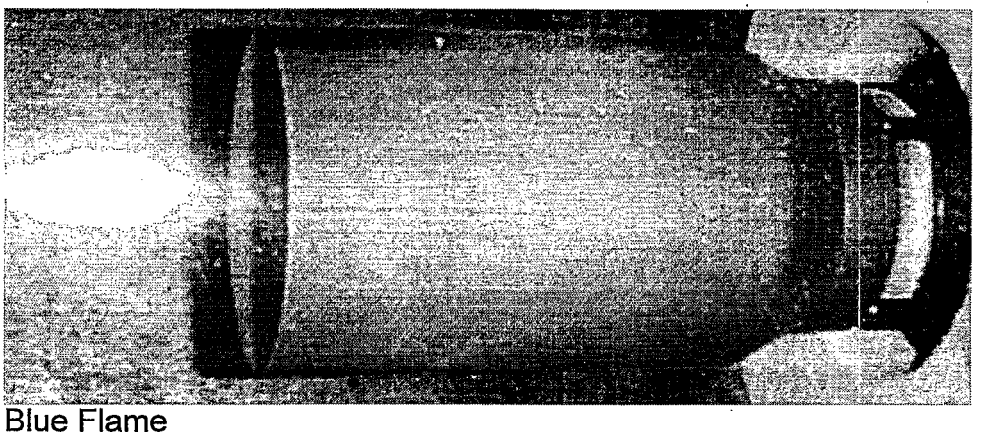


Later, Blue Ray boilers were introduced. At the same time in Europe, Mann Burners were produced exclusively with blue flame burners as retrofit equipment. They had special flame tubes and they cost more than twice the price of regular burners. But the market in Europe could absorb the high prices due to the efficiency of the units. That is to say that because the flame was clean, there was a market in Europe.

Burner	Smoke	CO_2%	CO ppm	NOx ppm
Regular Flame	0	14.0	48	94
	0	13.8	95	85
Blue flame	0	13.5	8	45
	0	13.4	5	45



Regular Flame

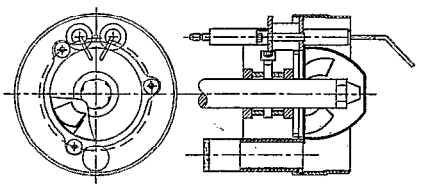


Blue Flame

The American designed furnace or boiler depended on various critical parts. The burner had a static plate with several holes near the edge with compound angles. The nozzle adapter itself was a long brass tube that acted like a heat sink for the special simplex nozzle to give a constant capacity; this was known as a CC nozzle. The nozzle was cooled by blower air constantly passing over the tight barrel of nozzle and into the six dimples at the tip. The burner cone had a gap for recirculation of hot gases through a donut attached at the front of the furnace. When everything worked properly, the whole chamber became a flame area, which held a loose floating blue mass.

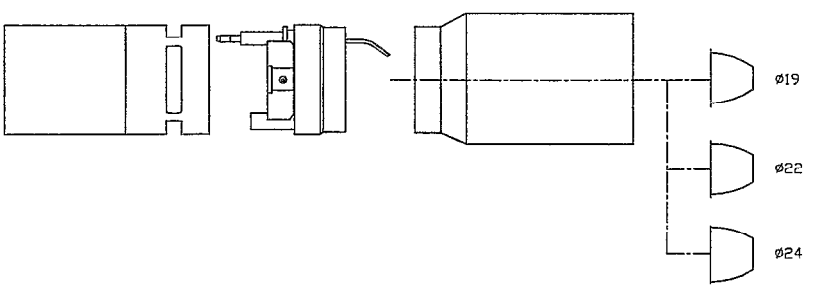
In Europe, the Mann Burner was making steady growth. They depended on the flame tube for hot flue circulation. Their patent never allowed others to copy the system. But when the patent elapsed, every other European manufacturer started to use the same design with various minor changes. Others developed better flame tubes, using less expensive material. Better controls were developed.

Meku Head



Meku, one of the major burner component manufacturers, introduced Inconnel flame tubes (US made material) and simple burner head parts for these burners. Similarly, major burner manufacturers in Europe came up with different burners associated with Meku designs. Today, every year more than 150,000 units are made by nearly 25 major manufacturers (Ref: 1).

Meku Standard Burner



As explained earlier, the blue flame is clean, cuts down pollutions, it keeps the heat exchangers clean. This type of burner is the growing trend in Europe by major manufacturers and many of them have come to the BNL oilheat technology conference to show their own systems. Blue Fan systems was very highly engineered product with its burner head it gave a blue flame. Some of them were very expensive burners. It made some headway in marketing, now it has slowed down. Another was Viessmann Blue burner design. This was also a very expensive burner, but at one time they were making around 10 burner/boiler units per day. They are now replaced by Meku design. Heat Wise used these parts and came up with a blue flame burner that can be fired in American heat exchangers with very good results. Only the cost of the burner keeps it out of the market in US.

Ref:(1) ABACO(MB) Bentone (MB) Brotje(MB) Riello(based on MB) Buderus, CEB (MB), Cuenod (MB), Wolf(MB), ELCO Klockner(MB), Domusa (MB), ELCOTHERM(MB), F.B.R(MB), Tifell(MB), Vaillant(MB), Viessmann(based on MB), WAP (MB) Scheer (MB),OFG(MB), Lamborghini(MB), Korting(MB)., Intercal(MB) Hermann(MB) Hansa(MB) Giersch.

Paper No. 01-13

Biodiesel as a Heating Oil Blend Stock

Dr. Shaine K. Tyson

Renewable Diesel Project Manager
National Renewable Energy Laboratory
Golden, CO, 80401
303-275-4616
k_shaine_tyson@nrel.gov

and

Paul J. Nazzaro

Advanced Fuel Solutions, Inc.
North Reading, MA 01864
978-664-5923
advancedfuel@mediaone.net

Biodiesel as a Heating Oil Blend Stock

Dr. Shaine K. Tyson[1] and Paul J. Nazzaro[2]

This paper is an introduction to biodiesel for the heating oil industry. The paper covers some basic information about biodiesel, how it is used, what is different from diesel fuel or heating oil, and what is currently known (or not known) about using biodiesel as a heating oil. It also outlines how firms involved in the heating oil market could benefit from using biodiesel in their fuel mix, if current research shows that it is feasible and that benefits occur from using the fuel. A brief description of the ongoing research on biodiesel as a heating oil fuel is presented.

1 Introduction

Biodiesel is a fuel manufactured from vegetable oils, recycled cooking grease, or animal fats. The fuel typically contains up to 14 different types of fatty acid methyl esters (FAME) as shown in Table 1. The different fractions of each type of FAME present in various feedstocks (Table 2) influence some of the properties of the fuel Table 3. A high level of saturates (C16:0, C18:0) raise cloud point, raise Cetane number, reduce NOx, and improve stability. More polyunsaturates (C18:2, C18:3) reduce cloud point and Cetane, reduce stability (unless stability additives are used), and raise NOx.

Biodiesel always refers to the pure fuel. Biodiesel blends or BXX always refers to a fuel that is composed of XX% biodiesel and 1-XX% diesel fuel. For example, B100 is pure biodiesel and B20 is a blend of 20% biodiesel and 80% diesel fuel. The diesel fuel can be No. 1, No. 2, JP8, or any other diesel fuel. Splash blending with biodiesel on top is the common mixing procedure, although rack blending is being considered in some states. Biodiesel blends stay mixed in the presence of water.

Biodiesel contains no nitrogen or aromatics and low levels of sulfur (< 25 ppm). Biodiesel contains 11% oxygen by weight. Biodiesel has approximately 120,910 Btu/gal compared to diesel fuel at 137,000 Btu/gal. Because of differences in fuel density, biodiesel provides 92% of the energy contained in diesel fuel. B20 provides 98% to 99% as much power, torque, and fuel efficiency as diesel fuel in transportation uses.

If biodiesel can be used in a mix with heating oil in home and commercial boilers, biodiesel may offer new market opportunities for the heating oil industry. While B100 is used as a stand-alone fuel in some transportation applications, we are not suggesting this approach for the heating oil industry at this time. This issue will be addressed in another section of this paper. Blends of biodiesel and heating oil are under investigation by the National Renewable Energy Laboratory (NREL) in partnership with Brookhaven National Laboratory, the New York State Energy Research and Development Authority, the National Biodiesel Board, and Griffin Industries (a biodiesel producer). Collectively, $160,000 is being invested to determine the appropriate blend level, equipment modifications, and identify operational issues that may arise. Concurrently the Global Companies, Brennan Oil, Rhode Island State Energy Office, NREL,

[1] Renewable Diesel Project Manager, National Renewable Energy Laboratory, Golden, CO, 80401, Telephone: 303-275-4616, Fax: 303-275-4675 E-mail: k_shaine_tyson@nrel.gov

[2] President, Advanced Fuel Solutions, Inc.; North Reading, MA. 01864, Telephone: 978-664-5923, Fax: 978-664-4020, E-mail: advancedfuel@mediaone.net

the Warwick Public School District, and World Energy (a biodiesel distributor) are conducting field trials of 10%, 15%, and 20% biodiesel blends in commercial school boilers. Through these combined efforts, we hope to identify a biodiesel blend that can lead to a new market opportunity within the heating oil industry.

There could be a variety of drivers that will contribute to a market for biodiesel heating oil blends:

- Green fuel product line (BXX)
- Positive public image
- Sulfur reductions (air quality)
- Lower maintenance costs from sulfur reduction
- Diversified customer base (summer transportation fuels, winter heating oil market)
- Supply and pricing not tied to petroleum/refinery industry
- Domestic production potential in all regions of the country

Biodiesel is a renewable fuel that reduces emissions in transportation uses; boiler emission data are still too limited to make solid claims except for CO2 and SOx reductions. Transportation studies also show that biodiesel fuels produce 78% less CO2 on a life cycle basis compared to No. 2 diesel fuel. Most biodiesel contains less than 25 ppm sulfur, and some biodiesel fuels are entirely sulfur free. Biodiesel blends do not significantly reduce the heating content of the fuel, depending on the amount of biodiesel present. For these reasons, biodiesel blends can be used to create a "green" fuel product line. Biodiesel blends could be used to develop a diversified market structure, e.g., a "generic" heating oil and a "premium" or "green" heating oil. This structure would allow for a variable markup structure and, hopefully, some increase in profitability for the industry. A green fuel line can be used to develop a "green" or environmental public image and may increase heating oil competition. There is an emerging possibility that the use of biodiesel could generate CO2 credits that would have global market value (although no domestic value). Similarly, sulfur credits produced by reducing fuel sulfur content may be marketable among commercial/industrial users and have considerable market value in some areas. Reducing fuel sulfur may also lead to lower maintenance costs through lower corrosion and fouling of heat exchangers. These savings would be revealed through lower maintenance contract costs and fewer service calls.

Some petroleum distributors can benefit by marketing biodiesel blends to both the transportation and the heating oil markets, and reducing the cost of storage and blending equipment across diversified markets and product lines. Markets for biodiesel blends are emerging at military bases, utility companies, state and federal fleets, some municipal and private fleets (garbage trucks and school buses), electricity generation facilities, marine fuels distributors, national parks, and underground mining operations. Firms that can maximize throughput, minimize storage costs, and expand into new market segments at low risk will succeed in this new area.

Biodiesel can be produced in all regions of the country. Some biodiesel is made from recycled restaurant grease and other waste greases of no value. These produce a "recycled" biodiesel that can be produced in all major metropolitan areas of the country. Other biodiesel is made from agricultural crops like soybeans, which are grown in many farm states. Biodiesel is also a byproduct from some chemical industries like detergent and lubricant manufacturing that can be found coast-to-coast. Biodiesel can be made from any of these feedstocks separately or in combination. So long as the biodiesel meets ASTM PS 121(**Table 4**), it is suitable for transportation use and probably for heating oil blending as well. As briefly alluded to in the beginning, each different type of biodiesel may pose some operational issues that consumers and distributors need to be aware of (cold weather, stability). There are similar issues in the diesel and heating oil market.

There are seven established biodiesel producers today and an equal number of newcomers poised to enter the marketplace this year. Sales have been projected to rise from 6.6 million gallons in 2000 to 36 million gallons in 2001. The production technology was established around World War I, and new plants can be built quickly for less than $1/gal capacity in some cases (large plants). Nearly 1 billion gallons of biodiesel can be produced from existing feedstock supplies in the near future. In the next decade, the industry could eventually expand to sales of 6-8 billion gallons per year as lower cost feedstocks from new crops are developed.

Because biodiesel is a domestic fuel, it is not tied to the woes of the Middle East, or the cartel powers of OPEC, or subject to profitability decisions at petroleum refineries. Biodiesel prices have been falling over the last few years as cheaper feedstocks are utilized, competition has emerged within the industry, and more flexible processing technology has been introduced. In recent public bids, biodiesel prices have been as low as $1.25/gal. The long-term goal of the U.S. Department of Energy (DOE) Renewable Diesel Program is to build an industry with a 6-8 billion gallons capacity that produces biodiesel for $1/gal or less. Internal projections show that biodiesel production costs could approach those for diesel fuel. Since some producers are approaching that cost target today, the primary challenge is to expand feedstock supplies while keeping their costs in line with projections.

Many of the tests and field trials conducted on biodiesel have been focused on the transportation sector. Only two preliminary trials using biodiesel as a heating oil have been conducted, neither of which is sufficient to support any claims that biodiesel or blends of biodiesel and heating oil can be used in home heating or commercial boilers without concern. This paper will identify what the preliminary research has found so far, and cover a range of issues that need to be considered with this new fuel.

2 Preliminary Tests of Biodiesel as a Heating Oil

Previous test data were generated by two different biodiesel producers: (1) Ag Environmental Products (AEP) commissioned the R.W. Beckett Group to test B100 made from soy oil, and (2) Griffin Industries worked with Brookhaven National Laboratory (BNL) to examine B20 and B100 made from recycled grease. The Beckett tests used a Dunkirk 3-Section wet-base boiler with a Beckett AFII 150 burner; the BNL tests used a "modern retention head burner in a residential boiler." AEP holds their data proprietary; however, it was released to both NREL and Brookhaven for research purposes.

In general, both studies found lower sulfur emissions, lower smoke emissions, and slightly lower NOx emissions. Additionally, reducing the sulfur content in biodiesel blends may reduce heat exchanger fouling and corrosion that correlate to sulfur content. Beckett and BNL reported difficulty with cold starts using B100 and both reported problems with the Cad cell at high excess air settings (6) due to the low brightness of biodiesel flames. BNL reported few or no problems associated with B20, whereas Beckett did not test B20. Beckett noted that the high pour point of biodiesel may require a nozzle line heater, and BNL expressed concern about storing B100 outside during cold weather without some type of tank heater and agitation system. Beckett conducted some material compatibility tests and found that B100 dissolved some gaskets and label adhesives, although other types of seals remained unaffected. Long term tests and field tests were not performed by either firm. Beckett suggested that burners would require air setting adjustments to insure acceptable smoke levels, although smoke nearly disappeared in B100 tests which appeared contradictory.

Beckett recommended performing the following tests on biodiesel:

- Cold oil starts

- Long term cycling to evaluate changes in nozzle varnishing caused by the proximity of the electrodes to the nozzle as seen with fuel oil, and impacts on heat exchanger fouling
- Field trials to determine if biodiesel caused unfavorable reactions with accumulated sediments and water in storage tanks that are generally poorly maintained (or in lieu of those types of self defeating tests, to develop protocols to avoid anticipated problems)

One private citizen in Maryland reported that he had tried to use B100 in his home heating system and it dissolved the seals on the fuel pump, flooding his basement with biodiesel. This person purchased a biodiesel compatible rebuilt kit from a European subsidiary of their fuel boiler manufacturer and has not reported any problems since. He did not consider blending biodiesel into diesel fuel in lower concentrations.

3 Operational Issues with Biodiesel Fuels

Through discussions with heating oil firms, customers, and other stakeholders, NREL has developed a list of issues or questions to be settled.

Biodiesel is a mild solvent and will loosen and dissolve the accumulated sediments in diesel and heating oil storage tanks. The dissolved sediments will travel with the fuel causing plugged fuel filters and lines, clogged injector nozzles, and significant damage to diesel engines, and residential and commercial oil burners. Field experience with biodiesel used in bulk transportation services (bus fleets, DOT, etc.) has shown that while blends of 50% biodiesel still cause this problem, blends of 20% biodiesel have not caused noticeable problems in over 50 fleets that are using B20 commercially. Customers interested in using B100 or high level blends will need to clean their storage tanks before switching to these fuels. Note that once the sediments have been removed, the problem tends to disappear unless the system reverts to continuous diesel fuel use (causing sediments to accumulate again).

Like heating oil or diesel fuel, biodiesel cold weather storage requires attention. B100 freezes at 25 to 35°F, and blends of biodiesel and diesel fuel exhibit higher cloud and pour points compared to diesel or heating oil alone. Mixing with kerosene has a positive impact on cold weather properties and it is common practice to transport biodiesel as a 50:50 blend with kerosene in the wintertime. Most cold flow additives tend to work only on the petroleum portion of blends and not at all on B100. Customers using B100 and high level blends will need insulated and heated storage facilities outdoors or will need to use underground storage tanks to keep fuel temperatures at least 10°F over the cloud point of the fuel or fuel blend. For this reason, B100 and high level blends may not be viable fuels for the heating oil industry except in specific cases with proper infrastructure.

It may not be sound public policy to recalibrate the burner each time a new fuel is introduced. The issue here concerns emissions and fuel efficiency. If a burner needs to be specially adjusted for B100 (or some other higher blend level), and the customer reverts back to diesel fuel, then the burner will experience poor combustion characteristics that may lead to increased maintenance and air pollution. A low-level blend of biodiesel and fuel oil that does not require special modifications to the burner combustion system may be desirable.

Oxidative stability is an important issue for biodiesel, just as it is with diesel fuel or heating oil. Biodiesel with high levels of polyunsaturated fatty acids are inherently unstable. The products of degradation include sediments, polymers, peroxides, higher acid value, and increased viscosity. Some of the unsaturated biodiesel sold today contains antioxidants that seem to be very effective. Some biodiesels contain higher amounts of saturated fatty acids and can be expected to experience fewer stability issues (these fuels experience more cold weather problems). Antioxidants may be required for all biodiesel used

in heating systems because of summer storage conditions. NREL and Southwest Research Institute are currently developing oxidative test methods for B100 and B20 fuels.

Biological growth occurs in diesel and heating oil storage systems and biodiesel is susceptible to this problem. Most standard biocides are effective for controlling this problem in biodiesel and biodiesel blends, but would need to be present in the fuel to be effective. The best control technology for biological growth for any fuel is to keep tanks free of accumulated water.

Biodiesel is a lubricant in and of itself. Low blends of 2% or less can provide superior lubricity to dry fuels such as kerosene and Fischer-Tropsch diesel. There should be no concerns over the durability of fuel-lubricated equipment such as fuel pumps. Biodiesel has been proposed as a lubricant for future low-sulfur diesel fuels.

Material compatibility is an important issue. Beckett and the National Biodiesel Board (NBB) have already identified several materials that fail or deteriorate in the presence of B100, such a nitrile rubber seals (**Table 5**). Blends such as B20 dilute the problems. Few material compatibility issues have been reported with B20. Higher level blends tend to experience more problems. Many burner manufacturers who market systems in Europe have biodiesel compatible rebuild kits for key components. Other materials to be avoided or replaced regardless of the blend level are copper and brass fittings, valves, pipes. Also components made of lead or zinc, including lead-based welds, that may be exposed to the fuel should be replaced. These materials are strong oxidizing materials for biodiesel.

Because of the issues identified above, it appears unlikely that most customers will use B100. It has been for these reasons and others (emissions) that the transportation market has selected a B20 as a fuel standard. There could be synergies in proposing the same blend level for the heating oil market, and problems can be minimized or avoided. However, some people will always want to use B100 or higher-level blends for environmental reasons. A 50:50 blend with kerosene may be the best "high-blend" product for cold flow, although it may still pose solvency and material compatibility problems. These potential customers will need to be educated on the full range of biodiesel issues and operational recommendations.

Residential and commercial tests are needed. There is a great deal of popular interest in biodiesel fuels from homeowners with fuel oil heating systems. Reaching out to this class of customers has high education expenses and potentially high start up costs (in terms of some of the issues raised above). Targeting the small commercial or industrial class of customers reduces education and start up costs, although these customers are more cost conscious than some homeowners are. Industrial customers with fuel switching capability tend to put pressure on regional demand and prices during times of fuel cost run ups, making them a good target for public policy reasons. Each class of customers has different questions and concerns.

4 Biodiesel Heating Oil Research Plans

The NREL/Brookhaven project will compile data that describes the performance, operational recommendations, and other salient information for customers using two types of biodiesel fuels: a 50% blend of biodiesel with kerosene (BK50) and a low-level blend with standard heating oil. The low-level blend will minimize start up costs (such as tank cleaning), maintenance costs (such as sediment clogging or filter replacement), and equipment adjustments (requiring adjustments may lead to poorly tuned furnaces, especially if the customer switches back and forth between fuels and blends). In addition, we need more information on fuel efficiency (Beckett never tested the Btu's of their biodiesel or diesel, they simply used assumptions), system issues, material compatibility, and ultimate consumer costs or benefits.

The NREL/Brookhaven project will test biodiesel blends in residential and commercial space heating equipment in the laboratory and conduct field trial tests in BNL's on-site burners. The tests will be geared towards identifying any potential problems with existing equipment and resolving them as feasible. If these tests are successful, biodiesel blends could supplement home heating oil during shortages similar to the one that caused the price shock of the last heating season. The biodiesel industry and the home oil heating industry have expressed interest in the project's success.

The Warwick School District project will address the issue of cold storage and solvency to determine if blends as high as 20% cause filter plugging or other unanticipated problems. The Warwick School District has not optimized their boilers to run on biodiesel blends. Blends of 10, 15 and 20% biodiesel are being run in (3) boilers in the public school buildings against one control building. All have similar equipment and storage environments. This is a 12-month study that began in the spring of 2001 and will end in the spring of 2002.

The National Biodiesel Board will conduct a study to assess the economic, regulatory, and logistical issues associated with introducing biodiesel into the heating oil industry. Issues such as new fuel standards may also be addressed.

By this time next year, we hope to be able to answer many of the previously discussed questions, and perhaps have some limited field experience to share with you.

5 Taxes and Incentives

Biodiesel is not exempt from federal excise taxes, and it is not exempt from state or local taxes in most states and locales. That means that biodiesel and biodiesel blends are taxed at the same rate as diesel fuel, and the taxes are handled in the same manner. For local exceptions to this statement, please contact the local tax authorities.

At the present, there are no financial incentives such as excise tax credits or government subsidies for purchasing biodiesel. The City of Cincinnati was able to qualify for a grant from the Department of Transportation Congestion Mitigation and Air Quality Program in 2000 that paid the difference between the cost of biodiesel and the cost of diesel fuel. These grants are available to other communities through the Clean Cities Program but are limited to transportation use. Some state energy agencies, such as Vermont's, have expressed an interest in expanding their Energy Efficiency and Assistance programs to include updating residential boilers during maintenance to make them "biodiesel compatible." This may be an avenue for industry and government synergies in the future.

The Energy Policy Act of 1992 (EPAct) provides an indirect incentive program to federal and state transportation fleets which may be applied to municipal fleets and large commercial fleets in the near future. This regulation requires federal and state fleets to purchase alternative fueled vehicles. The regulation requires that a certain fraction of the year's vehicle purchases must be able to run on alternative fuels. Unfortunately, the government is not willing to claim that all diesel vehicles are alternative fueled vehicles just because biodiesel can be used in all existing diesel vehicles. Therefore, a special exemption was created for biodiesel. The government will give an "alternative vehicle credit" (a paper credit, not a financial credit) to a qualified customer (federal or state and some utilities) that purchases 450 of pure biodiesel and uses it in a blend of at least 20% (B20) in a heavy-duty vehicle with a gross weight of 8,500 pounds or more. There is no requirement to use B20 year round. For multiple credits, multiple purchases of 450 gallons of B100 are all that is required, and they can be burned in one or more vehicles as long as the mixture exceeds 20%. Most federal and state fleets have started to shift a large part of their heavy-

duty fleets to biodiesel on a regular basis. Some fleets in northern climates limit purchases in winter months, but resume again in the spring and use B20 throughout the spring, summer, and fall months. For more information, contact the DOE.

Table 1. Structural Formula for Fatty Acids used in Biodiesel

Fatty Acid Name	No. Of Carbons & Double Bonds	Chemical Structure (= denotes double bond placement)
Caprylic	C8	$CH_3(CH_2)_6COOH$
Capric	C10	$CH_3(CH_2)_8COOH$
Lauric	C12	$CH_3(CH_2)_{10}COOH$
Myristic	C14	$CH_3(CH_2)_{12}COOH$
Palmitic	C16:0	$CH_3(CH_2)_{14}COOH$
Palmitoleic	C16:1	$CH_3(CH_2)_5CH{=}CH(CH_2)_7COOH$
Stearic	C18:0	$CH_3(CH_2)_{16}COOH$
Oleic	C18:1	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$
Linoleic	C18:2	$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$
Linolenic	C18:3	$CH_3(CH_2)_2CH{=}CHCH_2CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$
Arachidic	C20:0	$CH_3(CH_2)_{18}COOH$
Eicosenoic	C20:1	$CH_3(CH_2)_7CH{=}CH(CH_2)_9COOH$
Behenic	C22:0	$CH_3(CH_2)_{20}COOH$
Eurcic	C22:1	$CH_3(CH_2)_7CH{=}CH(CH_2)_{11}COOH$

Table 2. Weight Percent of Fatty Acids in Fat and Oil Feedstocks

Fatty Acid Fat or Oil	C8:0	C10:0	C12:0	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0 C22:0	C20:1 C22:1	Other
Cod Liver	--	--	--	2-6	7-14	10-20	0-1	25-31	--	--	--	35-52	--
Tallow	--	--	0.2	2-3	25-30	2-3	21-26	39-42	2	--	0.4-1	0.3	0.5
Lard	--	--	--	1	25-30	2-5	12-16	41-51	4-22	--	-	2-3	0.2
Butter	1-2	2-3	1-4	8-13	25-32	2-5	25-32	22-29	3	--	0.4-2	.2-1.5	1-2
Coconut	5-9	4-10	44-51	13-18	7-10	--	1-4	5-8	1-3	--	--	--	--
Palm Kernal	2-4	3-7	45-52	14-19	6-9	0-1	1-3	10-18	1-2	--	1-2	--	--
Palm	--	--	--	1-6	32-47	--	1-6	40-52	2-11	--	--	--	--
Safflower	--	--	--	--	5.2	--	2.2	76.3	16.2	--	--	--	--
Peanut	--	--	--	0.5	6-11	1-2	3-6	39-66	17-38	--	5-10	--	--
Cottonseed	--	--	--	0-3	17-23	--	1-3	23-41	34-55	--	--	2-3	--
Corn	--	--	--	0-2	8-10	1-2	1-4	30-50	34-56	--	--	0-2	--
Sunflower	--	--	--	--	6.0	--	4.2	18.7	69.3	0.3	1.4	--	--
Soybean	--	--	--	0.3	7-11	0-1	3-6	22-34	50-60	2-10	5-10	--	--
Rapeseed	--	--	--	--	2-5	0.2	1-2	10-15	10-20	5-10	.9	50-60	--
Linseed	--	--	--	0.2	5-9	--	0-1	9-29	8-29	45-67	--	--	--
Tung	--	--	--	--	--	--	--	4-13	8-15	72-88	--	--	--

Table 3. Selected Fuel Properties for Diesel and Biodiesel Fuels

	Diesel	Biodiesel
Fuel Standard	ASTM D975	ASTM PS 121
Fuel composition	C10-C21 HC	C12-C22 FAME
Lower Heating Value, Btu/lb	130,250	120,910
Kin. Viscosity, @ 40 °C	1.3-4.1	1.9-6.0
Specific Gravity kg/l @ 60 °F	0.85	0.88
Density, lb/gal @ 15°C	7.079	7.328
Water, ppm by wt	161	.05% max
Carbon, wt %	87	77
Hydrogen, wt %	13	12
Oxygen, by dif. wt %	0	11
Sulfur, wt %	.05 max	0
Boiling Point		
°F	370-650	360-640
°C	188-343	182-338
Flash Point, °C	60-80	100-170
Cloud Point, °C	-15 to 5	-3 to 12
Pour Point, °C	-35 to -15	-15 to 16
Cetane Number	40-55	48-60
Stoichiometric Air/Fuel Ratio, wt./wt.	15	13.8
RVP		
psi @ 100 °F	<0.2	n/a
kPa @ 37.8 °C	<1	n/a
BOCLE Scuff, grams	3,600	>7,000
HFRR, microns	685	314

Table 4. ASTM PS 121 Biodiesel for B20

Property	ASTM Method	Limits	Units
Flash Point	D93	100.0 min	Degrees C
Water & Sediment	D2709	0.050 max.	% vol.
Kinematic Viscosity, 40 C	D445	1.9 - 6.0	mm2/sec.
Sulfated Ash	D874	0.020 max.	% mass
Sulfur	D5453	0.0015 max.	% mass
Copper Strip Corrosion	D130	No. 3 max.	
Cetane Number	D613	46 min.	
Cloud Point	D2500	Report to Customer	Degrees C
Carbon Residue, 100% sample	D4530**	0.050 max.	% mass
Carbon Residue, Ramsbottom	D524	0.090 max	% mass
Acid Number	D664	0.80 max.	mg KOH/gm
Free Glycerin	D6584	0.020 max.	% mass
Total Glycerin	D6584	0.240 max.	% mass

Table 5. Material Compatibility with Biodiesel Fuels

Material	BXX	Effect compared to diesel fuel
Teflon	B100	Little change
Nylon 6/6	B100	Little change
Nitrile	B100	Hardness reduced 20%
	B100	Swell increased 18%
Viton A401-C	B100	Little change
Viton GFLT	B100	Little change
Fluorosilicon	B100	Little change in hardness
	B100	Swell increased 7%
Polyurethane	B100	Little change in hardness
	B100	Swell increased 6%
Polypropylene	B100	Hardness reduced 10%
	B100	Swell increased 8-15%
Polyvinyl	B100	Much Worse
	B50	Worse
	B40	Worse
	B30	Worse
	B20	Comparable
	B10	Comparable
Tygon	B100	Worse

Paper No. 01-14

Lab Tests of Biodiesel Blends in Residential Heating Equipment

C.R. Krishna, Yusuf Celebi, George Wei,
Thomas Butcher and Roger McDonald

Brookhaven National Laboratory
Department of Energy Sciences and Technology
Energy Resources Division
Oilheat Research
12 North Sixth St.
Upton, NY 11973
631-344-4025
krishna@bnl.gov

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C.R. Krishna, Yusuf Celebi, George Wei, BNL
Thomas Butcher and Roger McDonald, BNL

1.0 Introduction

Biodiesel is a 'diesel-like' fuel that is derived from processing vegetable oils from various sources, such as soy oil, rapeseed or canola oil, and also waste vegetable oils resulting from cooking use. The American Society for Testing and Materials (ASTM) is in the process of finalizing a standard for biodiesel (PS 121). A German standard exists (DIN 51606) and a European standard is in preparation. In view of its similarity to diesel fuel, it has been tested fairly extensively in diesel engines. It has not been as widely tested for boiler applications and in residential heating applications.

Brookhaven National laboratory is initiating an evaluation of the performance of blends of biodiesel and home heating oil in space heating applications. This paper presents some preliminary results from this activity, which is being conducted under the sponsorship of the National Renewable Energy Laboratory (NREL). It also includes the results from some preliminary laboratory experiments done prior to the start of the project. The work will be expanded to do field tests under a coordinated effort with sponsorship from the New York State Energy Research and Development Authority (NYSERDA).

If it can be demonstrated that a domestic fuel source such as biodiesel or blends of biodiesel and heating oil can be used with few modifications, substantial benefits may be realizable. A fraction of the national fuel needs can be met with domestic and potentially locally produced agricultural based fuels, which are renewable and also viewed as environmentally ***greener*** (sulfur-free, biodegradable, nontoxic, higher flash point). They can also contribute to the fuel source diversity as used in space heating equipment, reducing the vulnerability to national and international petroleum market trends, and cushion the effects of future price spikes such as the ones which have occurred in recent years. The combined research effort will also include an evaluation of the potential benefits, such as the reduced occurrence of heat exchanger fouling and consequent reduced maintenance requirements and costs. The research will also investigate any potential difficulties that might occur during testing when using biodiesel blends with conventional components used in residential and commercial sized systems. It is also intended to document experience from planned field tests and from the experience of others such as the National Park Service who reportedly ran some limited tests with biodiesel last winter.

2.0 Background

Biodiesel is a name applied to fuels manufactured by the esterification of renewable oils, fats and fatty acids. The fatty acids may be derived from vegetable oils such as soybean or rapeseed (canola), rendered tallow, or waste materials such as cooking and trap greases. (Michael S. Graboski and Robert L. McCormick, Prog. Energy Combust. Sci. Vol. 24, pp. 125-164). The resulting product has 10-12% oxygen by weight and little or no sulfur, which have been shown to reduce the particulate emission in diesel engine use. Chemically, it is essentially non-aromatic and has a higher cetane number than normal

diesel fuel. Compared to home heating oil, it has about 10% less heating value per gallon. Neat (100%) biodiesel also has higher cloud and pour point temperatures than home heating oil. There is a provisional ASTM specification for biodiesel fuel blend stock, PS 121-99. Biodiesel is completely miscible with home heating oil and so blends can be easily generated

The use of biodiesel blends would be environmentally beneficial; as biodiesel typically has negligible sulfur, their burning will contribute to lower sulfur dioxide emissions. It has also been seen that biodiesel generates lower particulate emissions. The effects of lower sulfur dioxide and lower particulate emissions translate also to much less fouling of heat exchangers and hence to lower maintenance costs especially for small, residential systems. These effects obtain with blends as well, although obviously to a lower extent. The pure biodiesel, being derived primarily from sources of vegetable oil, is inherently biodegradable and so less polluting in the event of a spill.

Currently, biodiesel blends have been tried in diesel engines. There has been some limited burning in residential equipment including at the BNL's facility. However, more extensive testing must be preformed before the goal of this project can be met. It is expected at present, that the biodiesel blends may be more expensive than No. 2 fuel oil. But there are other benefits deriving from its use, as described above, that might offset the increased cost if any.

Some years previously, Ag Environmental Products (AEP) commissioned the R.W. Beckett Corporation to test straight biodiesel (referred to as B100) made from soy oil. More recently, Griffin Industries worked with BNL to do preliminary tests of blends of home heating oil and biodiesel made from recycled grease. The R.W. Beckett generated data has been shared with the National Renewable Energy Laboratory (Dr. Shaine Tyson) and BNL. R.W. Beckett's work concluded, from preliminary tests using soy diesel in a wet-base boiler with an AFII 150 burner, that their burners could easily be usable by soy diesel. They also indicated that the performance was close to that with fuel oil. It was also noted that the materials in the burner were compatible with soy diesel, with the exception of some door gaskets and label adhesives. They suggested additional work with blends such as B20 to solve the effects of the 'solubility properties' of the biodiesel.

3. Tests

3.1 Fuel Samples

The first series of tests were done prior to the start of the NREL funded project. They were a relatively quick set of emission measurements in steady state operation. Griffin Industries, Inc. supplied a five-gallon sample of biodiesel produced from recycled vegetable oil. The tests that are ongoing under NREL sponsorship are being conducted with blends from a biodiesel produced from soy and supplied by the same company. The blends are made with ASTM No. 2 home heating oil and with kerosene to ASTM no. 1 specifications.

3.2 Blend preparation

The biodiesel provided by Griffin Industries, Inc. in plastic drums is being stored inside the laboratory. This will ensure that the fuel will be maintained above 50 degrees Fahrenheit. The biodiesel is mixed with heating oil and with kerosene in small batches of a gallon or two at a time as required. The blend percentages reported are on a volumetric basis. For the preliminary steady state tests, a blend of 20% biodiesel in no. 2 oil, designated B20 was made. For the transient tests under the NREL project, three blends of 10%, 20% and 30% biodiesel in no. 2 oil, designated B10, B20 and B30 respectively were made. Also, a blend of 50% biodiesel with 50% kerosene, BK50 was also prepared. These latter samples of the blending fuels and the blends were sent to a testing laboratory for measurement of some fuel properties relevant to the current use.

3.3 Steady State Tests

The test facilities in the oilheat research lab were used in the testing. A modern retention head burner was used in a steel, low mass, wet base boiler in the tests. The boiler water is cooled by circulation through a plate heat exchanger, which in turn is cooled by building water. Standard fuel system was used with a nominal 0.6 GPH, 80^0 hollow nozzle was used at a pump pressure of 140 psi. This was held constant for the three blends and therefore the fuel mass flow rate was slightly different for each blend, being higher for the blends than for no. 2 fuel. In use, this higher flow compensates partially for the lower heating value of the biodiesel. An Enerac model 2000 analyzer was used to make the emission measurements in the stack. The majority of the tests were conducted after the boiler water had reached the normal operating temperature and at different stack oxygen values obtained by changing the burner airflow setting. Customary procedures call for the flue gas oxygen to be converted to an excess air level and also for all flue gas measurements to be converted to a constant excess air basis. For these preliminary tests, however, we did not have a fuel ultimate analysis and so the results are presented "as measured". The following figures give a summary of the measurements.

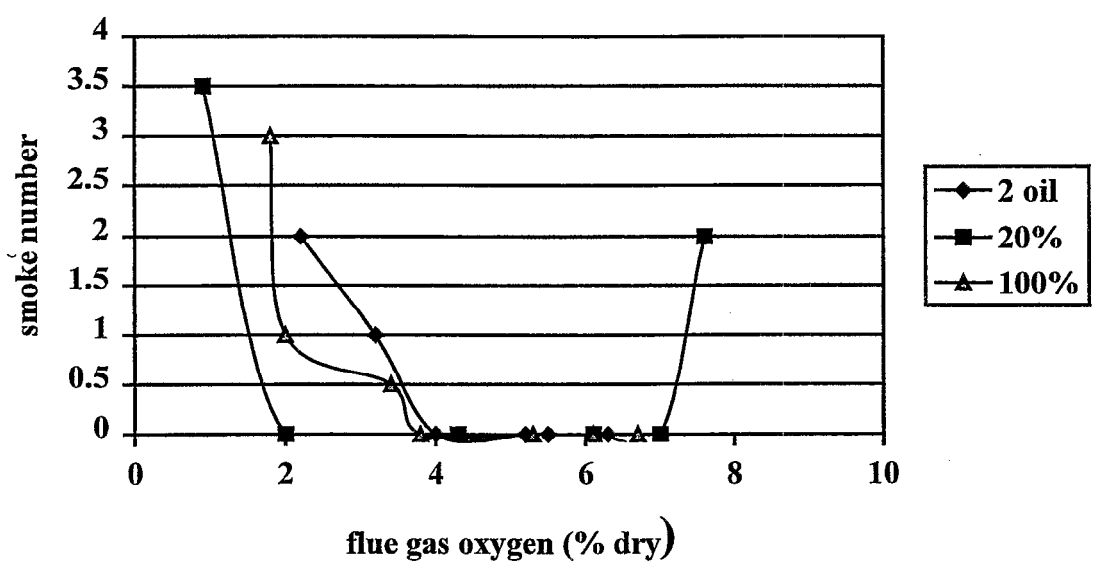

Figure 1. Smoke number vs. flue gas oxygen

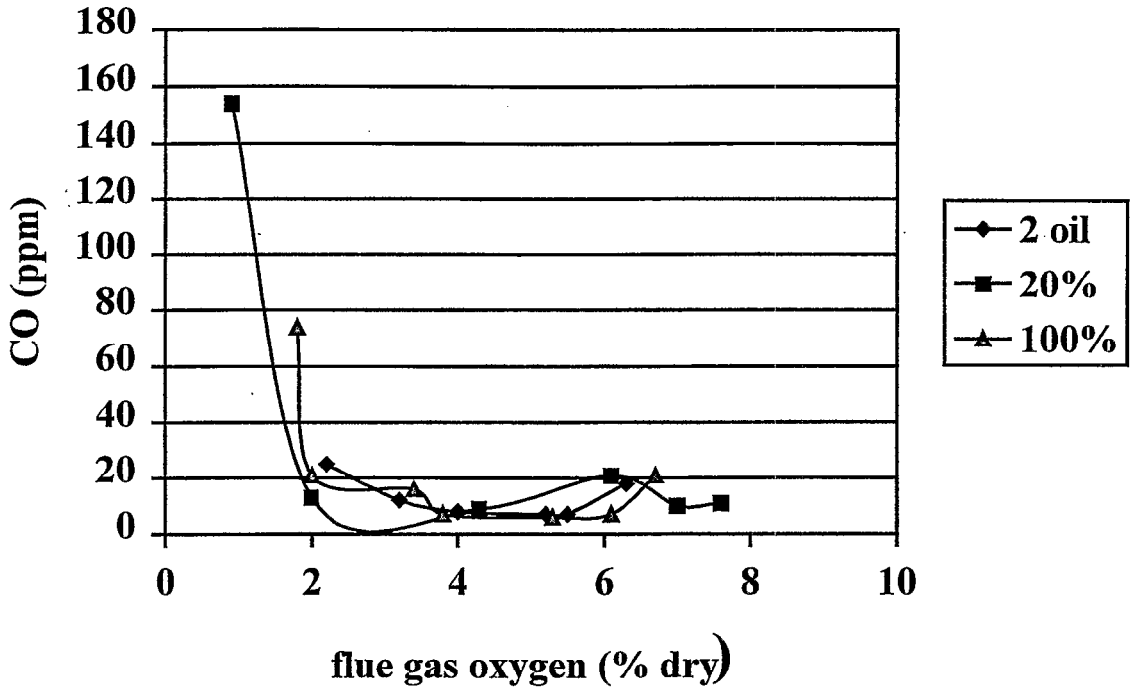

Figure 2. CO vs. flue gas oxygen

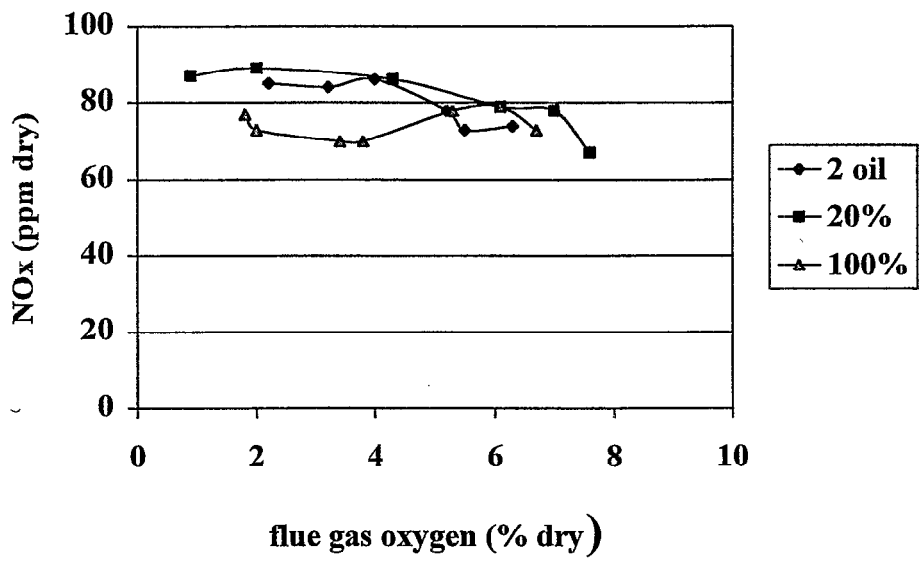

Figure 3. NOx vs. flue gas oxygen

Some preliminary conclusions are suggested by the above figures. At similar measured oxygen levels in the flue gas, the biodiesel blends appear to have similar performance as

No. 2 fuel in terms of smoke numbers and carbon monoxide. It seems that the NOx levels might be slightly higher with the blend, but lower with the neat biodiesel than with no. 2 fuel. While it is possible to come up with an explanation for this seeming anomaly, it would seem that more and definitive data needs to confirm this finding before one attempts an explanation. The general conclusion would be to support the one from the Beckett report that the performances are similar in this burner and boiler combination as well. While sulfur dioxide emissions are not reported, obviously they are lower with the B20 and nearly zero with B100.

A few scooping cold start tests were carried out with the neat biodiesel, B100. It was observed that successful start was achieved only at the lower excess air settings. Additionally, at very high excess air levels, the control system would shut the burner down, as if the cad cell could not 'prove' the flame. This could relate to the 'lower emissivity' of the flame at the locations and the wavelengths that the cad cell is most sensitive to. Again, more data is required to confirm and quantify these observations.

3.4 Transient tests

The test facilities in the oilheat research lab are being used in this phase of the testing as well. A three section, cast iron, wet base boiler is used for the tests. The boiler water is cooled by circulation through a plate heat exchanger, which in turn is cooled by building water. A modern retention head type burner with a pressure nozzles rated at 0.6 gallons per hour and fired at a pump pressure of 140 psi was used in the tests. Again, these conditions were maintained for all the blends and hence the fuel flows change slightly depending with the blends. The operating conditions in terms of excess air (as measured from the oxygen in the stack) and in terms of Bacharach smoke number were set with the No. 2 oil and were left unaltered for subsequent runs with the different blends. No changes were made to the nozzle, the ignitor, the cad cell and the control. Figure 4 is a photograph of the test set up.

Constant sampling flue gas emission analyzers were used to measure the concentration of oxygen (paramagnetic measurement), nitrogen oxides (chemi-luminescent measurement) and carbon monoxide (infrared measurement) in the exhaust stack. A special sampling line built to meet the requirements of the analyzers is used to draw the sample from the stack. Smoke was measured using the ASTM # D2156-80 method and a manually operated piston type sample pump.

The transient tests were started from a 'cold' boiler condition. The 'cold' condition was obtained by reducing the measured boiler water temperature to around 55 degrees F by prolonged circulation through the plate heat exchanger prior to starting the burner. It should be emphasized that this is not a normal operation of the system, which cycles under aquastat control usually between 160^0 F and 180^0 F for boiler water temperature. Transient measurements of carbon monoxide and smoke were made during startup from 'cold' conditions. The analyzer output was fed to a data acquisition system for later analysis, while the smoke measurements were made using the manual system on a timed basis. B10, B20, B30 and BK50 defined above in addition to No. 2 fuel were used in these tests.

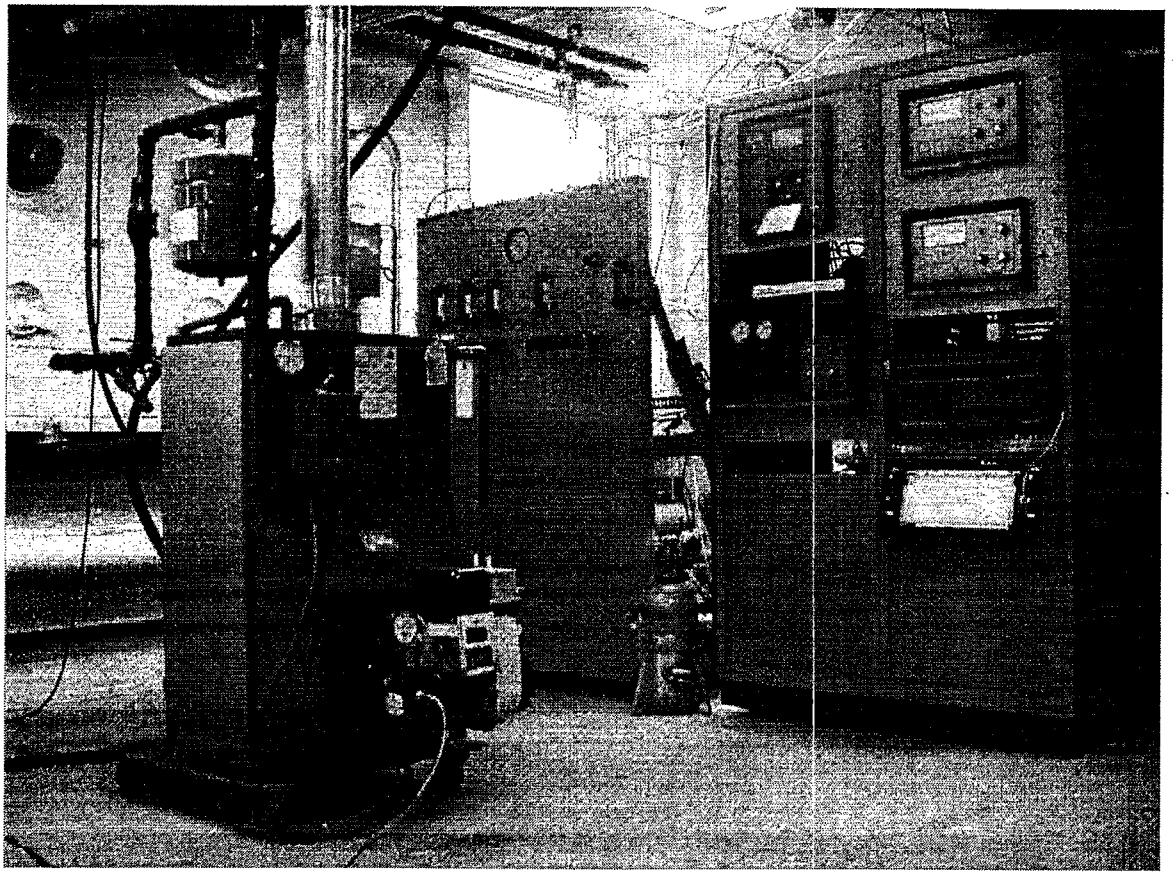

Figure 4. Test Setup for Transient Tests

3.4.1 Test results

The results of the tests for transient Carbon Monoxide are given below as Figures 5, 6, 7, 8 and 9. Taken together, they suggest a strong similarity in behavior, although it should be reiterated that there are small differences in heat input, as the firing rates and the heating values of the blends differ slightly.

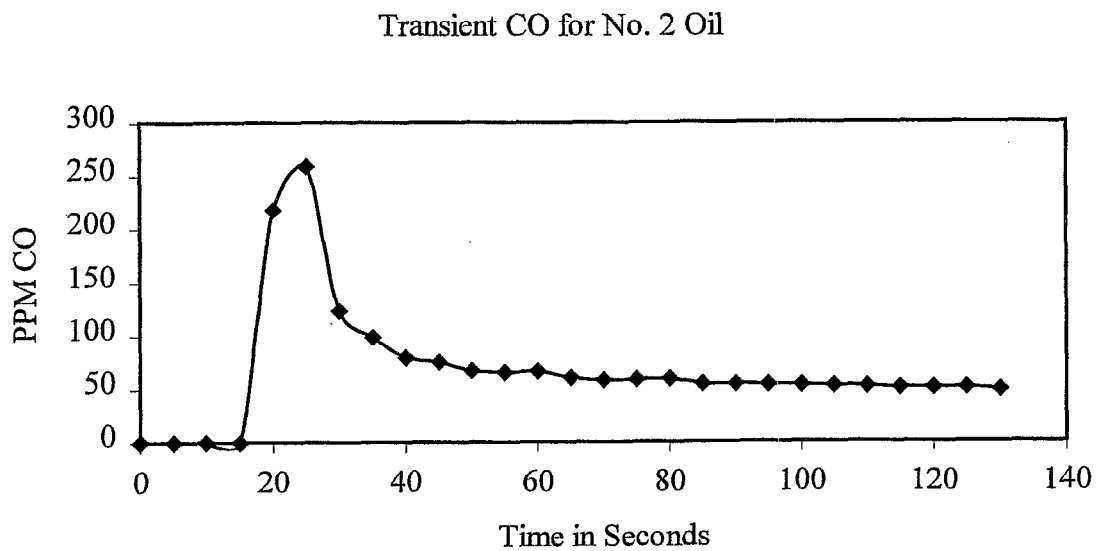

Figure 5. Transient carbon monoxide for # 2 fuel oil.

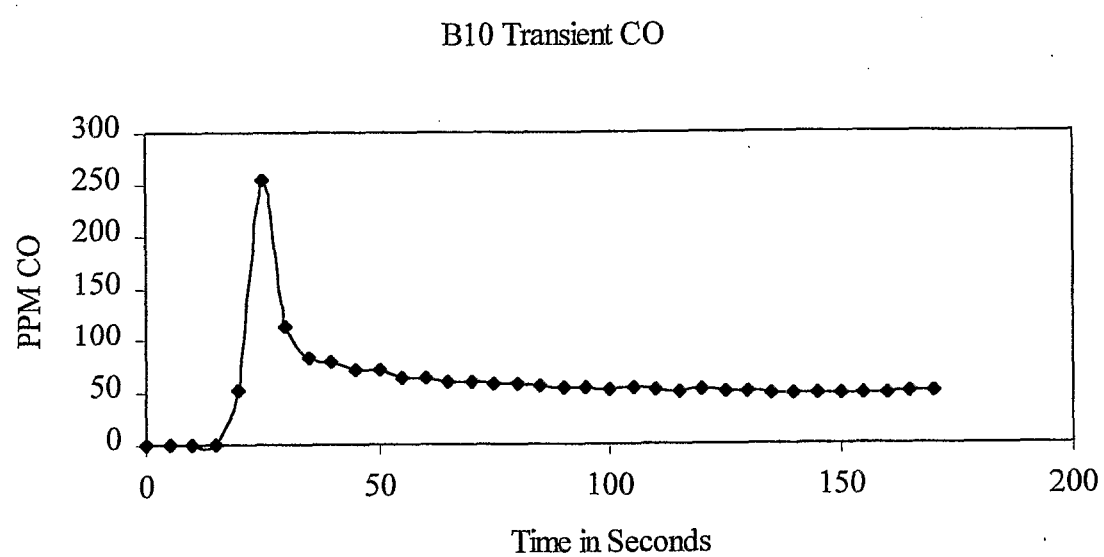

Figure 6. Transient carbon monoxide for B10.

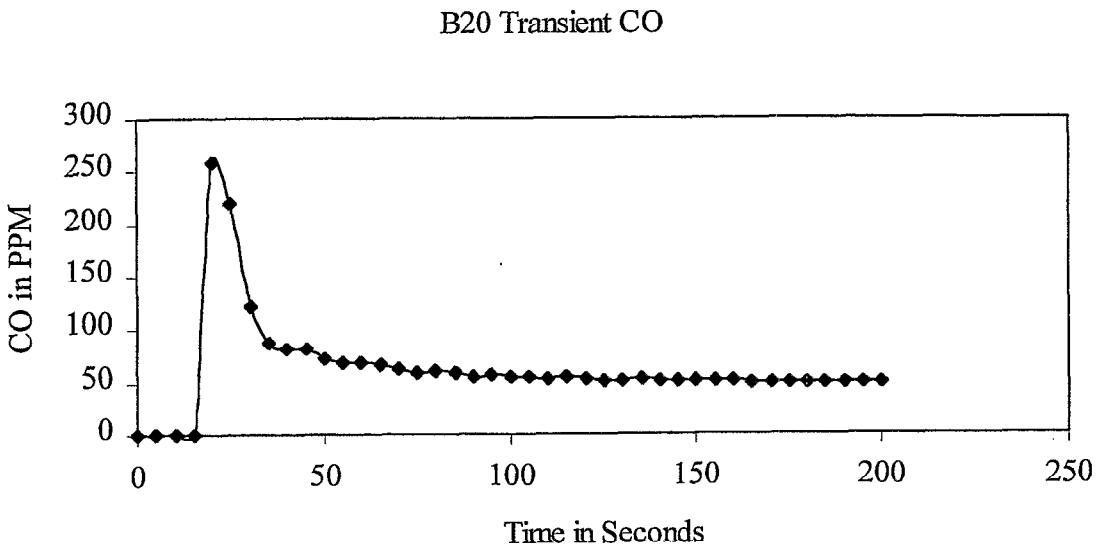

Figure 7. Transient carbon monoxide for B20.

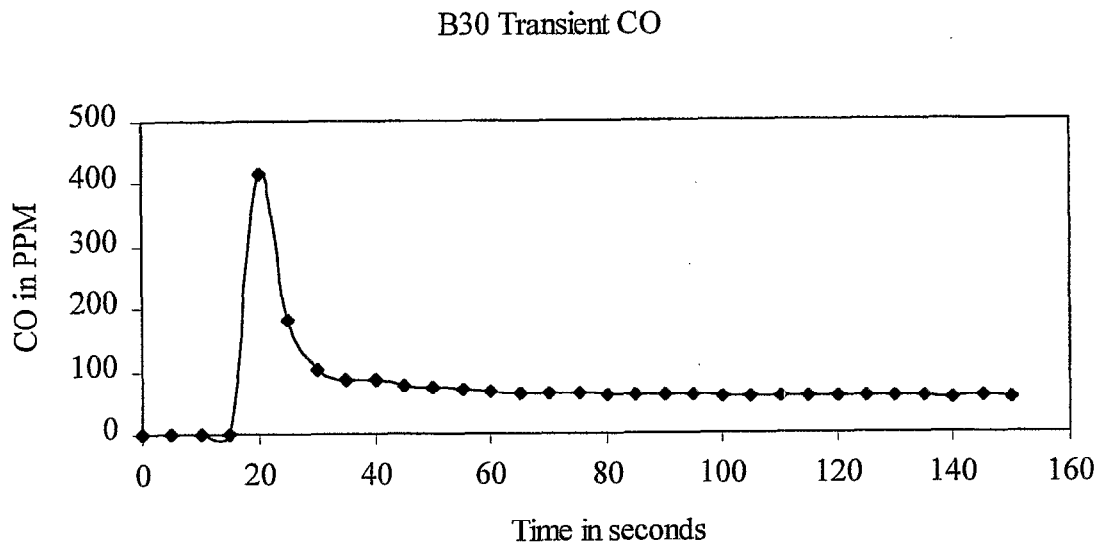

Figure 8. Transient carbon monoxide for B30.

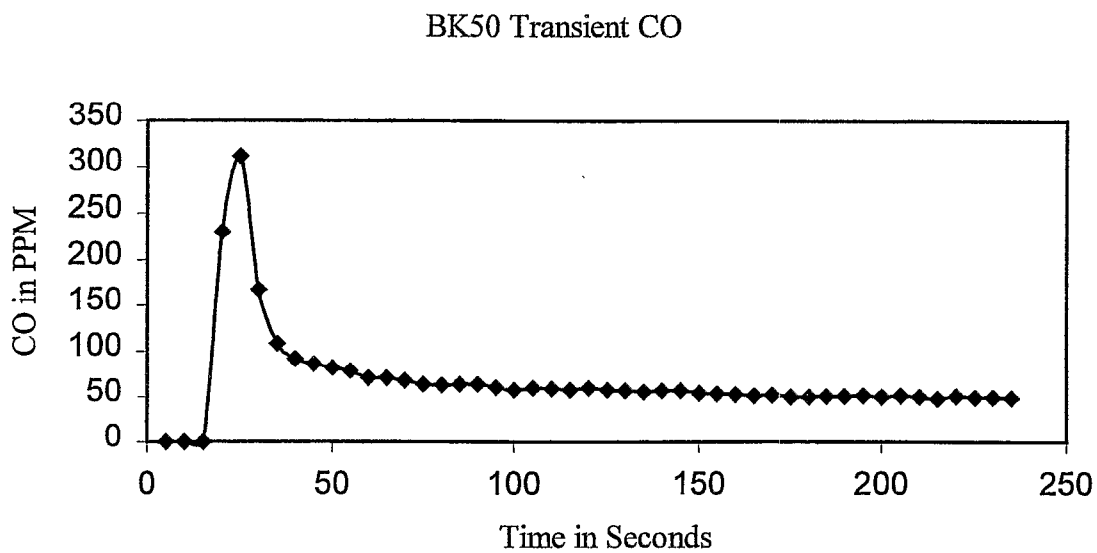

Figure 9. Transient carbon Monoxide for BK 50.

The transient smoke numbers did not increase much beyond a trace for all the blends and for no. 2 oil. In view of the result reported in the steady state tests where the control shut off the burner when it seemed to be operating normally with B100, Cad cell resistances were measured in the set up used above for heating oil and B100. The numbers turned out to be very similar, 960 ohms for No. 2 and 1000 ohms for B100 and the burner ran successfully. The stack oxygen level was about 5.0%. While this is encouraging, more tests are needed if one is expecting to use B100.

The preliminary data presented here suggests that the cold start performance of one boiler and burner combination as measured by transient smoke and carbon monoxide without any adjustment to the burner is similar with number 2 fuel oil and the blends of biodiesel.

4.0 Conclusions and Future Work

The major conclusion so far has been to show that biodiesel blends perform like heating oil, both in steady state and in cold starting. This is similar to the conclusions from the Beckett report. However, there could be problems under certain conditions in the cad cell control for neat biodiesel. In this project, we hope to come up with a recommended blend that can be used with the expectation of no problems in a typical system. More testing is planned with this 'chosen' blend and with BK50 in the NREL project, including tests in a commercial size hot water heater in the laboratory. Under the NYSERDA project, field tests are planned with the selected blend to ferret out practical operational problems such as material and equipment compatibility associated with the differing solubility properties of biodiesel. The precise scope and nature of the field tests are in the discussion stage.

3.0 **Acknowledgements**

We would like to thank Dr.Shaine Tyson of NREL for funding the research, for cooperative guidance and for facilitating the delivery of the biodiesel. We thank Hart Moore at Griffin Industries, Inc. for supplying the fuel and providing information.

Paper No. 01-15

Alternative Fuel Oils and the Effect of Selected Properties on Combustion

Victor J. Turk, P.E., John M. Laisy, P.E., and William R. Mastrangelo

R.W. Beckett Corporation
Post Office Box 1289
Elyria, OH 44036
800-645-2876
vturk@beckettcorp.com

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Victor J. Turk, P.E., John M. Laisy, P.E., William R. Mastrangelo
R.W. Beckett Corp.

Abstract:

A number of middle distillate fuels exist that can be used satisfactorily in lieu of regularly specified fuel oils. These include highway, aviation and marine fuels manufactured to a variety of standard national specifications. Comparative properties include distillation range, viscosity, flash point, density and sulfur content. Properties such as grade (i.e., distillation range) and sulfur content have measurable but minimal effects on combustion performance and burner operation.

1. Introduction

A variety of petroleum-derived or related products are currently marketed that serve as fuels in different applications. Although these fuels are blends from common base stocks, they are tailored to specific applications either by varying the proportion of different blending stocks, using different finishing processes, or incorporating additives. The resulting fuels are called by a variety of names and numbers specific to their intended application, even when significant properties are similar or even identical.

Practically all North American residential oil burners are designed and manufactured in accordance with UL 296 and CSA B140.2.1. Burners listed as complying with UL 296 are designed to be used with ASTM D396, fuel oils (generally grades 1 and 2) both for testing and normal operation. (Burners are certified as complying with CSA B140.2.1 under similar conditions, however due to the broader use of ASTM standards, this paper will focus on these standards.) Most local codes require that burners meet one or both of these standards. Once the burners are installed into actual service, users often are confronted with situations where alternative fuels are likely to be used. Although technically these conditions seem to violate the terms of the approval, the alternative fuels, when carefully selected, will likely meet the basic requirements of the specified fuel. This paper will discuss the basis for selecting appropriate alternatives from a number of fuels intended for highway, aviation and industrial applications, primarily from petroleum sources, but considering biological sources as well.

2. Basic Properties

Basic properties that affect the suitability of a fuel for use in a pressure atomized residential burners are those that determine its combustion performance, handling characteristics and effects on its operating environment. Although all of these properties are a function of the final composition of the fuel, they are grouped for discussion as primarily physical properties, chemical properties or some other special combination of properties.

2.1 Physical properties – A wide range of petroleum-derived products is commercially available, produced by distillation of crude oil and blending of the resulting fractions. Distillation is essentially a process of boiling followed by cooling the vapor to condense it back into a liquid. Crude oil (petroleum) is heated in a pressure vessel, with the different "fractions" of the crude boiling off at different temperatures. These distillation fractions of petroleum

produce different end products, and their respective boiling temperatures are listed below in Table 1. In addition to straight distillation, heavier crude oil or the higher boiling fractions of crude oil can be reacted, either thermally or in the presence of a catalyst, to break it down into smaller compounds. This process, known as *cracking*, yields a number of products that are used as blending stocks to produce middle distillate products. The most common of these is called light cycle oil (LCO) and is a common component of most fuel oils. Regardless of the method of production, the resulting products are graded based on their boiling range.

Table 1. Boiling Ranges of Petroleum Fractions

Fraction	Boiling Range (°F)
Naphtha (solvent)	30 – 300
Gasoline (light distillate)	30 – 355
Kerosine / Grade 1 fuels (middle distillate)	300 – 575
Grade 2 fuels (middle distillate)	320 – 650
Heavy fuel oil	600 – 800
Lubricating oil	>750
Residue	>1100

Grade – Approximate boiling ranges, as indicated in Table 1, above, define grades of fuels and determine physical properties. All of the common fuel grades used for residential burners are part of the middle distillate group of petroleum products. These products are characterized by relatively low volatility with a boiling range of approximately 300 to 650°F. Physical properties, including viscosity (resistance to flow), density (weight per gallon or specific gravity) and heat content (higher heating value), are dependent on the grade of fuel, with all three properties increasing as the grade number increases. (A notable exception to this is the grading of kerosine, which will be explained in section 2.2.)

The cut-off boiling points between one grade and another are not sharply defined and this is used advantageously to extend the supply of different grades to meet changing supply and use conditions. The initial boiling point (the temperature at which boiling begins for a specific blend) is also controlled to maintain flash point temperatures above specification minimums for safe handling and storage. Boiling range, viscosity, density and flash point limits for middle distillate fuels are listed in Table 2, below.

2.2 Chemical properties – Chemical properties include the amount of specific chemical elements or compounds present in the fuel (either intentionally or inadvertently). Sulfur is one element that significantly affects the results of the burning process, and higher sulfur contents contribute to increased corrosion of heat exchanger surfaces and particulate emissions. It is related to the source of the crude oil used to prepare the fuels as well as any process steps that are used in finishing the intermediate blend stocks. The grade number for kerosines is used to differentiate between sulfur levels in the fuels, with the lower fuel grade designating the lower sulfur fuel.

Fuel bound nitrogen also affects the result of the burning process, and increased nitrogen contributes to increased oxides of nitrogen (NOx) in combustion gas streams. It also is related to

the source of the crude oil used to prepare the fuels as well as any process steps that are used in finishing the intermediate blend stocks.

Additionally, the type of hydrocarbon chemicals (the arrangement of hydrogen and carbon in the fuel molecules) present can affect the burning process. Aromatic fuels actually have ratios of hydrogen to carbon that are significantly different from aliphatic or paraffinic fuels (about 1:1 for aromatics versus about 2:1 for aliphatics). This can affect the air-fuel ratio required for proper combustion in extreme cases (greater than 80% aromatic). Seal elastomers behave differently in aromatic hydrocarbons than they do in aliphatic hydrocarbons, with some materials swelling significantly more in the aromatics than in the aliphatics.

Residual metals present in fuels can have serious affects on the materials used to contain the combustion process. Although this is not usually an issue with conventional pressure atomized oil burners, high concentrations of certain metallic elements, notably vanadium, can have serious corrosive effects on materials used in gas turbines.

2.3 Other properties – Certain properties of fuels are a function of a number of factors including physical and chemical properties, processing steps and additization. Low temperature properties are one group of these properties. The low temperature operability temperature of a fuel (the lowest temperature of a fuel at which it is able to function properly) is related to the grade, base hydrocarbon chemistry and additives used to prepare the fuel. This property is traditionally thought of in terms of the cloud and pour point temperatures of a fuel, and without additives, the low temperature operability temperature and the cloud point temperature are essentially the same. Wax crystals that precipitate in the fuel at low temperatures and their distribution in the fuel are responsible for degradation of low temperature operation. Additives are effective in improving the operability of fuels (although the cloud point temperature usually is not affected). The lower grade number fuels (grade 1 fuels, kerosines) have inherently better low temperature properties related to the compounds that boil at the higher temperatures. Blending lower grade number fuels with grade 2 fuels is also helpful.

Stability of a fuel either in storage or at elevated temperatures is often a function of the finishing steps following the preparation of and blending of the intermediate stocks. Long-term stability of the fuel can be enhanced by neutralizing the reactive compounds that are left from the cracking process either by treating the fuel with hydrogen or by mixing stabilizer additives into the finished product. Biological stability of a fuel is primarily a function of housekeeping (fuel cleanliness throughout the distribution process). Biocides are used only after normal methods have failed, and are not added to fuels as a normal practice. This is because biocides are toxic to other organisms besides microbes, and overuse tends to produce the development of biocide-resistant strains.

3. Specific products

A discussion of a number of commonly marketed fuels follows. Characteristics of the fuels that suggest either satisfactory or unsatisfactory performance are discussed, and a table of selected properties of middle distillate candidate burner fuels is included in Table 2.

3.1 Automotive / aviation gasoline

- Gasoline fuels (and the even lighter naphtha solvents) are not at all acceptable for use in conventional pressure atomizing burners. High volatility, low viscosity and low flash point cause these fuels to be unsafe in some storage conditions, and may result in an explosion during oil burner operation. These fuels also tend to burn with a blue flame that cannot be detected by a cadmium sulfide flame detector (*cad cell*) therefore not allowing the primary safety control to function properly.

3.2 Aviation turbine fuels (Jet fuels)

- Jet A and Jet A-1 are similar compositions of high-quality products similar to kerosine that are the most widely used aviation fuels today. Jet A is available only in the U.S. and accounts for about half of the civil jet fuel used throughout the world. It is used for domestic flights and the majority of international flights originating in the U.S. Jet A-1 has better low temperature properties than Jet A (to satisfy the demands of long-range high altitude flights) and is the standard grade for international flights outside of the U.S. JP-8 is the military designation for what is essentially Jet A-1, to provide a common "single fuel" for U.S Air Force and European NATO aircraft. JP-5 is a kerosine-type high flash point fuel for naval aircraft carrier use.

  Jet A products have been tested in the laboratory, and work well. Their heat content is typical of kerosine products, lower than grade 2 fuels, and produce a water temperature rise 20°F lower than a grade 2 fuel in a typical residential boiler at the equivalent firing rate. Jet A, Jet A-1 and JP-8 fuels are expected to work satisfactorily in typical pressure-atomizing oil burners. They have similar properties to grade 1 heating oil and can be used in typical fuel pumps. See Table 2 for selected properties of these fuels.

- Jet B (and the military equivalent JP-4) are of similar compositions to wide cut gasolines that are still used in some aviation applications. These fuels are not acceptable for use in typical pressure atomizing residential burners. These fuels have lower viscosities, lower boiling ranges and lower flash points than grade 1 heating oil. Also, these fuels demand special fuel pumps that are built specifically for Jet B and JP-4.

3.3 Fuel Oils (Heating Oils) / Diesel Fuel Oils / Kerosines / Gas Turbine Oils

Domestic heating oils that are suitable for pressure atomized residential burners are middle distillate products. Fuel oils (heating oils), diesel fuels, kerosines and gas turbine oils all fall into this category and are prepared from common blending stocks. There are heavier residual grades of these fuels that are produced wholly or in part from undistilled petroleum fractions from a number of refinery processes. These products will be discussed by grade.

Fuel oils tend to be products with minimal restrictions and additives, and are produced mainly with heat content in mind. Diesel fuels are usually formulated with enhanced properties for high performance diesel engine operation that requires higher temperature stability, more consistent low temperature properties and improved lubricity for pump and injector performance. Kerosines are more refined products typically used in wick-type appliances, often in closed spaces (buildings). Gas turbine oils are controlled for specific trace metal contaminants that may

chemically attack the special metal components in high temperature stationary gas turbine engines.

Notes:
- The names and designations used in this paper are the accepted ASTM spellings and designations , and are used for consistency.
- Kerosine is often spelled "kerosene" and is often referred to as "K-1" kerosine. These all refer to the same product and are used interchangeably.
- Grade 1 or grade 2 products are often referred to as no. 1 or no. 2 products. These are also interchangeable.

- Grade 1 fuel (heating) oil, grade 1-D diesel fuel, grade 1-K and 2-K kerosine and grade 1-GT gas turbine oil are similar in composition and properties. Distillation range, viscosity, specific gravity and heat content are all similar and lower than number 2 grades of diesel fuel, fuel oil and gas turbine oil. Grade 1-D diesel (the fuel used for on-highway applications) and 1-K kerosines are low sulfur fuels, whereas grades 1 fuel oil, 1-GT gas turbine oil and 2-K kerosine are higher sulfur fuels. The lower sulfur fuels tend to operate with fewer deposits on appliance heat exchangers since they generate lower concentrations of sulfuric acid in the combustion gas streams. Only grade 1 fuel oil is specifically included by regulating agencies for listing burners in accordance with existing burner standards, although the properties of all of these fuels are essentially the same. See Table 2 for selected properties of these fuels.

- Grade 2 fuel (heating) oil, grade 2-D diesel fuel, and grade 2-GT gas turbine oil are also similar in composition and properties. As with the number 1 grades, distillation range, viscosity, density and heat content are all similar. Grade 2-D diesel (the fuel used for on-highway applications) is also a low sulfur fuel, whereas grade 2 fuel oil and grade 2-GT gas turbine oils are higher sulfur fuels. Only grade 2 fuel oil is specifically included by regulating agencies for listing burners in accordance with existing burner standards, although the properties of all of these fuels are essentially the same. See Table 2 for selected properties of these fuels.

- Grade 4 fuel (heating) oils and grade 4-D diesel fuel are similar to each other in composition. These are considered residual fuels, and are controlled by viscosity rather than boiling range. Although they can be adequately handled in a conventional residential pressure-atomizing burner using conventional fuel pumps, lab testing has determined that poor atomization of these oils by pressure atomization using simplex nozzles makes ignition and clean combustion impossible.

  Additional investigation of the performance limits of these heavy oils involved combustion testing with a 1:1 blend of grade 2 and grade 4 fuel oils. This blend would ignite, but would not burn cleanly (i.e., smoke could not be eliminated from the flue gasses). Heavy carbon build up was observed on the retention head and ignition electrode assemblies of the burner.

- Grade 5 fuel (heating) oils are not acceptable fuels in pressure atomizing residential oil burners. The fuels have high viscosities and must be heated before burning. These fuels

typically require high pressure air or steam atomization. Even when heated, these fuels are difficult to burn cleanly using conventional pressure atomizing technology for residential burners.

- Grade 6 heating oil (also known as Bunker C) is not an acceptable fuel in pressure atomizing residential burners for the same reasons as grade 5 fuel oils.

3.4 Lubricating Oils / Engine Oils

These oils are not acceptable as fuels in pressure atomizing residential burners due to their hydrocarbon composition (carbon number or molecular size) and associated high viscosity. For combustion of these oils, a waste-oil type burner (with oil preheating and air atomization is typically required.

3.5 Biodiesel Fuels

Fuel products derived from biological sources (typically, soybeans, rapeseed, and other agricultural products from which vegetable oils are derived) are being evaluated as a supplement for petroleum fuels. A key target market for this development is highway diesel fuel, although heating applications are being evaluated as well.

Biodiesel fuels can be formulated to have physical properties similar to petroleum fuels, although they are different chemically. In this regard, one attractive feature of biodiesels is their inherent low sulfur content (essentially sulfur-free). Biofuels are esters (reaction products of alcohols and long chain organic acids that include carbon, hydrogen and oxygen in the molecule) compared with the plain hydrocarbon petroleum fuels (only carbon and hydrogen in the molecule). At this point, biodiesel is used primarily as a blending stock and for use in highway diesel applications. The neat biodiesel fuel typically is blended 20:80 with petroleum diesel.

Screening tests in 1993 of the neat fuel in a pressure atomizing residential burner showed that the fuel performed well in a test application. As expected, oxides of sulfur were reduced compared to a grade 2 fuel oil. The biodiesel tested had a slightly lower heat content than the grade 2 petroleum fuel oil, but it had a higher viscosity which increased the flow rate at a given pump pressure and nozzle size. The higher flow rate coupled with the lower heat content minimized any change in the overall heat release in the appliance.

Brightness of the biodiesel flame (as measured by the cad cell flame detector resistance) was slightly less than with the petroleum fuel oil. At a typical operating level, the cad cell resistance measured about 50 higher with the biodiesel than with the petroleum fuel oil. This difference would not be expected to cause problems with primary safety control functions with properly tuned burners.

Gaskets and labels on burners were adversely affected by saturation with biodiesel, and the biofuel is expected to compromise fuel pump seals over time. This is due to the chemical differences between plain hydrocarbons (for which the gaskets, labels and seals are designed) and esters.

4. Combustion Performance

Four of the above fuels were tested in two different burner applications to evaluate relative performance differences among the fuels. The four fuels included two grade 1 distillation range fuels and two grade 2 distillation range fuels, each with two different sulfur contents. The fuels are listed in Table 3. Differences in combustion results were insignificant, given the different heat contents of the various fuels, and were consistent with expectations. Cad cell flame detector resistances variations had not been previously documented, and became the focus of this evaluation.

Table 3 – Fuel descriptions

	Fuel	BTU/gal. (typical)	% S (typical)	% S (by spec.)	ASTM
High BTU, High sulfur	No. 2 Fuel Oil	139,000	0.35	0.5, max.	D396, Grade 2
High BTU, Low sulfur	No. 2 Diesel	139,000	0.03	0.05, max.	D975, Grade 2-D
Low BTU, High sulfur	Jet A	135,000	0.25	0.3, max.	D1655, Grade A
Low BTU, Low sulfur	1-K Kerosine	135,000	0.03	0.05, max.	D3699, Grade 1-K

The fuels were evaluated in a typical residential cast iron boiler and a typical residential warm air furnace. The boiler had a refractory target wall and blanket and was fired at 1.18 gph, and the furnace had a refractory ceramic fiber chamber and was fired at 0.75 gph. Ambient temperatures were not strictly controlled, and were at nominal lab temperatures. Chimney draft was controlled by barometric draft control (no draft inducer). Oil flow rate was measured by burette only with the No. 2 heating oil from the lab oil supply system, as the other three fuels were pumped out of drums. Typical production application conditions were used to develop the data.

4.1 Cad cell resistance

Cad cell resistances were measured at the flue gas CO_2 levels representing the trace point, typical operating level and last stable ignition point. The results are charted to show comparisons at the typical operating level, and are shown in Table 4. The results were plotted to show trends in cad cell resistance as a function of % CO_2, and these data are shown in Figures 1 to 8.

Analyzing the cad cell resistance readings at 11% CO_2 (typical operating level, and one common combustion condition for all fuels) the following was observed:

- The higher BTU content, higher sulfur fuel (grade 2 fuel oil) provided the lowest (best) cad cell resistance.
- Starting with the higher BTU content higher sulfur fuel (grade 2 fuel oil), *either* reducing the BTU content *or* reducing the fuel sulfur increased the cad cell resistance.
- Starting with the higher BTU content, higher sulfur fuel (grade 2 fuel oil), reducing *both* the BTU content and fuel sulfur increased the cad cell resistance reading, but not as much as changing either of these factors singly.

Table 4 – Cad cell resistance readings at 11% CO2

	Boiler - Cad cell resistance (@ 11% CO2)			Furnace - Cad cell resistance (@ 11% CO2)		
	High Sulfur	Low Sulfur	Diff., Hi S to Low S	High Sulfur	Low Sulfur	Diff., Hi S to Low S
High BTU fuel	186	203	+17	471	530	+59
Low BTU fuel	205	196	-9	479	505	+26
Diff., Hi BTU to Low BTU	+19	-7		+8	-25	

5. Conclusions

5.1 The following products are fully acceptable in pressure atomized residential burners:

- Grade 1 fuel oil.
- Grade 2 fuel oil.

5.2 The following products are expected to function acceptably in pressure atomizing residential burners:

- Jet A, Jet A-1 and JP-8 aviation fuels (similar to grade 1 fuel oil).
- Grade 1-D diesel fuel, grade 1-K and 2-K kerosines (similar to grade 1 fuel oil).
- Grade 2-D diesel fuel (similar to grade 2 fuel oil).
- Grade 1-GT and grade 2-GT gas turbine oils (similar to grades 1 and 2 fuel oils, respectively).

These fuels are essentially identical to grades 1 and 2 fuel oils in all significant respects.

5.3 The following product is expected to function acceptably (from a combustion standpoint) in pressure atomizing residential burners, but requires additional scrutiny to assure that all chemical-related properties are matched to burner component design criteria:

- Biodiesel (neat and blends with fuel oil or diesel fuel).

5.4 The following are not suitable for use in pressure atomizing residential burners and should not be used:

- Jet B aviation fuel.
- Grades 4, 5 and 6 fuel oils and grade 4-D diesel fuel.
- Gasolines of all types.

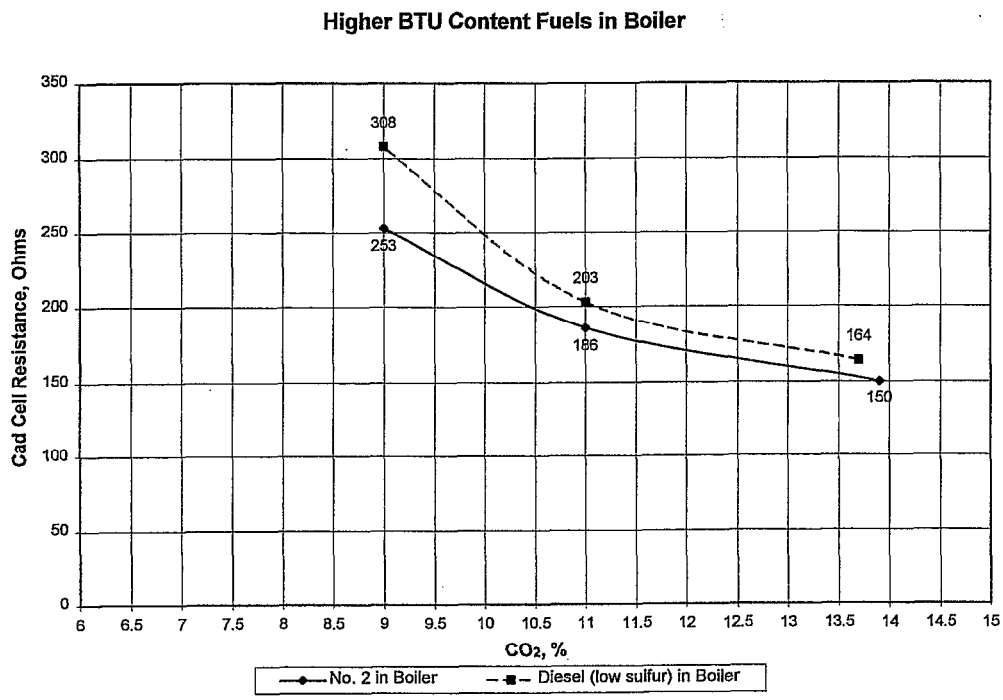
5.5 Higher sulfur content and higher BTU fuels will tend to give slightly lower (i.e., better) cad cell resistances than other combinations of sulfur and BTU content.

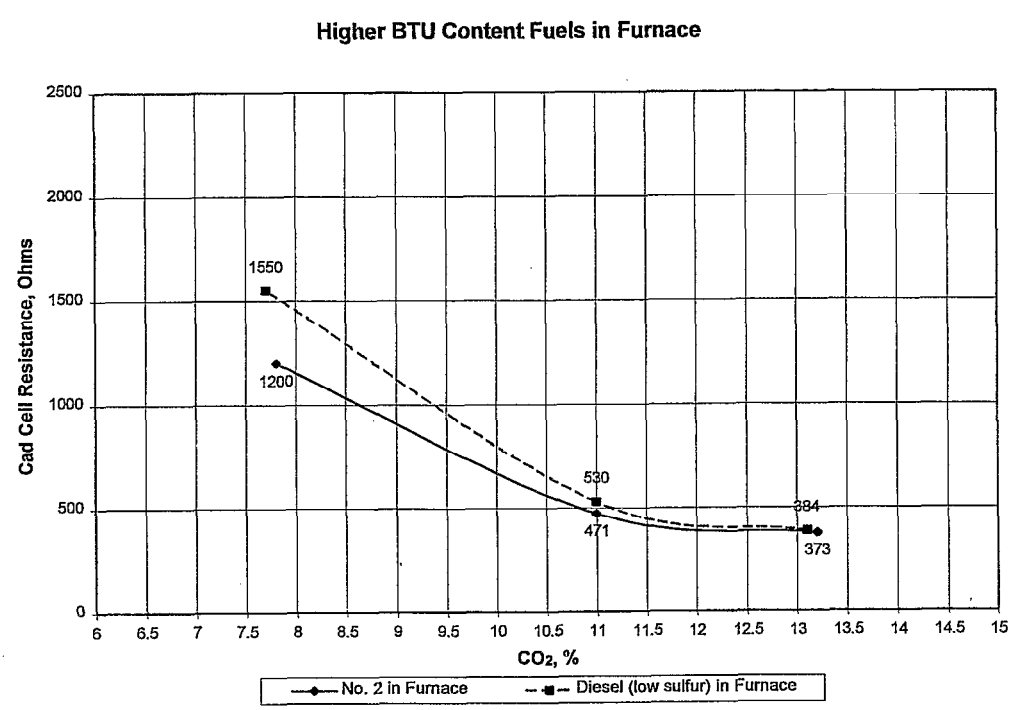
5.6 The differences in cad cell resistances due to lower sulfur and lower BTU content are minimal (on the order of 10 to 60) and should not affect oil burner primary safety control function.

Table 2 – Selected Properties of Middle Distillate Fuels

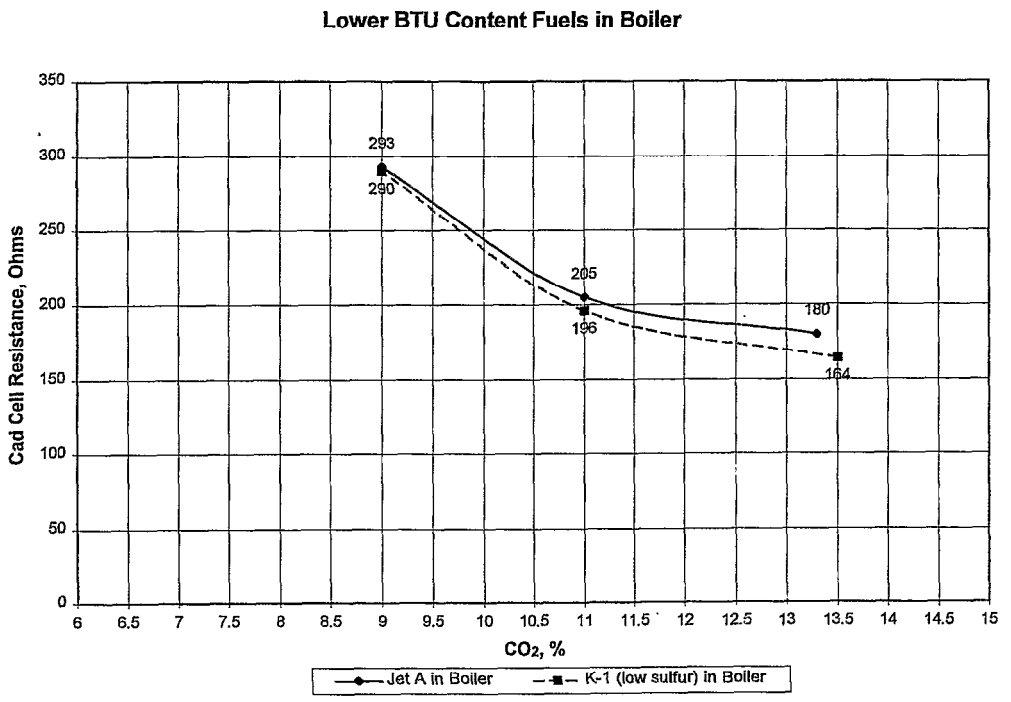
COMPARISON OF NO. 1 & 2 MIDDLE DISTILLATE FUEL SPECS:

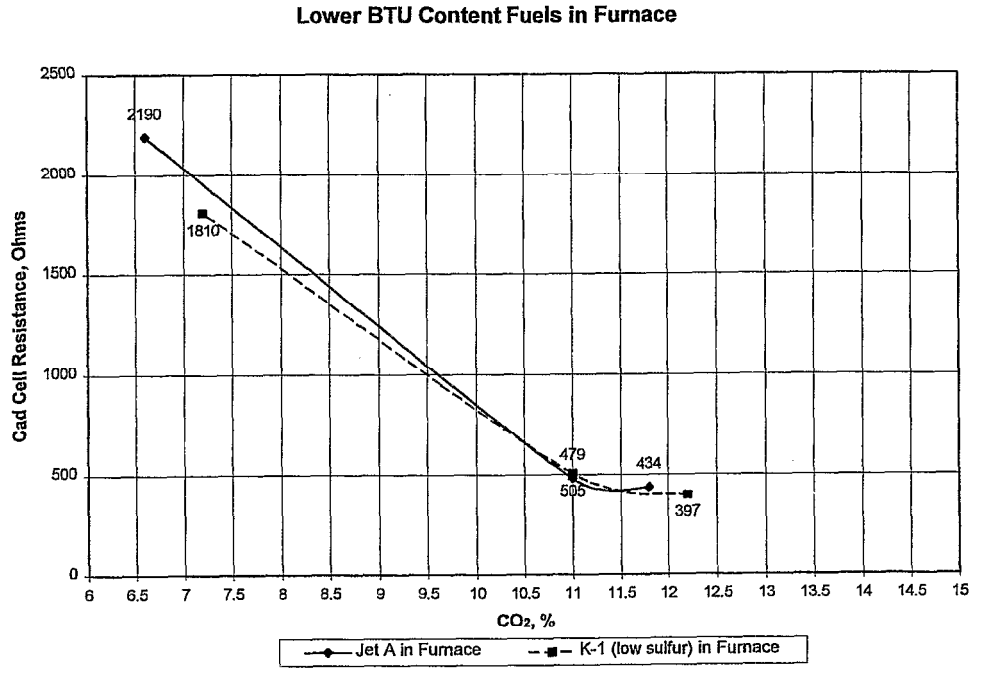
	D396	D396	D975	D975	D3699	D3699	D2880	D2880	D1655
	NO. 1	NO. 2	NO. 1-D	NO. 2-D	NO. 1-K	NO. 2-K	NO. 1-GT	NO. 2-GT	JET A
Flash Point, °C (°F), min.	38 (100)	38 (100)	38 (100)	52 (125)	38 (100)	38 (100)	38 (100)	38 (100)	38 (100)
Distillation Range:									
10%, °C (°F), max.	215 (420)	-	-	-	205 (400)	205 (400)	-	-	205 (400)
90%, °C (°F), min.	-	282 (540)	-	282 (540)	-	-	-	282 (540)	-
90%, °C (°F), max.	288 (550)	338 (640)	288 (550)	338 (640)	-	-	288 (550)	338 (640)	-
Final, °C(°F), max.	-	-	-	-	300 (570)	300 (570)	-	-	300 (570)
Viscosity, cSt:									
min. (@ 40°C)	1.3	1.9	1.3	1.9	1.0	1.0	1.3	1.9	-
max. (@ 40°C)	2.1	3.4	2.4	4.1	1.9	1.9	2.4	4.1	-
Cetane, min.	-	-	40	40	-	-		-	-
Density, sp. gr., max. / range (API, min. / range)	.850 (35)	.876 (30)	-	-	-	-	.850 (35)	.876 (30)	.775-.840 (51-37)
%S-Mercaptan, max.	-	-	-	-	0.003	0.003	-	-	0.003
%S-Total, max.	0.5	0.5	0.05	0.05	0.04	0.3	- (0.5)	- (0.5)	0.3



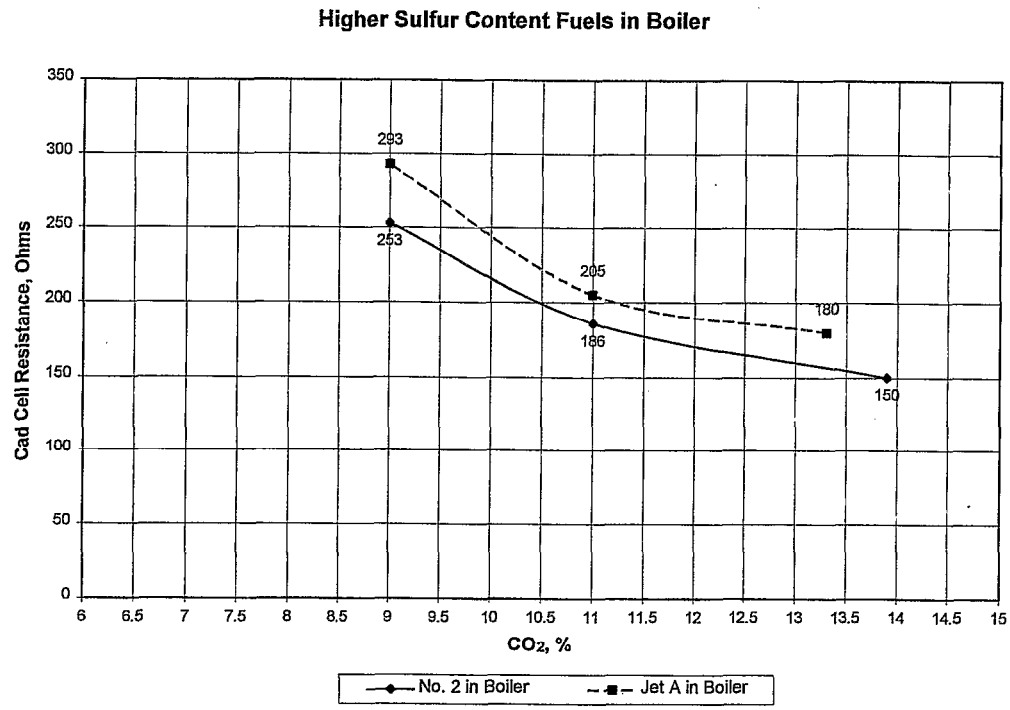


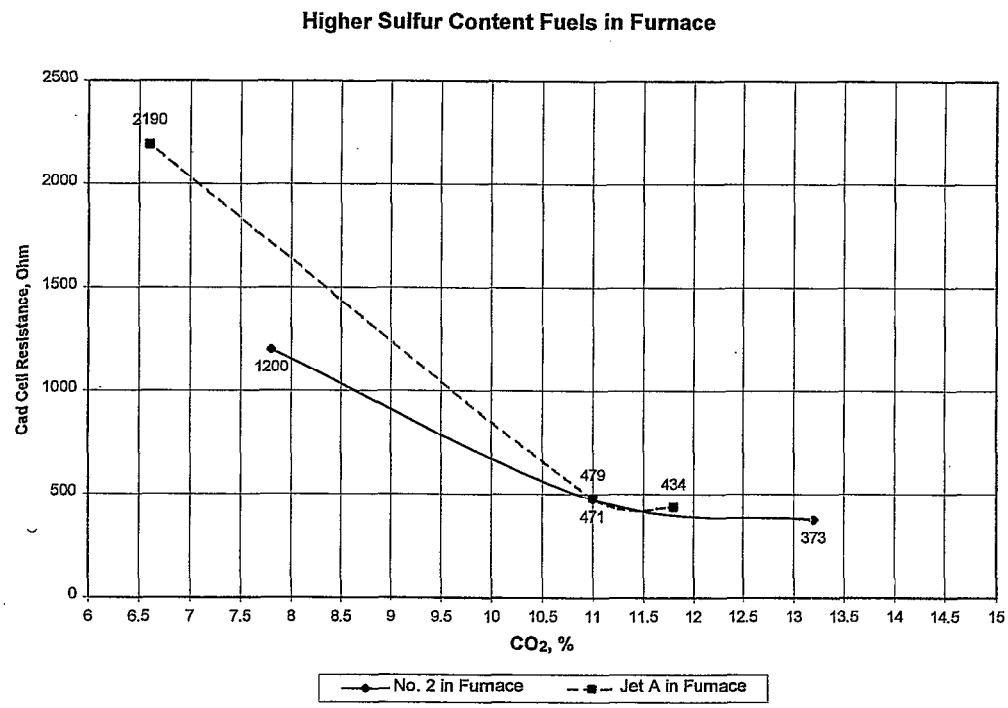
Figures 1 (top) and 2 (bottom) – With the higher BTU content (and distillation temperature) fuels (No. 2 heating oil and No. 2-D diesel), the higher sulfur No. 2 heating oil provided a lower cad cell resistance than the No. 2-D diesel.



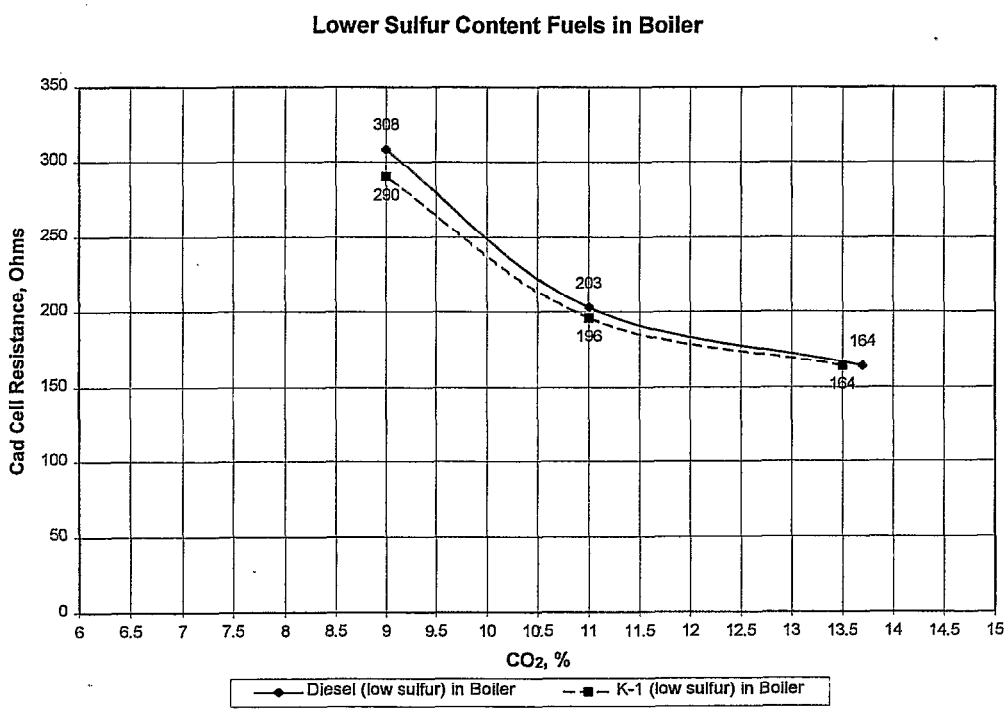


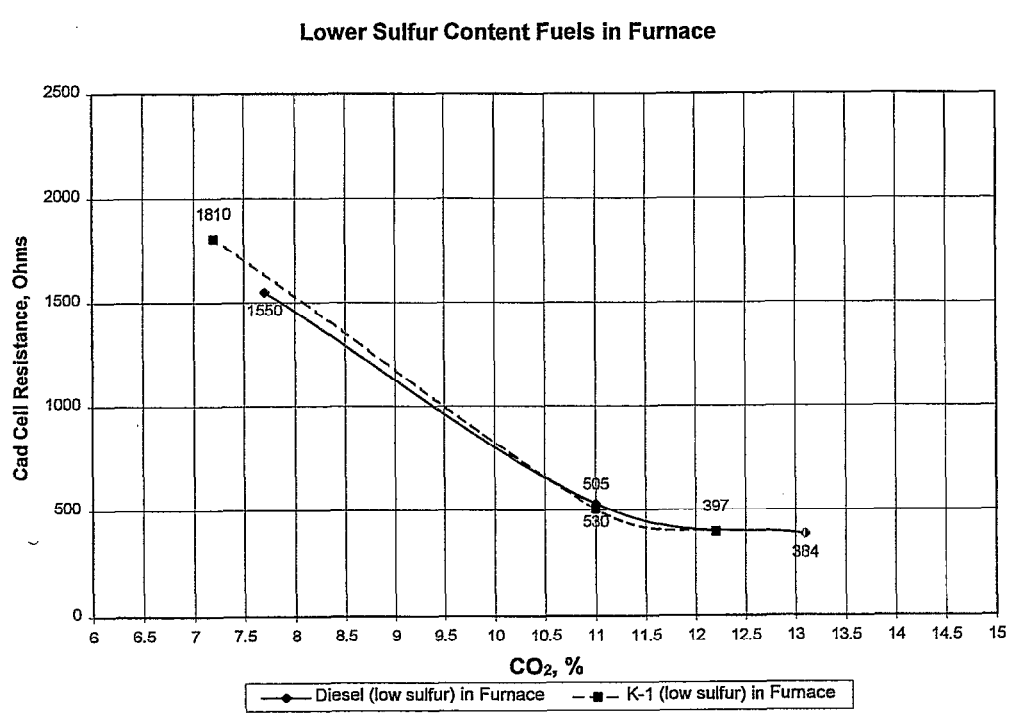
Figures 3 (top) and 4 (bottom) – With the lower BTU (and distillation temperature) fuels (Jet A and 1-K), the higher sulfur Jet A provided a higher cad cell resistance than the 1-K fuel in the boiler, but a lower cad cell resistance in the furnace.





Figures 5 (top) and 6 (bottom) – With the higher sulfur fuels (No. 2 heating oil and Jet A), No. 2 heating oil, which has a higher distillation temperature and BTU content, provided a lower cad cell resistance than Jet A in both the boiler and the furnace.





Figures 7 (top) and 8 (bottom) – Between the lower sulfur fuels (No. 2-D diesel fuel and 1-K), No. 2-D diesel fuel, which has the higher BTU value, provided a slightly higher cad cell resistance than the 1-K in both the boiler and the furnace.

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D3699 – Specification for Kerosines

Paper No. 01-16

New York State Premium Low-Sulfur Heating Fuel Marketplace Demonstration

A Project funded by the New York State Energy Research and Development Authority (NYSERDA)

Roger J. McDonald
Brookhaven National Laboratory
Department of Energy Sciences and Technology
Energy Resources Division
Oilheat Research
12 North Sixth St.
Upton, NY 11973
631-344-4197
mcdonald@bnl.gov

and

John Batey, PE
Energy Research Center, Inc.
35 Fawn Rd.
Easton, Ct. 06612
(203) 459-0353
energyresearchcenter@worldnet.att.net

Funded by: NYS Energy Research & Development Authority

New York State Premium Low-Sulfur Heating Fuel Marketplace Demonstration

A Project funded by the New York State Energy Research and Development Authority (NYSERDA)

By: John Batey, PE, President, Energy Research Center, Inc.
Roger J. McDonald, Oilheat Research Program Manager, BNL

Abstract

Fuel oil now used in homes in the US has an average sulfur content of about 0.25 percent. This produces sulfur oxide emissions and contributes to fouling of the heat transfer surfaces in oil powered heating equipment. The fouling from sulfate deposits decreases efficiency and increases the need for and frequency of equipment cleaning. Fuel oil with a lower sulfur content (0.05%) is available that can reduce air emissions and lower the operating costs for home oil burners.

The objective of this program is to demonstrate the advantages of reduced sulfur fuel oil through field-testing in a collaborative project between the New York State Energy Research and Development Authority (NYSERDA), Energy Research Center, Inc, Brookhaven National Laboratory, the Empire State Petroleum Association, and participating fuel oil dealers. This study will accurately evaluate actual changes in heating equipment performance with the lower sulfur fuel compared to conventional fuel oil by measuring differences in heating unit deposits, changes in stack temperature, and other measures that are applicable to this field investigation.

The expected environmental and cost benefits to New York State and the US by using lower sulfur fuel oil are substantial and will be fully evaluated and quantified during this study. Sulfur Oxide emissions in New York State can be lowered by more than **30,000 tons a year**, with an estimated "environmental cost" benefit of **$137 million a year**. New York state homeowners can lower fuel costs by approximately **$11 million a year** through improved annual efficiency. In addition, annual service costs by switching to low sulfur oil can potentially be reduced **by $65 million a year**.

New York State is the largest consumer of home heating oil in the US, and can benefit the most from a voluntary low sulfur fuel oil program. This project will demonstrate important benefits. It will also investigate potential obstacles to expanded use of low sulfur oil in homes including fuel availability, added sales tax for low sulfur oil, and equipment compatibility concerns.

Introduction/Background

In normal service, the efficiency of oil-fired boilers and furnaces degrades over time as heat exchanger surfaces become fouled. The rate of this efficiency degradation has been estimated at 2% per year. Annual cleaning of the heat exchanger is required to maintain equipment performance. The sulfur content of typical No. 2 heating fuel is about 0.25%. This sulfur contributes significantly to the process of heat exchanger fouling as will be discussed. The sulfur in any fuel results in sulfur dioxide being released into the atmosphere when it is burned. Changing to low sulfur content fuel (0.05 %) could **eliminate 80 percent** of the sulfur dioxide generated by residential oil heating systems. In volunteering to market a lower sulfur fuel, heating oil dealers can make a substantial contribution to helping preserve the clean air that we all breathe and, at the same time, providing better maintenance and service to their customers.

The mechanisms of heat exchanger fouling have been studied at Brookhaven National Laboratory (BNL) as part of the Combustion Equipment Technology program funded by the US Department of Energy. This work has included the use of uncooled fouling probes, controlled temperature test sections with cast iron and steel exposed surfaces, side-by-side four-month boiler studies, and field tests. Studies on fouling and the effects of sulfur on fouling rate have also been conducted by the CANMET Energy Technology Center (CETC) in Ottawa under sponsorship of the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE). BNL participated in the planning and monitoring of this ASHRAE study. In all tests, a dominant conclusion has been the very important role that fuel sulfur plays in the rate of fouling.

During combustion, about **99%** of the sulfur in the fuel is oxidized to **sulfur dioxide (SO_2)** and emitted from the stack. This combustion product contributes to air pollution but does not directly affect the heat exchanger. The remaining **1%** of the fuel sulfur converts to **sulfur trioxide (SO_3)** in the flame. This then reacts to form **sulfuric acid**, which condenses on any boiler or furnace surfaces below the dewpoint of the acid/water system - about 220 F. The acid reacts with iron from the wall to form iron sulfate scale on heat exchanger surfaces. *Over 50% of the mass of the fouling deposit typically removed from heat exchanger surfaces is iron sulfate scale (corrosion product).* Studies at BNL and CETC with controlled surface test sections showed a direct correlation between fuel sulfur content and the rate of heat exchanger fouling. Side-by-side boiler tests at BNL showed a dramatic reduction in the rate of fouling and efficiency decline when normal fuel was replaced by low sulfur fuel.

Currently in the U.S., heating oil for residential use has an average sulfur content of about **0.25%**. The ASTM limit for No. 2 heating oil is **0.5% sulfur** by weight. Considerably higher levels have been allowed, however, and regulations vary by state and area. Low sulfur fuel, **0.05%** by weight, is now mandated for use in highway diesel engines as an emissions control measure. There is interest in the voluntary use of such low sulfur fuels in residential heating systems to reduce boiler fouling rates, extend boiler life, and reduce air pollutant emissions.

Low sulfur heating oil is gaining acceptance in Europe. In Switzerland there is now a legal limit for sulfur content of **0.2%**. However, there is a tax in place for all fuel oil, which is higher than **0.1%**, and this tax is equal to 2.5 cents per gallon. According to Dr. Rolf Hartl of the Swiss Oil Heat Association, there is very little fuel sold with a sulfur content higher than 0.1%. There are low sulfur fuels – **0.05%** - on the market and some dealers have started marketing **0.03%** sulfur fuel. The market share for the **0.05%** sulfur fuel is about 20% and increasing slightly. The price premium for such fuel is about 2.5 cents per gallon. Across the European community there is a sulfur limit of **0.2%**. In Germany some dealers are also starting to market 0.05% sulfur oil.

Even with documented benefits, there are concerns which impact acceptance of low sulfur heating oil. Reduced lubricity may lead to increased pump failure rates. Reduced sulfur content may also lead to decreased fuel stability against oxidation in storage, with increased service requirements for plugged fuel line filters and nozzle strainers. This field study program will serve to overcome impediments to widespread use of low sulfur heating oil in the U.S. market by quantifying the reduced fouling benefits as well as any changes in service requirements and component failure rates in a large sample field study.

References

1. Litzke, W., Butcher, T., and Celebi, Y. Fuel sulfur and boiler fouling, Proceedings of the 1995 Oil Heat Technology Conference and Workshop at BNL, March 1995. R. McDonald ed. BNL Report 52475 (April 1995).

2. Butcher, T., Lee, S.W., Celebi, Y., and Litzke, W. Fouling of heat-transfer surfaces in oil-fired boilers for domestic heating, Journal of the Institute of Energy, v. 70, pp 151-159 (Dec. 1997).

Energy and Related Benefits

The primary benefits of using distillate fuel oil with reduced sulfur content are: an **80% reduction in sulfur oxide emissions**, **higher system efficiency** and fuel cost savings, and **lower service costs** for homeowners by reducing the rate of deposits on heat exchange surfaces in boiler and furnaces.

The immediate benefit for New York State and the US is a substantial decrease in Sulfur Oxide emissions by reducing fuel sulfur from 0.25% to 0.05%. The emission rate decreases from **0.26 to 0.05** pounds of SOx per million BTU of fuel oil that is burned, based on research by Brookhaven and the Energy Research Center, using US Environmental Protection Agency publications. The benefit to New York can be estimated. Based on the US Census data for 1990, there are approximately 2,630,000 oil-heated homes in New York State - the highest in the US. This represents about 40% of all homes in the state. Research by Brookhaven indicates that the average home in the US consumes 873 gallons of fuel oil a year (ref: DOE/EIA-032(93)).

Applying this average use to New York produces an estimated fuel oil use of 2.3 billion gallons a year. This is equivalent to 322 trillion BTU of oil a year at 140,000 BTU per gallon. By applying the emission rates for normal and low sulfur fuel oil, the potential reduction in sulfur oxide emissions by using low sulfur fuel oil in New York State is 67,620,000 pounds or **33,800 tons of sulfur oxide per year**. The potential reduction of sulfur oxide emissions for the US is **140,000 tons a year**.

Past work on environmental costs of air pollution (ref: Pace University, Environmental Costs of Electricity, 1991) have assigned dollar costs for air pollutant emissions to account for environmental damage and the cost of pollution control devices. Sulfur oxides were assigned a value of 2.03 per pound. Applying this emission cost factor, the potential environmental cost savings for New York State by using low sulfur fuel oil is **$137 million a year**.

Additional cost savings are available to homeowners through reduced fouling of heat exchanger surfaces in boilers and furnaces. Brookhaven has estimated that the efficiency drops off about 2% a year by fouling, and approximately 50% of deposits are created by sulfur oxides (sulfates). Therefore, reduced sulfur fuel can increase efficiency by about 1 percent over the heating season for a 0.5 percent average annual efficiency increase. The net savings by residential fuel oil users in New York State is estimated to be **$11.5 million a year**.

Homeowners can save even more each year through lower service costs from extended intervals between heating unit cleanings. At a nominal cost for equipment cleaning of $50 a year, the savings to homeowners by cutting these costs in half is $25 a year. Approximate cost savings for oil heated homes in New York State is **$65 million a year**. This cost savings, and all the other benefits will be evaluated in more detail during the study.

Statement of Work

This demonstration program for low sulfur home heating oil will monitor changes in the performance of oil home heating systems when low (0.05%) sulfur fuel oil is used. Key operating parameters will be studied for an entire heating season including: the mass of deposits vacuumed from heating equipment, changes in flue gas temperature, changes in K-Factors (degree-days per gallon), changes in service call frequency, and other operating features that will be finalized during Task 2- Define Test Program and Data Collection Procedures. Both low sulfur and control (normal sulfur) groups will be included in the study. A primary objective is to maintain normal operation of the fuel supplier(s) and monitor the impact of reduced sulfur fuel oil. Environmental benefits in terms of reduced sulfur oxide emissions in New York will be evaluated. The following tasks are included.

Task 1. Project Management and Reporting.

Meetings and telephone conferences with the project team - Energy Research Center and Brookhaven National Laboratory - will be conducted on a regular basis. Meetings will also be held with the Empire State Petroleum Association and participating fuel oil companies to track progress, collect data for analysis, and review and/or revise operating procedures to assure data quality. Other activities include:

- Oversight of selection process for bulk supplier(s) of the low sulfur fuel oil, and screening and selection of candidate home fuel oil companies to participate in the program. The skill and training level of existing service technicians including PMAA national certification will be part of the selection process to assure consistent results and minimize training needs.
- Planning of overall project scope and procedures to assure low sulfur deliveries to homes and normal fuel deliveries to control group, and to establish data collection and analysis approach.
- Organization of training programs to be conducted with Brookhaven to present data collection procedures and establish consistent cleaning methods based on accepted industry practices (and included in the Advanced Oil Heat training manual produced by Brookhaven and Energy Research Center).
- Visits with participating home oil dealer(s) and field visits to check procedures and data collection methods.
- Oversight of subcontracted work and preparation of monthly progress reports.

Task 2. Define Test Program and Data Collection Procedures.

A two-level study is planned that will include a **detailed study** of approximately 50 homes (including control and test homes) with added instrumentation and analysis, and a **broad-based study** of approximately 500 to 1000 homes using data normally collected by the fuel oil company. The detailed study will include specified cleaning procedures at the start and end of the test period, detailed procedures for data collection, installation of Flame Quality Indicator devices for accurately tracking changes in stack gas temperatures, and precise site characterization. The broad-based study will include the general population of customer homes, include a low sulfur and control group, use standard combustion testing and cleaning methods, and may include installation of low-cost instrumentation (eg. stack temperature monitors). Normal computer-based monitoring of each account by the oil dealer will be used to generate weekly reports of service frequency, actual K-Factors, combustion test results, and other information selected during this data collection-planning task. At the completion of this task, detailed test procedures and data collection methods will be finalized.

Task 3. Training Sessions for Participating Oil Companies and Service Technicians, and Site Preparation.

Project team engineers will develop written procedures to prescribe cleaning of boiler deposits, combustion test procedures, flue gas temperature measurement methods, recording combustion test data, collection and labeling of boiler deposits after cleaning,

transmittal of vacuum bags containing boiler deposits to Brookhaven, and all other data collection procedures that need to be specified. The boiler cleaning and combustion test procedures will be based on the PMAA Advanced Oil Heat manual that was produced by Brookhaven, which represents good industry practice, and is the basis for a national certification program. Data collection procedures to be used by service technicians and oil company participants will be delineated. Brookhaven will conduct one or more training sessions for service technicians and oil company employees with ERC oversight. A mid-term review of program procedures will be completed. A final debriefing of technicians at the end of the study is planned.

Site preparation assistance will be available from Brookhaven to offer guidance on the installation of Flame Quality Indicators and other instruments. Oversight of some installations by the equipment supplier and Brookhaven will be available at the start of the program to assure reliable operation of test instruments and procedures. Brookhaven will observe some of the boiler cleaning, combustion testing, and data recording procedures at the start of the program.

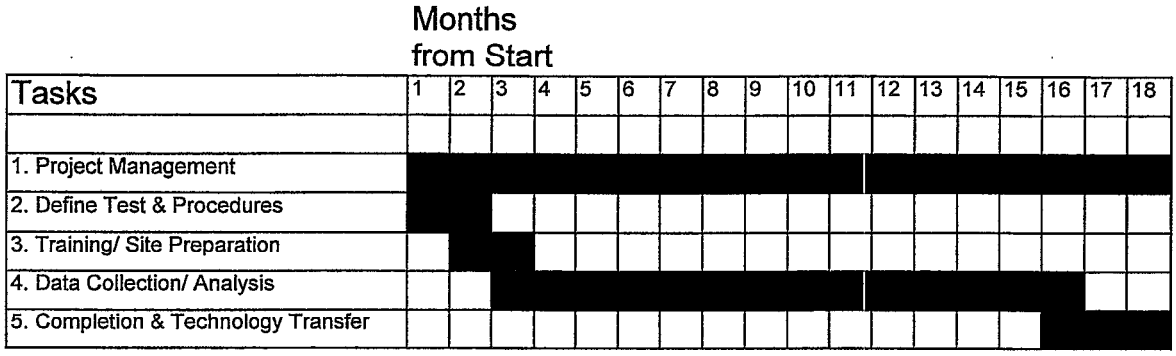
Task 4. Data Collection and Analysis

Data collection began in the Winter of 2000-2001 and included stack temperatures, service records, combustion test results, and all other relevant information identified during Task 2. This will include data from both the detailed and broad-based groups. Data collection will continue for a minimum of 12 months for each test site. Information from on-site FQI/dataloggers (if available) will be downloaded frequently (once per day or week) through automated software. Computer reports of service records for each customer will be collected from participating oil companies on a weekly basis. Boiler deposits from initial and final cleanings will be collected and sent to Brookhaven for analysis. This will include all the homes in the detailed study and random samples of homes in the broad-based study may be included. Deposit analysis will include weighing to determine the total mass and a chemical analysis of a limited number of samples. Changes in flue gas temperatures, K-factors, and other parameters identified during Task 2 will be evaluated, in addition to changes in service call frequency. An interim review and analysis of data is planned for the spring of 2001 to determine if modifications to the operating and data collection procedures are needed.

Task 5. Project Completion and Technology Transfer

Analysis of all the data collected during the study will be completed and overall findings will be presented. A **summary report** will be prepared for review by NYSERDA. Broad-based dissemination of the results of the study will be initiated through a range of presentations, seminars, and publications including oil heat trade magazine articles.

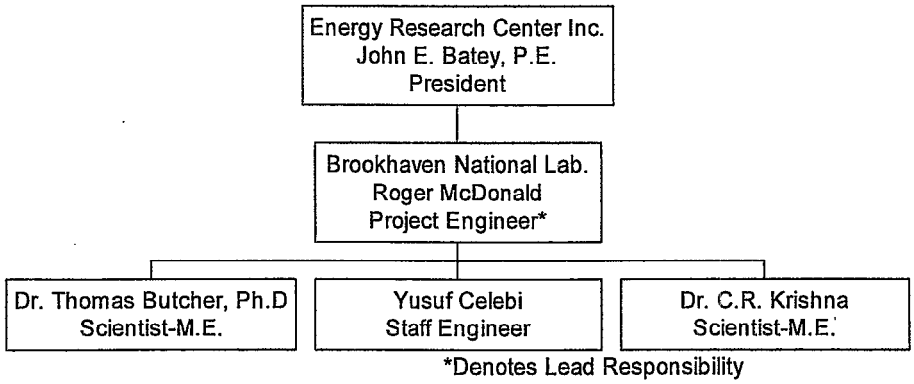
Project Plan and Schedule



Management Plan

Project Control- Overall Management by New York State Energy Research and Development Authority (NYSERDA)

New York State Premium Heating Low Sufur Heating Fuel Marketplace Demonstration



*Denotes Lead Responsibility

The project manager is John Batey, P.E., who is the President of the Energy Research Center Inc. (ERC), and Roger McDonald, Project Engineer at Brookhaven National Laboratory heads up the team from the Energy Science and Technology Division within the Department of Applied Science. ERC provides technical contract management for the overall project including the effort at BNL. Brookhaven National Laboratory provides a four-person team for the performance of the proposed project. In addition to the team leader, Roger McDonald, Project Engineer, BNL project staff will include Dr. Thomas Butcher, C.R. Krishna, Scientist-Mechanical Engineer, and YusufCelebi, Staff Engineer.

Implementation and Technology Transfer Strategy

This field demonstration study has the potential of initiating a significant reduction in the emissions of air pollutants in New York State and the US. The amount of sulfur dioxide produced by oil-heated homes could be reduced by 80% when compared to the amount currently generated when using conventional fuel oil containing 0.25% sulfur. It also has the potential of significantly reducing the level of required maintenance expended by the fuel oil marketers and paid for by homeowners. This is due to the reduced levels of sulfuric acid formation. This acid which condenses in the heat exchangers of boilers and furnaces results in fouling deposits, scale and corrosion products. These deposits reduce the efficiency of the heating appliance and are difficult to remove which requires frequent cleaning of the heat exchanger. These expected improvements are based on BNL's prior laboratory studies.

The Energy Research Center and BNL will work to educate the oil heat industry regarding the key advantages of using the proposed **premium low sulfur fuel oil** through various means. ERC and BNL will publish the results of this study in professional engineering journals and technical reports, and also by presenting results at oil heat industry meetings and conferences. These include BNL's own Oil heat Technology Conference, as well as the Petroleum Marketers Association of American's annual Oil Heating Conference, the New England Fuel Institute's conference, and New York State oil heat marketing association conference meetings. BNL will also provide for continued exposure of the technology produced by this effort by publishing articles in the national trade journals published for the oil heat industry and newspapers. The New York State Energy Research and Development Authority will be recognized as the sponsor of this field study in all forms of communication regardless of format.

Any heating oil companies who are interested in participating in this demonstration program should contact John Batey at 203-459-0353, Roger McDonald at 631-344-4197, or Tom Peters at Empire State Petroleum Association at 518-449-0702.

NOTE: This work is funded by the New York State Energy Research and Development Authority under cost-sharing agreement 6204-IABR-BR-00.

Paper No. 01-17

The Need for a New Fuel Oil Stability Specification

Robert E. Tatnall, PE

Fuel right
Fairville Products, Inc.
302 Robinson Lane
Wilmington, DE 19805
800-642-1910
fuelright@aol.com

The Need For a New Fuel Oil Stability Specification

Robert E. Tatnall, PE
Fairville Products, Inc.

Fouling and plugging of oil heat systems continues to be a major problem. Contamination leading to sludge has historically been the main cause of system fouling and plugging. As newer technology begins to eliminate sludge and contamination, however, another type of fouling problem has become apparent, and that is plugging of nozzles due to fuel *thermal* instability.

Thermal instability is also a concern in diesel fuels. This fact was recognized by certain railroad companies many years ago and led them to develop a test for fuel thermal stability that later became known as the F-21 test. This test recently became ASTM Standard Method D6468. It now appears that this established test is not adequate for judging the quality of fuel to accurately predict nozzle or injector plugging, and should be modified.

The Role of Metals in Fuel Instability

It is widely known that pickup of certain *dissolved* metals by middle distillate fuels can trigger fuel instability – both storage and thermal instability. Dissolved copper is one of the worst offenders, and contamination of No. 2 fuel oil by copper picked up from refinery equipment is one of the more common causes of poor fuel oil quality.

What has recently been learned, both in the U.S. and in Germany, is that even the heating of fuel oil while in contact with copper metal can trigger fuel instability. This is true even for some fuels that show excellent stability when stored for long periods at room temperature – and also for fuels that are stable when heated in glass. Presently accepted thermal stability tests, including the F-21/D6468 test, heat the fuel sample in glass.

While copper and copper alloys such as brass appear to be the worst offenders in this regard, it turns out that steel and aluminum also trigger fuel instability to a lesser extent. Metals that appear not to trigger instability include stainless steels (300 and 400 series), chrome plating, nickel plating, and "electroless nickel" (NiP) plating.

Why Instability Causes Plugging

Diesel injectors heat up while in service. The fact that they are normally made of steel, which triggers instability, explains why some injectors plug. Studies by the Beckett Corporation have shown that oil burner nozzles also heat up – not while the burner is running, but just after it shuts off. This heating occurs as a result of radiation back to the nozzle by the heat exchanger and other fireside surfaces, and apparently varies with system design and setup. Beckett's studies indicate that this is not a problem, for example, with unchambered boilers, because the heated surfaces in that case are water cooled and not likely to radiate heat back upon shut-off.

Residential burner nozzles are made mostly of brass. The pre-filters on the nozzles are usually sintered bronze, another copper alloy. The available alternative pre-filters are stainless steel screens mounted on a brass support. Most nozzle adapters are brass. The small tube carrying fuel from the pump to the nozzle assembly is copper. In other words, almost all surfaces in contact with fuel oil at and near the nozzle are likely to be catalytic to fuel thermal instability.

The Nature of Fuel Particles

It is presumed that the particles formed during either storage or heating of No. 2 distillate fuel are cross-linked, polymerized hydrocarbon. What is known is that these particles have a much higher ratio of carbon to hydrogen than does the liquid fuel, which would be expected when a hydrocarbon polymerizes and cross-links. Analysis shows that the particles also tend to contain significant levels of sulfur and sometimes copper or other "catalytic" metals.

Figure 1 shows such particles that formed during storage of a "typical" high-sulfur heating oil. These particles are equi-axed, somewhat rounded, and measure on the order of one micron (10^{-6} meters) in diameter. If these particles were fully dispersed like individual grains of sand it would be very difficult to filter them out of the fuel. Fortunately, the particles are sticky and tend to agglomerate into particle clusters. As sticky clusters they are readily trapped by filters – even the coarser felt and rayon filters used in most heating oil systems.

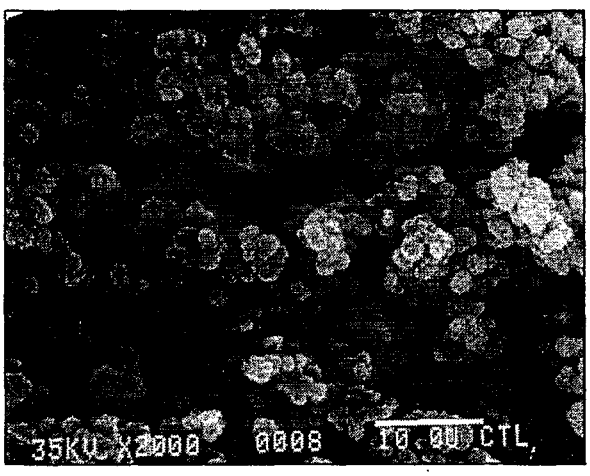


Figure 1 – SEM photo of particles that formed during storage of unstable fuel oil. (Bar at bottom indicates 10 microns)

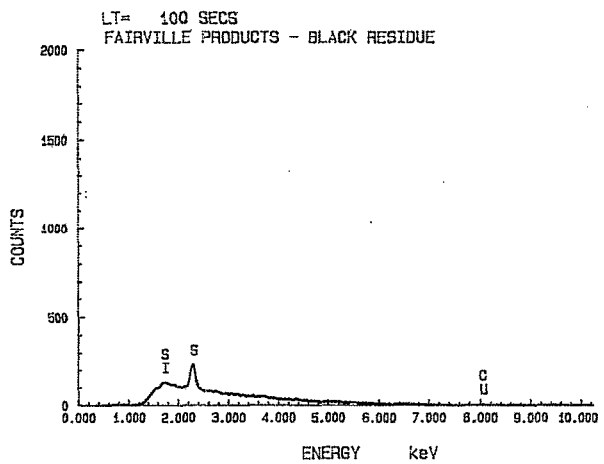


Figure 2 – EDS (elemental) scan of particles seen in Figure 1.

Figure 2 shows an energy dispersive spectroscopic (EDS) analysis of these particles. Note the peak for sulfur. These particles show no discernible peak for copper or other catalytic metals, which indicates that the instability that led to formation of these particles was most likely caused by things other than metal contamination.

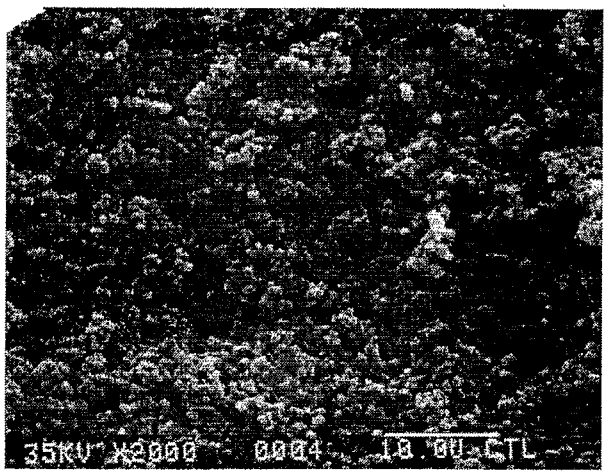


Figure 3 – SEM view of particles formed during heating of fuel oil in the presence of copper metal. Note the smaller size than the particles in Figure 1. (Bar indicates 10 microns)

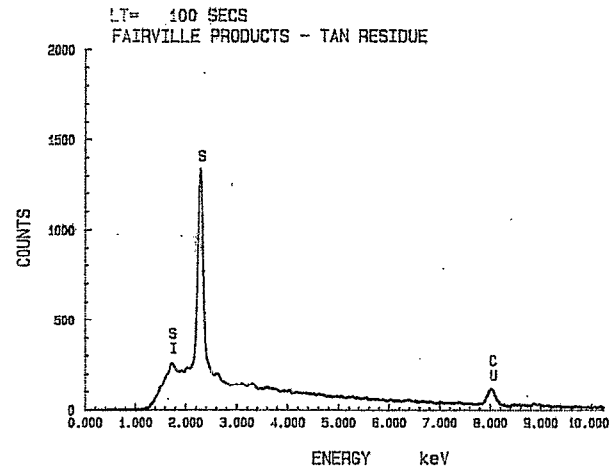


Figure 4 – EDS scan of particles shown in Figure 3. The peak heights shown are misleading. The actual weight ratio of sulfur to copper is about 55:45.

Figure 3 shows particles formed in an otherwise "clean" fuel oil by heating in the presence of copper metal. These are similar in appearance to those formed during storage, but roughly half the size. Again, there appears to be a strong tendency to agglomerate.

Figure 4 is the EDS curve for these particles. Note the very strong peaks for copper and for sulfur. What the copper peak implies is that the fuel *dissolved* copper from the piece of tubing and then tied it up as a part of the cross-linked hydrocarbon particles.

Fuel Thermal Instability – The Numbers

To understand test results, it is first necessary to understand how they are generated. In the current F-21/D6468 test, a fuel sample is first filtered to remove most particles that might already be in the fuel due to contamination or storage instability. The sample is then placed in a glass tube, heated to 300° F, held for 90 minutes and then slow-cooled to room temperature. A measured amount of the sample is then pulled through a standard grade of filter paper, and the filter paper examined for darkening due to particle buildup. A comparison standard chart is provided for scoring the filter. This chart shows twenty filters, starting with a blank white circle and proceeding in gradations to a filter that is completely covered with dark particles with no white filter showing through. These reference "filters" are numbered 1 through 20 – "1" being the blank white circle. The scoring of the fuel against this chart is said to be its "PAD" rating.

A perfectly stable fuel, therefore, should score a "1" in the F-21/D6468 test. Anything higher than that indicates the fuel has some degree of instability and theoretically would eventually produce enough particles to foul a nozzle or injector. The Colonial Pipeline

Company adopted the F-21 method for fuels to be transmitted in their system, and chose to allow up to a "7" PAD rating as being "acceptable".

The only significant difference between the standard F-21 test and the test with copper metal was the addition of a small length of freshly pickled copper tubing during the heating/cooling process. The exposed surface area of this copper tube was approximately one cm^2 for each ml of sample volume.

In this study, a total of ninety six (96) fuel samples were tested, including eighty (80) with normal "high" sulfur level (0.30% max.), fifteen (15) with "low" sulfur (0.05% max.) as currently required for on-road diesel fuel, and one sample with reputedly "medium" sulfur level. The latter was a blend of high-sulfur No. 2, low-sulfur No. 2 and aviation (No. 1) fuel that would normally have very low sulfur level.

Of the high-sulfur samples, 88% passed the F-21 stability test in glass (i.e. scored a PAD rating of 7 or lower). 74% had a perfect "1" PAD rating in this test. When the F-21 test was repeated with copper present, however, only 44% of the samples that passed the F-21 test scored a PAD rating of 7 or lower, and only 28% scored a perfect "1". To look at this another way, of the 59 high-sulfur samples that scored a perfect "1" in the standard F-21 test, only 37% even *passed* with a score of 7 or lower when heated in the presence of copper.

The medium- and low-sulfur samples were another story. Of the sixteen total samples in this category, all but one scored a perfect "1" not only in the standard F-21 test, but with copper present as well. The one exception sample scored a "1" in the standard test and a "2" in the presence of copper.

Effect of Age and Storage Conditions

It has been stated that fuel samples fresh from the refinery tend to pass the F-21 test easily, but that their performance deteriorates with age. While there might be some truth to this, our study tended to refute that theory. Samples that scored very well when just received still showed similar performance two or even three years later. Even when stored in contact with water and biological contamination, originally good fuel samples appear still stable after about a year.

Fuel samples that showed exceedingly poor stability when first received continued to show similarly poor stability with passing time up to three years – but did not seem to get appreciably worse. Some of these bad fuels, in fact, appear to become somewhat more stable with time. This makes some sense to fuel chemists for reasons too complex to be discussed here. The key thing is that really unstable fuels never seem to become "acceptable" – rather, they may become slightly less unacceptable.

Fuels that scored "moderately acceptable" – i.e. a PAD rating of 5 to 7 – when new, *did* show a tendency to get somewhat more unstable with age. Perhaps that is what has led to the above referenced theory regarding the effect of age on stability.

Effect of Chemical Stabilizers

Chemical stabilizers generally fall into any of three categories: antioxidants, metal deactivators, or acid neutralizers. These address the three most common causes of fuel instability. Antioxidants are the type most often found in commercial stabilizing additive packages, because fuel oxidation is the most common cause of storage instability. Metal deactivators tend to be expensive, and are usually offered for use only where metal contamination of the fuel is believed to be the problem. Acid neutralizers address problems associated with free acidity in the fuel left from the refining process, and are the least common of the three types of chemical stabilizers.

To determine whether chemical stabilizers are a ready fix for fuel thermal instability problems, a panel of seven stabilizer additives was tested on six fuel oil samples, all of which had failed the F-21 test (i.e. PAD rating above 7) when heated in the presence of copper metal. The oil sample untreated PAD ratings in this test ranged from 8 to 17. The additives included three antioxidants, two combined antioxidant/metal deactivators, and three commercial additives of unknown nature (but all of which claimed to include fuel stabilizers). While it is not known exactly what types of stabilizers these latter three contained, it is assumed that they were most likely antioxidants. The seven products chosen for evaluation represent a small portion of those on the market today, but these ones were chosen because they 1) were available in our laboratory, and 2) came from among the largest and most reputable additive suppliers in the U.S.

In this test, each of the six oil samples was first treated at the manufacturers' normal recommended doses for the various additives. Some samples were also dosed at twice the normal dose, and one oil sample was even treated at ten times the normal dose of each product. The test results, expressed in percent reduction in instability, are shown in Table 1 below.

Table 1 – PAD ratings with and without stabilizer(s) added

Oil Sample Code	Untreated PAD Rating	Stabilizer Dose	Stabilizer Code: 1(A)	2(A)	3(2A+M)	4(A+M)	5(C)	6(C)	7(C)
A	13	NORMAL	12	7	9	10	13	13	12
"		2X	13	8	10	11	7	14	13
B	9	NORMAL	9	7	8	7	7	9	8
"		2X	8	8	7	8	5	9	8
C	9	NORMAL	11	8	12	7	9	9	8
"		2X	8	8	9	10	11	11	9
"		10X	7	7	12	9	4	7	5
D	17	NORMAL	13	14	16	12	15	15	14
E	13	NORMAL	12	13	13	13	13	14	14
F	13	NORMAL	12	12	11	9	9	11	11

The various stabilizers listed in Table 1 are identified as to type where known. An "A" indicates a known antioxidant while an "M" indicates a metal deactivator. The code "C" refers to a commercial additive product that claims to stabilize fuel, but with no indication of what type(s) of stabilizer may be present.

It is seen that the results were variable and inconsistent. Some additives caused significant improvement with certain oil samples, but little or no improvement with others. In several cases, in fact, adding the stabilizer actually produced *negative* results. In other words, the fuel appeared less stable *with* the stabilizer than without it.

To determine whether this scatter in the results was inherent in the method, one fuel sample was tested four times concurrently with no stabilizer, and then again with an antioxidant added. These replicates showed excellent reproducibility. It is assumed, therefore, that the large variations shown in this table are largely due to the additive effects.

It is also seen in Table 1 that doubling the stabilizer dose – or even increasing it tenfold – generally did not improve the results. In some cases the higher dose produced an incrementally better result, but in other cases it actually produced *poorer* results. At normal dose, the best additive product improved stability in this test by an average of 34% overall. The worst performer in this panel reduced instability an average of only 5 percent.

In only five cases out of the eighty shown did chemical treatment result in a clearly unacceptable fuel improving to a PAD rating of 7 or lower. These are shaded in Table 1. This benefit was achieved in only one case with normally recommended additive dose. The other such "success" examples required double, or in one case, ten times the recommended dose.

From these tests we conclude that fuel stabilizers – at least the seven represented here – are generally ineffective (and certainly not cost-effective) in reducing thermal instability in contact with copper.

What Is Needed

These studies help to explain why nozzle plugging continues to be a major problem in the oil heat business. If oil heat is to become more trouble-free and continue to compete with alternate fuels, oil retailers must offer a more stable fuel oil on a consistent basis.

It is tempting to conclude from these studies that all that is needed is to lower the sulfur level of heating oil. It should be pointed out, however, that there are differences in the production of today's on-road diesel fuel and No. 2 heating oil that go beyond red dye and sulfur level. It is quite possible to make unstable, low-sulfur fuel oil, especially if the refining process is not properly controlled. For this reason it is imperative to have a meaningful stability specification as a part of any fuel oil specification.

Specific recommendations are:

1. **The F-21/D6468 test procedures should be changed** to include a piece of an appropriate metal placed in the sample container during the heating/cooling cycle. For heating oil this metal should be copper or an appropriate copper alloy, and
2. A PAD rating of "7" may be too high to avoid plugging of nozzles and injectors. **The pass/fail criteria for the revised thermal stability test should be set at a level that will assure long-term operation of systems without plugging.** This level should be determined by actual controlled studies using "typical" oil heat systems.

Acknowledgements:

Victor Turk and associates at the Beckett Corporation have been most helpful in sharing their knowledge and test results. Cyrus Henry of Octel Starreon, LLC provided insight into fuel oil stability and the history of its measurement. Brad Krantz of Corrosion Testing Laboratories did the scanning electron microscopy and EDS analyses.

III. ATTENDANCE LIST

Albrecht, Ray
NYSERDA
286 Washington Ave., Ext.
Albany, NY 12203
Tel. 518-862-1090 X3253
FAX: 518-862-1091

Babington, Robert
Sippin Energy Products, Inc.
234 Main St., P.O. Box 220, Monroe, CT 06468
Tel. 203-261-3668
FAX: 203-268-0769
Gary@sippin.com

Bartlett, Bruce
Meenan Oil Co., L.P.
3020 Burns Ave.
Wantaugh, NY 11793
Tel. 631-783-1000
FAX: 631-781-2332

Barnes, Robert W. , Jr.
Standard Oil of Connecticut
299 Bishop Ave.
Bridgeport, CT 06607
Tel. 203-334-5532
FAX: 203-333-3358

Batey, John E.
Energy Research Center, Inc.
35 Fawn Rd.
Easton, CT 06612
Tel. 203-459-0282
FAX: 203-459-0282
Energyresearchcenter@worldnetatt.net

Bayless, Rich
Energy Kinetics
51 Molasses Hill Rd.
Lebanon, NJ 08833
Tel. 908-735-2066 X220
FAX: 908-735-2068
Richard.Bayless@att.net

Becker, Jim
Thermo-Dynamics
P.O. Box 325
Schuylkill Haven, PA 17972
Tel. 570-385-0731
FAX: 570-385-5403

Beckett, Kevin
R.W. Beckett Corporation
P.O. Box 1289
Elyria, OH 44036
Tel. 440-353-6237
FAX: 440-353-6037
Kbeckett@beckettcorp.com

Behrens, Drew
Dowling Fuel Company
100 Industrial Ave.
Ridgefield Park, NJ 07660
Tel. 201-440-1000
FAX: 201-440-1481

Bessette, David A.
ARLEX Oil Corp.
275 Massachusetts Ave.
Lexington, MA 02420
Tel. 781-862-3400
FAX: 781-863-8711
Dbessette@arlexenergy.com

Blair, Keith
ECR International Olsen Division
6800 Base Line
Wallaceburg, ON N8A-5E5
CANADA
Tel. 519-627-0791
FAX: 519-627-8176
Scottl@olsenrvac.com

Boltz, Robert V.
Vincent R. Boltz, Inc.
45 Guildord St.
Lebanon, PA 17046
Tel. 717-272-4881
FAX: 717-272-7688
Rvboltz@vrboltz.com

Boyce, Lewis S.
Riello Corporation of America
451 Rimmon Hill Road
Beacon Falls, CT 06403
Tel. 203-888-1823
FAX: 203-888-1823
L.BOYCE@Riellousa.com

Brown, Gail A.
Brookhaven National Laboratory
Bldg. 526
Upton, NY 11973-5000
Tel. 631-344-5850
FAX: 631-344-2359
Brown9@bnl.gov

Bunting, John
On Watch Electronics Inc.
P.O. Box 448
New Boston, NJ 03070-0448
Tel. 603-487-3400
FAX: 603-487-3399
Jb@onwatchinc.com

Bursey, Charles
HAGO Manufacturing Co.
40 Laurel Drive
Voluntown, CT 06384
Tel. 860-326-4835
FAX: 860-376-4835
Bcharles@snet.net

Butcher, Thomas
Brookhaven National Laboratory
Bldg. 526
Upton, NY 11973-5000
Tel. 631-344-7916
FAX: 631-344-2359
Butcher@bnl.gov

Calia, Vincent
Insight Technologies
1150 Walnut Ave.
Bohemia, NY 11716
E-mail: vcalia@insighttechnologies.net

Caputo, Frederick, J.
Bayside Fuel
1820 Cropsey Ave.
Brooklyn, NY 11214
Tel. 718-946-4000
FAX: 718-946-3808

Carini, Peter J.
Champion Energy Corporation
4 Greenwich Office Park
Greenwich, CT 06831
Tel. 203-862-9595
FAX: 203-629-6066
Pjcgroup@aol.com

Celebi, Yusuf
Brookhaven National Laboratory
Bldg. 526
Upton, NY 11973-5000
Tel. 631-344-4033
FAX: 631-344-2359
Celebi@bnl.gov

Charland, Richard
Carlin Combustion Technology
70 Maple Street
E.Long, MA 01028
Tel. 413-525-4400
FAX: 413-525-8306

Cogan, Charles
Lewis Oil
175 Sunnyside Blvd.
Plainview, NY 11803
Tel. 516-349-8980
FAX: 516-349-8904
Ccogan@championenergy.com

Cullen, Peter
Carlin Combustion Technology
70 Maple Street
E. Long, MA 01028
Tel. 413-525-7700
FAX: 413-525-8306

Curtis, Mike
The Lee Company
55 Bokum Rd.
Essex, CT 06425-1506
Tel. 860-399-6281
FAX: 860-767-0395
Curtism@TheLeeCo.com

D'Anthony, James
Riello Corporation of America
451 Rimmon Hill Road
Beacon Falls, CT 06403
Tel. 203-888-1823
FAX: 203-888-1823
L.Boyce@Riellousa.com

Darley, Greg
JW Pierson Co.
89 Dodd Street
East Orange, NJ 01019
Tel. 973-673-5000
FAX: 973-673-6616
Kcoachman@jwpierson

Davenport, Ken
Heritagenergy, Inc.
P.O. Box 797
Lake Katrine, NY 12449
Tel. 845-336-2000
FAX: 845-336-7410
Kendavenport@heritagenergy.com

Davis, Douglas
Insight Technologies
1150 Walnut Ave.
Bohemia, NY 11716
Tel. 800-424-3484
FAX: 631-563-1117
Ddavis@insighttechnologies.net

DeMaria, James F.
The Hydronics Institute Div. GAMA
P.O. Box 218
Berkeley Heights, NJ 07922
Tel. 908-464-8200
FAX: 908-464-7818
GAMAORG@aol.com

Dolan, Bob
Castle Oil Corporation
290 Locust Avenue
Bronx, NY 10454
Tel. 718-579-3422
FAX: 718-292-9042

Driver, Nelson
Driver Heating Oil, Inc.
P.O. Box 1765
Waynesboro, VA 22980
Tel. 540-946-9111
FAX: 540-946-9112

Eckert, Mike
Brookhaven National Laboratory
Bldg. 526
Upton, NY 11973-5000
Tel. 631-344-5850

Erickson, Stephen
SUNTEC Industries
2210 Harrison Ave.
Rockford, IL 61125
Tel. 815-226-3779
FAX: 815-226-3848

Fairchild, Phil
Oak Ridge National Laboratory
P.O. Box 2008
1 Bethel Valley Road
Oak Ridge, TN 37831-6070
Tel. 865-574-2020
FAX: 865-574-9329
Fairchildpd@ornl.gov

Farrell, Donald J.
Oilheating Journal
3621 Hill Road
Parsippany, NJ 07054
Tel. 973-331-9545
FAX: 973-331-9547
DONFOOH@AOL.COM

Feldman, Charles
Carlin Combustion Technology
70 Maple Street
E. Long, MA 01028
Tel. 413-525-7700
FAX: 413-525-8306

Fisher, Leonard
P.E. Consultant
171 Ed Clark Road
Colrain, MA 01340
Tel. 413-624-3060
FAX: 413-624-3060
LAFisher@javanet.com

Fiskum, Ronald
FORS / EE-16, Room 5H-088
U.S. Department of Energy
Office of Power Technology
1000 Independence Ave., S.W.
Washington, DC 20585-0121
Tel. 202-586-9154
FAX: 202-586-1640
Ronald.fiskum@hq.doe.gov

Flaherty, Patrick
Texas Instruments, Inc.
34 Forest St., MS 02-03
Attleboro, MA 02703-0964
Tel. 508-236-1109
FAX: 508-236-3448
Pflaherty@ti.com

Forney, David
Burnham
P.O. Box 3079
Lancaster, PA 17604
Tel. 717-397-4701
FAX: 717-293-5819
Dforney@burnham.com

Garber, Judith
NAOHSM
P.O. Box 67
East Petersburg, PA 17520
Tel. 717-625-3076
FAX: 717-625-3077
Judyg@desupernet.net

Geiger, Paul
Oilheating Journal
3621 Hill Road
Parsippany, NJ 07054
Tel. 973-331-9545
FAX: 973-333-9547
Editor@oilheating.com

Gilbertson, Greg
Standard Oil of CT
299 Bishop Ave.
Bridgeport, CT 06607
Tel. 203-334-5532
FAX: 203-333-3358
Ggilbertson@sncd.net

Hague, William
Sippin Energy Products, Inc.
234 Main Street, P.O. Boix 220
Monroe, CT 06468
Tel. 203-261-3668
FAX: 203-268-0769
Gary@sippin.com

Heaney, Allison
Skaggs-Walsh
119-02 23rd Ave.
College Point, NY 11356
Tel. 718-353-7000
FAX: 718-445-0936

Heck, Robert
Deull Fuel Co.
P.O. Box 658
Atlantic City, NJ 08404
Tel. 609-344-1104
FAX: 609-344-6368

Hedden, Robert
Oilheat Manufacturing Association
3125 Lilly Hill Road
Pawlet, VT 05761
Tel. 802-325-3519
FAX: 802-325-3437
Bhedden@sover.net

Heinerichs, Paul F.
Mennan Oil Co.
8301 Lansdowne Ave.
Upper Darby, PA 19082
Tel. 610-789-4200
FAX: 610-789-4098

Hills, Brian
Baker Petrolite
124 Pitman-Downer Road
Sewell, NJ 08080
Tel. 856-582-0008
FAX: 856-582-7268
Brian.Hills@BakerPetrolite.com

Horak, William C.
Brookhaven National Laboratory
Bldg. 475B
Upton, NY 11973-5000
Tel. 631-344-2627
FAX: 631-344-7650
Horak@bnl.gov

House, Terrance
Carpenter & Smith
P.O. Box 686
Monroe, NY 10950
Tel. 845-782-8164
FAX: 845-783-7643

Huber, John
V.P. Chief Counsel
PMAA/NORA
1901 N. Ft. Myer Drive
PMAA/ NORA
1901 N. Ft. Myer
Arlington, VA 22209
Tel. 703-351-8000
Jhuber@pmaa.org

Kamath, Bola
Heat Wise, Inc.
P.O. Box 662
Ridge, NY 11961
Tel. 631-345-0447
FAX: 631-345-0451
Bkamath106@aol.com

Kaminshi, Peter
Flex-L International Inc.
POB 29140
Columbus, OH 43229-0140
Tel. 800-561-1980
FAX: 800-267-1980

Keaveney, Tom
Baker Petrolite
35 Piscassic Road
Newfields, NH 03856
Tel. 603-778-1374
FAX: 603-778-1378
Timothy.Keavene@BakerPetro

Kitchen, Edward
Fuel Management Services, Inc.
17321 Berkshire Dr.
Jeffersonton, VA 22724
Tel. 540-937-8226
FAX: 540-937-3454
Edkitchen@aol.com

Koehler, Tom
JW Pierson Co.
89 Dodd Street
East Orange, NJ 01019
Tel. 973-673-5000
FAX: 973-673-6616
Kcoachman@jwpierson

Krishna, C.R.
Brookhaven National Laboratory
Bldg. 526
Upton, NY 11973-5000
Tel. 631-344-4025
FAX: 631-344-2359
Krishna@bnl.gov

Richard F. Krajewski, P.E.
Engineering Consultant
12 Carlson lane
Medford Ny 11763
Tel. 631-286-3471

Kuhnemund, Ralf
Testo Inc.
35 Ironia Road
Flanders, NJ 07836
Tel. 800-227-0729
FAX: 973-252-1729
RALF@TESTO.COM

Lackie, Scott
ECR International Ltd. Olsen Division
6800 Base Line
Wallaceburg, Ontario N84-5E5
CANADA
Tel. 519-627-0791
FAX: 519-627-8176
Scottl@olsenhucic.com

Levi, Alan
O.S.I. – Oil Services, Inc.
3555 Hargale Road
Oceanside, NY 11572
Tel. 516-763-1400
FAX: 56-763-1463
Info@osi-ny.com

Levi, Richard
O.S.I. – Oil Services, Inc.
3555 Hargale Road
Oceanside, NY 11572
Tel. 516-763-1400
FAX: 56-763-1463
Info@osi-ny.com

Lindtveit, Lindy
SID Harvey Industries, Inc.
100 E. Mineola Ave.
Valley Stream, NY 11580
Tel. 516-825-5654
FAX: 516-825-7254
Llindtveit@SidHarvey.com

Lingner, Walter
PETRO Inc.
522 Grand Blvd.
Westbury, NY 11590
Tel. 516-686-1925
FAX: 516-686-1938
Wlingner@petroheat.com

Lynch, Robert D.
Energy Matters
30 Prospect St.
White Plains, NY 10605
Tel. 914-761-5835
FAX: 914-328-3158

Markarian, Michael
New England Fuel Institute
20 Summer Street
Watertown, MA 02472
Tel. 617-924-1000
FAX: 617-924-1022
Mmarkarian@nefi.com

Marran, John D.
Energy Kinetics Inc.
51 Molasses Hill Road
Lebanon, NJ 08833
Tel. 908-735-2066
FAX: 908-735-2068

McCallum, Andrew J.
Baker Petrolite
12645 West Airport Blvd.
Sugar Land, TX 77478
Tel. 281-276-5422
FAX: 281-276-5491
Andrew.McCallum@bakerpetrolite.com

McDonald, Roger
Brookhaven National Laboratory
Bldg. 526
Upton, NY 11973-5000
Tel. 631-344-4197
FAX: 631-344-2359
Mcdonald@bnl.gov

McElwee, Richard
Williamson-Thermoflo
8201 W. Calumet Road
Milwaukee, WI 53223
Tel. 800-736-2378

Miller, Craig
Skylands Energy Service
2 Thompson St.
Baritown, NJ 08867
Tel. 908-707-1776
FAX: 908-707-4158

Mills, Ralph L.
Abbott & Mills Inc.
P.O. Box 2550
Newburgh, NY 12550
Tel. 875-561-0462
FAX: 845-561-0558
Rlm@abbottandmills.com

Mills, Ralph R.
Abbott & Mills Inc.
P.O. Box 2550
Newburgh, NY 12550
Tel. 875-561-0462
FAX: 845-561-0558
Rrm@abbottandmills.com

Mohrfeld, Richard G.
PETRO
24 Lees Ave.
Collingswood, NJ 08108-1926
Tel. 856-854-4033
FAX: 856-858-9506
Fmfuel@home.com

Tutu, Narinder K.
Brookhaven National Laboratory
Upton, NY 11973-5000
Nazzaro, Paul
Advanced Fuel Solutions, Inc.
25 Duane Drive
N. Reaping, MA 01864
Tel. 978-664-5923

Nowakowski, Matthew
Moyer & Son Inc.
P.O. Box 64198
Souderton, PA 18964-0198
Tel. 215-799-2000
FAX: 215-721-2806

Oman, Richard
Insight Technologies
1150 Walnut Ave.
Bohemia, NY 11716
Tel. 800-424-3484
FAX 631-563-1117
Roman@optonline.net

Oswald, Kurt
R.W. Beckett Corporation
P.O. Box 1289
Elyria, OH 44036
Tel. 440-353-6219
FAX 440-353-6019
Koswald@beckettcorp.com

Panacciulli, Joseph
Skaggs-Walsh
119-02 23rd Ave.
College Point, NY 11356
Tel. 718-353-7000
FAX: 718-445-0936

Panchagnula, Mahesh
DELAVAN Inc.
P.O. Box 969
Bamberg, SC 29003
Tel. 803-245-6575
FAX: 803-245-7209
Mahesh@delavan.btg.com

Pihanich, Joseph
Boyertown Furnace Co.
156 Holly Road
Boyertown, PA 19521
Tel. 610-367-6800
FAX: 610-367-6800
Jpihanichj@enter.net

Pilger, John J.
Chief Chimney Services, Inc.
24 Hofstra Drive
Smithtown, NY 11787-2019
Tel. 631-863-2460
FAX: 631-863-2460
Chimneyman@aol.com

Polvino, Tony
SUNOCO Home Comfort Services
1824 Horseshoe Pike
Honeybrook, PA
Tel. 610-942-1908
FAX: 610-942-1919
Anthony_M_Polvino@sunoil.com

Rieber, Dan
Northern Manhattan Improvement Corp.
76 Wadsworth Ave.
New York, NY 10033
Tel. 212-822-8338
FAX: 212-928-4180
DanRieber@mmic.org

Ritz, Harry W.
Story-Winn Fuel Company
109 Fairview Road
Crum Lynne, PA 19022
Tel. 610-833-1000
FAX: 610-833-1745
Harryritz@hotmail.com

Rody, Steve
Thermo Products
P.O. Box 217
North Judson, IN 46366
Tel. 219-896-2133
FAX: 219-896-5301

Rudin, Andy
Insight Technologies
1150 Walnut Ave.
Bohemia, NY 11716
Tel. 800-424-3484
FAX: 631-563-1117
Arudin@InsightTechnologies.net

Sanfardino, Neal
Castle Oil Corp.
290 Locust Ave.
Bronx, NY 10454
Tel. 718-579-3422
FAX: 718-292-0942

Santa, Thomas S.
Santa Energy
Box 1141
Bridgeport, CT 06601
Tel. 203-362-3332 X:1326
FAX: 203-362-3348
SantaT@SantaEnergy.com

Schneider, Herbert
Carpenter & Smith, Inc.
P.O. Box 686
Monroe, NY 10950
Tel. 845-782-8161
FAX: 845-783-7643
CANDSOIL@aol

Schultz, George
Fuel Oil News
15 Caddy Road
Rotenda West, FL 33947
Tel. 941-697-8684
FAX: 941-697-4169
GEOSCHULTZ@EWOL.com

Shupe, Larry
Skyland Energy Service
2 Thompson St.
Raritan, NJ 08869
Tel. 908-782-3001
FAX: 908-782-1211
LSHUPE@EMY.NET

Signore, Dave
AMBLEC Coal Co. Inc.
252 N. Main St.
Ambler, PA 19002
Tel. 215-646-0192
FAX: 215-646-3368

Sippin, Gary L.
Sippin Energy Products, Inc.
234 Main Street
P.O. Box 220
Monroe, CT 06468
Tel. 203-261-3668
FAX: 203-268-0769
Gary@sippin.com

Spiegel, Jeffrey
M. SPIEGEL & SONS Oil Corp.
10 East Village Road
Tuxedo, NY 10987
Tel. 845-351-4700
FAX: 845-351-4694
SOSFUELS@AOL.COM

Stellmach, Mark
Fuel Management Services, Inc.
101A Post Kennel Road
Far Hills, NJ 07931
Tel. 908-204-0415
FAX: 908-204-0199

Stembridge, Jeff
Delavan
P.O. Box 969
Bamberg, SC 29003
Tel. 803-245-4347
FAX: 803-245-7209

Sullivan, Jack
New England Fuel Institute
20 Summer Street
P.O. Box 9137
Watertown, MA 02471-9137
Tel. 617-924-1000

Sweetser, Richard
Exergy Partners Corp.
12020 Meadowville Court
Herdon, VA 20170
Tel. 703-707-0293
FAX: 703-707-0138
Rsweetser@energypartners.com

Tatnall, Robert E.
Fairville Products, Inc.
302 Robinson Lane
Wilmington, DE 19805
Tel. 302-425-4400
FAX: 302-425-5661
Fuelright@aol.com

Theurer, Richard
HAGO Manufacturing Co.
1120 Globe Ave.
Mountainside, NJ 07092
Tel. 908-232-8687
FAX: 908-232-7046
Rtheurer@aol.com

Troost, Henry E., IV
Honeywell
1985 Douglas Dr. MN10-2483
Golden Valley, MN 55422
Tel. 763-954-6581
FAX. 763-954-4003
Henry.troost@honeywell.com

Trout, Richard
Fuel Advantage Marketing, Inc.
14 Old Aurburn Road
Derry, NH 03038
Tel. 603-437-9723
FAX: 603-437-9723

Tubman, Thomas J.
Carlin Combustion Technology
70 Maple Street
E. Long, MA 01028
Tel. 413-525-7700
FAX: 413-525-8306

Turk, Vic
R.W. Beckett Corporation
P.O. Box 1289
Elyria, OH 44036
Tel. 440-353-6280
FAX: 440-353-6080
Vturk@beckettcorp.com

Tuthill, Todd
T.L. Tuthill Heating Service
P.O. Box 2013
Jamesport, NY 11947
Tel. 631-722-4394
FAX: 631-722-4063

Tutu, Narinder K.
Brookhaven National Laboratory
Bldg. 475B
Upton, NY 11973
Tel. 631-344-4929
FAX: 631-344-1430

Tyrrell, Kevin
Carpenter & Smith
P.O. Box 686
Monroe, NY 10950
Tel. 845-782-8164
FAX: 845-783-7643

Tyson, Shaine K.
National Renewable Energy Laboratory
Golden, CO 80401
Tel. 303-275-4616
K_shaine_tyson@nrel.gov

Vassallo, Joe
Bayside Fuel
1820 Cropsey Ave.
Brooklyn, NY 11214
Tel. 718-946-4000
FAX: 718-946-3808
Jvassallo@petroheat.com
Waltz, Arlene
Brookhaven National Laboratory
Bldg. 526
Upton, NY 11973-5000
Tel. 631-344-5850
FAX: 631-344-2359

Wei, George
Brookhaven National Laboratory233
Bldg. 526
Upton, NY 11973-5000
Tel. 631-344-4033
FAX: 631-344-2359
Gwei@bnl.gov

Wesley, Charles
NYSERDA
Corporate Plaza West
286 Washington Ave., Ext.
Albany, NY 12203
Tel. 518-862-1090
CMW@NYSERDA.org

Wilcox, John E.
Moyer & Sons Inc.
113 E. Reliance Road
Souderton, PA 18964
Tel. 215-723-9858
FAX: 215-721-2814

Woosnam, Douglas
The SICO Company
P.O. Box 302
Mount Joy, PA 17552
Tel. 717-653-3420
FAX: 717-653-0811
Dwoosnam@sicoco.com

Yaffa, Lee
Greystone Services Inc.
P.O. Box 482
Beverly, MA 01915
Tel. 978-927-0188
FAX: 978-927-8862
Grey@shore.net

Zaweski, Richard S.
Meenan Oil Co., L.P.
3020 Burns Ave.
Wantaugh, NY 11793
Tel. 516-783-1000
FAX: 516-781-2332

Zimmerman, Donnie
Thermo Products
P.O. Box 217
North Judson, IN 46366
Tel. 219-896-2133
FAX 219-896-5301