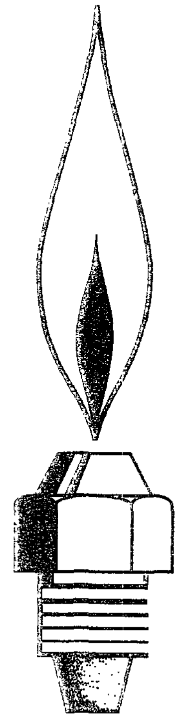
ENERGY

CONSERVATION

BNL-52544

PROCEEDINGS OF THE 1998 OIL HEAT TECHNOLOGY CONFERENCE



Held at
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973-5000
April 7-8, 1998

April 1998

Roger J. McDonald

Sponsored by the
OFFICE OF BUILDING TECHNOLOGIES,
STATE AND COMMUNITY PROGRAMS
UNITED STATES DEPARTMENT OF ENERGY

In cooperation with
PETROLEUM MARKETERS ASSOCIATION OF AMERICA

Under Contract No. DE-AC02-98CH10886 with the
UNITED STATES DEPARTMENT OF ENERGY

OFFICIAL FILE COPY

BNL-52544

PROCEEDINGS OF THE 1997 OIL HEAT TECHNOLOGY CONFERENCE

Held at
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973-5000
April 7-8, 1998

April 1998

Roger J. McDonald

Sponsored by the
OFFICE OF BUILDING TECHNOLOGIES,
STATE AND COMMUNITY PROGRAMS
UNITED STATES DEPARTMENT OF ENERGY
WASHINGTON, DC 20555

In cooperation with
PETROLEUM MARKETERS ASSOCIATION OF AMERICA

ENERGY EFFICIENCY AND CONSERVATION DIVISION
DEPARTMENT OF APPLIED SCIENCE
BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES
UPTON, LONG ISLAND, NEW YORK 11973-5000

UNDER CONTRACT NO. DE-AC02-98CH10886 WITH THE
UNITED STATES DEPARTMENT OF ENERGY

The timeliness of the material in this conference proceedings requires prompt publication. Therefore, to expedite publication, these papers have been reproduced directly from the author's manuscripts. The conference sponsors, organizing committee, and staff disclaim any and all responsibilities for the contents of individual papers and abstracts.

TABLE OF CONTENTS

TABLE OF CONTENTS

PAGE

II. TECHNICAL PRESENTATIONS (contd.)

ACKNOWLEDGMENTS

The 1998 Oil-Heat 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. Secondly, the high quality of the 1998 Oil Heat Technology Conference advanced preparations are thanks due to the professional efforts of the BNL conference coordinator: Gail Brown. The BNL authors wish jointly to acknowledge the significant and important contributions of our laboratory staff: Yusuf Celebi (Staff Engineer and Laboratory Manager) and Gang Wei (Associate Staff Engineer). There would be no results to report on without their professional efforts and dedication to the research effort. The editor also greatly acknowledges the hard work and effort required by the entire BNL program staff to make this meeting a success.

I. INTRODUCTION and KEYNOTE ADDRESS

INTRODUCTION

The 1998 Oil Heat Technology Conference will be held on April 7-8 at Brookhaven National Laboratory (BNL) under sponsorship by the U.S. Department of Energy, Office of Building Technologies, State and Community Programs (DOE/BTS). The meeting will be held in cooperation with the Petroleum Marketers Association of America (PMAA).

The 1998 Oil Heat Technology Conference, will be the twelfth since 1984, is an important technology transfer activity and is supported by the ongoing Combustion Equipment Technology (Oilheat R&D) program at BNL. The reason for the conference is to provide a forum for the exchange of information and perspectives among international researchers, engineers, manufacturers and marketers of oil-fired space-conditioning equipment. They will provide a channel 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:

- o 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;
- o 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 Dr. James Davenport, Ph.D. Chairman, Department of Applied Science, BNL, who will welcome the assembly on behalf of Brookhaven National Laboratory. Dr. Davenport will emphasize BNL's continued commitment to advancing oil heat technology and effecting technology transfer to the private sector. John Huber, Vice President & Chief Counsel, of the Petroleum Marketers Association of America (PMAA), will follow by welcoming the participants on behalf of PMAA and presenting his views on the subject and then he will introduce the Master of Ceremonies, James Buhrmaster, current Chairman of the PMAA Heating Fuels Committee. Mr. Buhrmaster will introduce the Keynote Address which will be given by Mr. Donald B. Allen Jr., Co-chairman of the NORA Legislative Committee and President of E.T. Lawson.

Fourteen 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 Canada, including:

- Integrated Oil Heat Appliance System Development in Canada
- A Miniature Heat-Actuated Air Conditioner for Distributed Space Conditioning
- High-flow Fan Atomized Oil Burner (HFAB) Development
- Progress in the Development of Self Tuning Oil Burners

- Application of HFAB Technology to the Development of a 500 Watt Thermophotovoltaic (TPV) Power System
- Field Tests of the HeatWise ***Pioneer*** Oil Burner and Insight Technologies ***AFQI***
- Expanded Use of Residential Oil Burners to Reduce Ambient Ozone and Particulate Levels by Conversion of Electric Heated Homes to Oilheat
- PMAA's Oil Heat Technician's Manual (Third Edition)
- Direct Venting Concept Development
- Evolution of the Chimney
- Combating Fuel Related Problems
- The Effects of Red Dye and Metal Contamination on Fuel Oil Stability
- New Standard for Above Ground and Basement Residential Fuel Oil Storage Plastic and Steel Composite Secondary Contained Tanks
- Money Left on the Table: An Economic Analysis of Tank Cleaning

Combustion Equipment Technology Laboratory

Conference participants will be welcome to visit the BNL combustion research facilities and witness equipment demonstrations of some of the advanced oil-fired heating systems under development at BNL. The equipment to be demonstrated include the HeatWise Inc. ***Pioneer*** oil burner based on the BNL FAN-Atomized Low-Firing-Rate, Low-Emission Oil Burner (FAB). Insight Technologies will display its Advanced Flame Quality Indicator (FQI) which is based on the FQI concept developed by BNL and licensed to Insight Technologies Inc. BNL will also provide numerous visual displays based on prior and ongoing research related to Oil Heat R&D.

The official BNL Oil Heat Technology Conference will be concluded with brief closing remarks by Roger McDonald, your editor, conference organizer and senior program manger for the Combustion Equipment Technology (Oilheat R&D) program. Following the conference PMAA will host an open session of the Education, Certification, Oilheat Advantages, and Tank Sub-Committee meeting of the PMAA Heating Fuels Committee. All conference attendees are welcome to attend if they so desire.

KEYNOTE ADDRESS

The 1998 Keynote Address will be presented by Mr. Donald B. Allen Jr., one of the dedicated industry leaders forging a new oil heat industry for the next millennia. The subject of his presentation will be the National Oil Heat Research Alliance, what it is, how it will enable the oil heat industry to grow in the future, how it will effect change through research and development, how it will transfer new technology through education and training, and how it will educate the future oil heat homeowners of America about the benefits of safe, clean, environmentally friendly, modern oilheat.

Outline of the 1998 Keynote Address

Call to Action for the Future of the Oil Heat Industry

NORA an Oil Heat Industry Checkoff Program for Research and Development, Consumer Education, and Industry Training

Presented by: Donald B. Allen, Jr.
NORA, Co-Chairman Legislative Action Committee
PMAA Heating Fuels Committee, Member & 1996/97 Chairman
President, E.T. Lawson, Hampton Virginia

1. Summary:

NORA, the National Oil Heat Research Alliance will save the oil heat industry. Aside from raising funds to educate consumers about the values of oil heat, NORA will provide the leadership and funding for oil heat technology development and transfer.

With NORA, the oil heat industry can stabilize its market share by replacing its obsolescent equipment, by converting electric systems to oil and by converting gas systems to oil. In addition with consumer education, we can re-enter the new home market.

2. Comparative Status of the Residential Space Heating Industry in the U.S.A.

A. Oil Systems

10.8 Million Systems Using No 2.
3.2 Million Systems Using No 1.

68% Located in Northeast and Mid-Atlantic

Represents 15% of the Residential Market Nationwide
However we have over a 30% market share in the
24 oil heated states engaged in NORA.

Annual Oil Furnace Sales -- 165,000
Annual Oil Boiler Sales -- 165,000
Annual Oil Fired Hot Water Sales -- 5,000
Annual Space Heater Sales -- 25,000

New Homes Built with Oil -- 41,000
Conversions to Oil--34,000

25% Is Non-Flame Retention Technology, Pre-1970

2. Comparative Status of the Residential Space Heating Industry in the U.S.A.--continued

B. Gas 46 Million Systems

Represents 51% of the Residential Market
Annual Furnace Sales 2,500,000
Annual Boiler Sales 165,000
Annual Water Heater Sales 4,800,000
New Homes Built with Gas 790,000
Conversions to Gas 300,000
10,000,000 Units have AFUEs less than 62%

C. Electric 23,700,000 Systems

Represents 26 % of the Residential Market
Annual Furnace Sales 400.000
Annual Heat Pump Sales 1,000,000
Annual Water Heater Sales 3,900,000
New Homes Built with Electric 300,000
Virtually Any Electric Furnace and
Air to Air Heat Pump in the 24 Oil Heat States
is economically obsolescent.

3. Comparative Status of the Relative Energy Cost in the Oil Heat Markets -- thru 1995

A. Oil Versus Electric -- Significant Price Advantages in All Regions

B. Oil Versus Gas -- Price Advantages in New England, the Northeast, and the Mid-Atlantic

C. Trends since 1995 Accentuate the Advantages over Gas and
Maintain the Advantage over Electric

4. Comparative Research and Development for New Products

A. Edison Power Research Institute
Founded 1972, 700 Members
Annual Budget Is $550,000,000 / $23 per Household

Purpose: Assess Needs, Develops Power Infrastructures
Conduct Research and Development and
Manages Costs and Risks

Funded by DOE Grants, Contracts and Cooperative
Agreements and by Surcharges from Public Utilities

4. Comparative Research and Development for New Products -- continued

B Gas Research Institute
Founded 1976
Annual Budget Is 205,000,000 / $4.45 per Household

Purpose: To Discover, Develop and Deploy Technologies and Information That Measurably Benefits Gas Customers and the Industry. GRI's Work Is Conveyed to Consumers and Others Through Quarterly Magazines, Publications, News Releases, Workshops, Seminars, Trade Shows, and Through Other Media.

Funding is from other Government Agencies and thru FERC authorized Tariffs on Pipeline Transmissions.

C. Brookhaven National Laboratory -- Oil Heat Research and Development Program
Originally founded in the mid 1970's
Current FY 1998 Budget is $420,000 / less than $0.03 per Oil Heat Household

Purpose: To Develop Ways to Conserve Heating Oil

5. Comparative Analysis of Residential Utility Infrastructure

A. The Oil Heat Industry is a **Free Market** of over 7,000 small businesses serving over 30,000,000 American Consumers. We employ over 250,000 people generating sales of almost $13,000,000,000 ($13 billion) in Energy and Service Sales.

B. The Gas Industry is a Regulated / Unregulated Business of about 600 Utilities serving the 46,000,000 Gas Heated Homes. In addition there are over 45,000 small HVAC businesses who service these homes also.

C. The Electric Industry is a Regulated Industry of about 200 Companies undergoing deregulation. This industry serves us all. In addition the electric residential space heating consumer is also served by the same 45,000 HVAC contractors that serve the gas consumer.

6. Role of Technology in the Development of Our Industry

A. From the 1920's thru the 1940's our industry was developed not by our Grandfathers who "Jobbed" a growing industry but, by the oil heat manufacturers. In 1948 they numbered over 1100 Companies. We fondly remember General Electric (G.E.) boilers, Stewart Warner Winkler Low Pressure Burners, Perfection Stoves and Hot Water Heaters, the list was endless.

Our Industry was the modern high tech solution to wood and coal. We were automatic.

B. From the 1950's thru the 1960's our industry grew dramatically. This growth was a direct result of the major oil companies funneling money into the NOFI and its affiliates. This money, millions of dollars each year was used for promotion, training, code compliance, research and development. Again our fathers serviced a market created by the economics of oil and the promotion of others. Funding in the 60's approached almost $4,000,000 annually.

The 1970 Census indicated there were over 14,000,000 No. 2 households and over 4,000,000 No. 1 households.

C. Funding was withdrawn in 1970. Our numbers have been declining ever since. Granted the price spikes of the 70's contributed significantly. But in the East we have had price parity with respect to Gas since 1986 and price advantages since the mid 90's.

7. Conclusion

In the history of the oil heat industry, research and development has been show to be a key part of our success. It led to our growth and caused us to be the fuel of choice in the fifties and sixties. Our decline as an industry is coincident with the decline in funding of oil heat promotion and R&D and the precipitous growth in R&D funding of our competitors.

NORA, coupled with favorable oil economics, will cause our industry to grow again.

NORA will fund promotion, yes but, also it will fund technical leadership.

8. Action statement

If you are a private citizen, write your Congress-person.

If you are a heating oil supplier, write your Congress-person.
- Send money to NORA.
- Support your state effort.
- Enlist the support of your employees to support NORA.

If you are the representative of an oil equipment manufacturer, get your corporate management to solicit the support of their congressional representation.
- Write your Congress-person yourself.
- Send money to NORA.
- Enlist the support of your employees in writing letters.

II. TECHNICAL PRESENTATIONS

Paper No. 98-01

Canadian Program to Develop Advanced Oil-Fired Integrated Mechanical Systems

A.C.S. Hayden[1], K. Lee[2]

[1] Advanced Combustion Technologies
[2] Buildings Group

CANMET Energy Technology Centre (CETC)
Natural Respurces Canada (NRCan)

ETB/CETC/ACT
1 Haanel Drive
Ottawa, Canada K1A 1M1

Canadian Program to Develop Advanced Oil-Fired Integrated Mechanical Systems

A.C.S. Hayden[1], K. Lee[2]

[1] Advanced Combustion Technologies
[2] Buildings Group
CANMET Energy Technology Centre (CETC)
NRCan
Ottawa, Canada

ABSTRACT

Research by NRCan's Advanced Houses Program indicates that at least 2.5 million fuel-fired integrated systems will be sold in Canada. By the year 2020, the next generation of advanced integrated systems are expected to capture at least 55% of the residential market in North America.

CETC is now working with Canadian industry to facilitate next generation product development, based on a range of different system bases.

The presentation will present potential systems and progress to date, with emphasis on overall system efficiency and assured consumer satisfaction.

BACKGROUND

Launched in 1991, the Advanced Houses Program challenged Canada's housing industry to build 10 demonstration homes meeting new levels of energy performance, indoor air quality and other environmental features. Characterized by an unprecedented level of industry participation and leveraged financing, these Advanced Houses fostered the development of more than 40 innovative emerging technologies having the potential to reduce energy consumption and greenhouse gas emissions from the housing sector, while creating new opportunities for business development.

Once the successful field trials were completed, the Program commissioned an assessment of the emerging technologies to identify those with the greatest potential to reduce energy consumption while succeeding in the marketplace.

There were nine "winning" technologies, six dealing with the space conditioning mechanical systems and three dealing with envelope products.

The building envelope products were
- high performance windows
- exterior air barriers
- engineered wall framing

Of the mechanical technologies, four were systems performing integrated functions from one energy source, and two dealt with air movement for heating.

Analysis of the emerging technologies predicted that integrated mechanical systems would have at least 55% of the North American marketplace by the year 2020.

AIMS PROGRAM

Based on the analysis and recommendations of the Advanced Houses Program, CETC has embarked on a program to develop Advanced Integrated Mechanical Systems (AIMS), through a series of technical partnerships with Canadian industry.

Essential integrated system components having the potential to be incorporated in the next generation integrated systems have been defined as:
- space heating
- service water heating
- fresh air ventilation with energy recovery
- energy-efficient fan-motor sets
- add-on cooling capacity
- advanced intelligent control strategies

In all systems, the efficient use of auxiliary power will be stressed, as will the cost-effectiveness of the systems to be developed.

The ability to utilize a range of distribution systems, such as small diameter, high velocity ducting, in-floor radiant heating, etc., will further assist in market uptake.

The AIMS program has set goals of ensuring effective combination space water systems but more importantly, of bring prototype space/water/ventilating systems to field trials within two years, with full market introduction within an additional 12 months.

The CETC presentation will describe the program, some potential combination systems which offer the most potential for further integration, as well as progress being made in a variety of integrated technologies to achieve these goals.

ADDITIONAL INFORMATION

Unfortunately a complete paper could not be made available for publication in the 1998 Oil Heat Technology Conference Proceedings due to the need to protect certain proprietary information at the this time. Additional information will be made available in the future. Please send requests directly to the author, A.C.S. Hayden.

Paper No. 98-02

A Miniature Heat-Actuated Air Conditioner for Distributed Space Conditioning Applications

Kevin Drost Ph.D. and Michele Friedrich

Pacific Northwest National Laboratory - Battelle
902 Battelle Boulevard
Richland, WA 99352

A MINIATURE HEAT-ACTUATED AIR CONDITIONER FOR DISTRIBUTED SPACE CONDITIONING APPLICATIONS

M. Kevin Drost, Ph.D.
Phone (509) 375-2017; Fax (509) 375-3614

Michele Friedrich
Phone (509) 375-5989; Fax (509) 375-3614
Pacific Northwest National Laboratory
P.O. Box 999, K5-20
Richland, Washington, 99352

ABSTRACT

The Pacific Northwest National Laboratory[1] (PNNL) is developing a miniature absorption air conditioner for a range of space conditioning applications. A 1-kW (3400 Btu/hr) air conditioner will have dimensions of 15 cm by 15 cm by 6 cm and will weight approximately 2 kg (4.4 lb). Compared to a macroscale absorption heat pump, this represents a reduction in volume by a factor of 60. Size and weight reductions are obtained by developing a device that can simultaneously take advantage of the high heat and mass transfer rates attainable in microscale structures. In distributed cooling applications, a number of small coolers (approximately 1-kW cooling capacity) would replace a central air conditioner, eliminating the need for ducting and significantly reducing the cycling losses. The miniature absorption cooler is heat actuated and could use a hot water hydronic loop as the heat source. This would convert an oil heating system to a heating and cooling system.

INTRODUCTION

Building space conditioning is an inherently distributed process that is currently done by a central system. The purpose of space conditioning is to provide a relatively small amount of heating or cooling around a residence. However, normal practice is to produce heating or cooling in a central location (such as a heat pump or furnace) and then distribute the heated or cooled air throughout the structure via a system of ducts. The combination of central generation and air distribution results in significant performance loss and costs. These include:

- Ducting Losses - Fan power, thermal losses through ducts, and air leakage can consume up to 30 to 40% of the output of a heat pump. Losses in poorly installed ducting can be much higher.
- Cycling Losses - A central heat pump is sized to meet the maximum design load. At part-load condition, the heat pump will only operate intermittently (cycling). While cooling, the heat pump must repeatedly cool heat pump components and ducting, only to have these components warm up when the heat pump cycles off. Typically cycling losses can reduce the output of a heat pump by 10 to 15%.
- Zoning - Conventional air distribution systems require modulating dampers for zoning, making zoning difficult and expensive.

---

[1] Operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

- Increased Capital Cost - The cost of ducting and ducting insulation represents a significant fraction of the capital cost of a residential space conditioning system.

A distributed space conditioning system, where a building is conditioned by a number of small heat pumps, would reduce each of the four penalties associated with central heating and air conditioning. Eliminating the need for ducts would eliminate duct losses. Some fan power may still be needed for optimum heat transfer from the distributed heat pumps. Cycling losses would be reduced by the modular nature of distributed heat pumps. Turning on additional heat pumps rather than cycling a single heat pump would provide increased cooling capacity. The use of multiple distributed heat pumps allows zoning without air flow modulation.

The price we pay for central systems is very high; a total reduction in the efficiency of the system of up to 50% and an increase in the system capital cost of 50 to 70% when compared to a distributed system. The opportunity to increase overall energy efficiency is the primary motivator for considering distributed systems.

A number of conventional options exist for distributed heating and cooling systems. Baseboard electric heating and window-mounted air conditioners are clearly distributed heating and cooling concepts, but low efficiency ones. Split condenser, vapor-compression cycle systems have some of the advantages of a distributed system. Finally, using water distribution of heat and chill can reduce losses associated with air distribution.

While these conventional options have some of the features of distributed systems, true distributed space conditioning will require new, small and highly modular systems. Recent developments in energy and chemical system miniaturization indicate that small and efficient heating and cooling systems are technically feasible. This paper presents an overview of technology development of small absorption cycle heat pump systems.

Research at the Pacific Northwest National Laboratory has focused on applying recent developments in microfabrication to the design and manufacturing of miniaturized energy and chemical systems. Mass production of microscale components and systems, using fabrication techniques developed for microelectronics, has the potential to make small-scale, space-conditioning systems economically attractive. And microtechnology has matured to the point where initial applications of microscale sensors are reaching commercialization. Development of microscale components such as motors, pumps, and actuators is also progressing, but combining components into systems such as microtechnology-based heat pumps has not yet been reported in the literature.

If successfully developed, microtechnology-based absorption cycle heat pump systems will offer at least six important advantages:

- Modular Design - Miniature energy systems are inherently modular and can be readily adapted to distributed space conditioning applications.
- Convenient Integration with Oil-Fired Hydronic Systems – Certain types of heat-actuated heat pumps can operate using low temperature energy sources (as low as 93°C, 200°F) allowing the use of an oil-fired hydronic loop for space cooling.
- Cost - Microfabrication techniques offer economies of mass production, in many cases building on mass production techniques developed for the electronics industry.
- Minimum Field Fabrication - In many cases, the actual installed performance of central systems is significantly below predicted performance. Additional losses result from poor system design, installation and lack of adequate commissioning. These losses can be minimized by factory installation of modular microtechnology-based sheet heat pump systems into prefabricated building systems, avoiding field fabrication.

- Environmentally Benign Refrigerants - The deployment of microtechnology-based absorption cycle heat pumps will reduce the use of harmful refrigerants. The proposed microscale absorption cycle heat pump will not use environmentally harmful refrigerants such as chlorofluorocarbons (CFCs and HCFCs), and any individual heat pump will have a very small inventory of potentially harmful working fluids such as ammonia.

- Heat and Mass Transfer Characteristics - Heat and mass transport can be significantly enhanced in microstructures. Heat transport is improved by increases in the ratio of surface area to volume and by the inherent reduction of the laminar sublayer in small channels. Mass transport is improved by the reduction in diffusion length, which reduces the molecular diffusion rate, by two orders of magnitude.

Recent research at the Pacific Northwest National Laboratory has focused on the development of a compact microtechnology-based, absorption cycle heat pump.

In addition to distributed space conditioning applications, the miniature absorption heat pump can meet a number of important microclimate control and space conditioning requirements including 1) vehicle space conditioning, 2) manportable cooling, 3) air-transportable space conditioning, and 4) autonomous cooling for shipping containers.

CONCEPT DESCRIPTION

Although the absorption and vapor-compression cycles differ in the way compression is provided, both systems take the same approach to heat absorption and rejection. In both cycles, superheated refrigerant enters the condensing heat exchanger, where it undergoes constant-pressure heat rejection. The resulting condensate or mixture of condensate and vapor is then adiabatically expanded through either a throttling valve or a capillary. The mixture is then routed to an evaporating heat exchanger for constant-pressure heat absorption.

Compression is accomplished in the absorption heat pump system with a single-effect thermochemical compressor consisting of an absorber, a solution pump, a regenerative heat exchanger, and a desorber (gas generator).

A conventional absorption heat pump relies on gravity to form falling films, which provide liquid to gas contact in the absorber and desorber. This approach has a decisive disadvantage for distributed space-conditioning applications. The falling films have a film thickness on the order of 1 mm , which becomes a significant barrier to mass diffusion and results in a physically large absorber and desorber. As discussed below, the miniature absorption heat pump avoids this disadvantage by relying on the high rates of heat and mass transfer available in microstructures.

The miniature absorption heat pump depends on the extraordinarily high heat and mass transfer rates available in microstructures to radically reduce its size while maintaining cooling capacity and efficiency. Its performance ultimately depends on microstructure with individual features as small as 5 microns. The heat pump is a miniature device, but is sufficiently large to initially use a small but conventional solution pump.

A number of cycles have been evaluated. Cycles can be classified based on the fluid combination and on cycle arrangements. The most widely used fluid combinations are lithium bromide (LiBr) and water, where water is the refrigerant; and water and ammonia (NH_3), where ammonia is the refrigerant. Cycle arrangements range from the single-effect cycle described above to progressively more efficient but complicated multiple effects. Previous research at PNNL simulated three absorption cycles: single-effect LiBr/H_2O, double-effect LiBr/H_2O, and single-effect H_2O /NH_3.

The single-effect LiBr/H_2O cycle requires a low pressure solution pump with a 28 kPa (4 psi) pressure rise and can operate with relatively low temperature energy sources (93°C, 200°F) but the cycle is inefficient compared to the double-effect cycle. While more efficient, the double-effect LiBr/H_2O cycle requires a higher pressure pump (103 kPa [15 psi] pressure rise), a higher temperature heat source (121°C, 250°F) and is more complicated than the single-effect cycle. The pressure rise required for a H_2O/NH_3 solution pump (1315 kPa, 190 psi) is too high for currently-available small pumps, and the H_2O/NH_3 heat pump requires a high-temperature heat source (175°C, 350°F).

Based on this screening, both the single-effect and double-effect LiBr/H_2O cycles are candidates for cooling applications using a hydronic loop as a heat source.

HEAT PUMP COMPONENTS

An ongoing research effort at PNNL focuses on development of the components necessary for a miniature LiBr/H_2O heat pump. All components of the single-effect absorption heat pump have been demonstrated, and this section describes the miniature version of each component with a brief overview of the experimental performance results generated at PNNL. A picture of the prototype test articles for each component is shown in Figure 1.

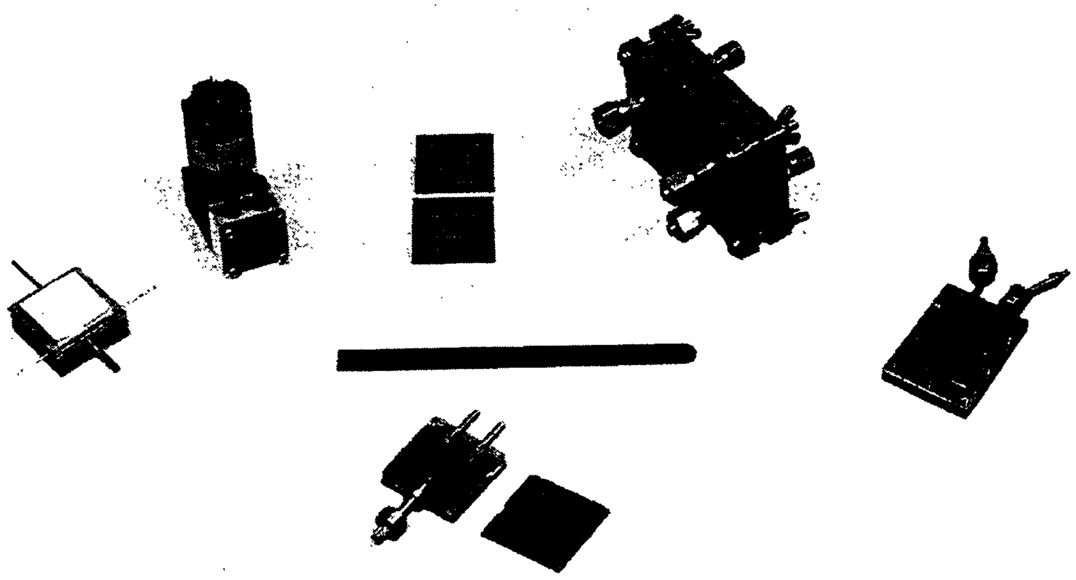


FIGURE 1. ABSORPTION HEAT PUMP COMPONENTS

- Desorber - Strong refrigerant solution enters the desorber and forms an ultra-thin desorbing film. The ultra-thin film (with a film thickness of approximately 100 microns) is maintained by a proprietary micromachined structure, which allows refrigerant vapor to evolve from the thin film. Thermal energy from a combustor or from a hot water or steam system can be used to heat the strong solution in the ultra-thin film, evaporating the refrigerant vapor from the solution at a fast rate. The refrigerant vapor passes through the micromachined structure and is transferred to the condenser.

  High heat and mass transfer in the desorber results from the use of a mechanically constrained, ultra-thin film, which has a thickness approximately one-tenth that of a falling film. In theory, this should reduce the refrigerant diffusion time in the thin film by a factor of 100. The use of a mechanically-constrained, thin film also means that the desorber works regardless of its orientation. PNNL has developed and demonstrated the desorber. Preliminary results show that water is desorbed from the strong solution at a rate of 0.3 $g/cm^2/min$. This exceeds the performance of conventional desorbers by a factor of 20. We expect to significantly improve this level of performance.

- Condenser - The condenser consists of an array of microchannels with channel widths between 100 and 300 microns and channel depths up to 1 mm. The microchannel condenser has been demonstrated by PNNL. Heat transfer rates in excess of 30 W/cm^2 were attained with a small temperature difference and a low-pressure drop.

- Evaporator - The evaporator also consists of an array of microchannels with channel widths between 100 and 300 microns and channel depths up to 1 mm. Extensive experimental investigations of microchannel evaporation have been published by PNNL (Cuta et al. 1996). Results show that convective heat transfer coefficients of 1.0 to 2.0 W/cm^2-K are readily attainable, and heat transfer rates up to 100 W/cm^2 can be obtained with a small temperature difference. These heat transfer coefficients and rates exceed those of conventional evaporators by a factor of 4 to 6. Pressure drop is typically less than 6 kPa (1 psi).

- Absorber - Weak refrigerant solution enters the absorber and forms an ultra-thin, absorbing film. As with the desorber, the ultra-thin film (approximately 100 microns) is maintained by a proprietary micromachined structure. Refrigerant vapor passes through the micromachined structure and is absorbed into the weak solution. The absorption process results in a high rate of heat generation, which is subsequently cooled by a microchannel heat exchanger.

  High absorber performance results from the use of the mechanically constrained, ultra-thin film, which has a film thickness approximately one-tenth that of a falling film. This reduces refrigerant diffusion time in the thin film by a factor of 100. In addition, the mechanically constrained, absorption process means that the absorber performance is independent of its physical orientation.

  PNNL has developed and demonstrated the absorber, and preliminary results show that ammonia could be absorbed in water at a rate that generated between 10 and 30 W/cm^2. This is an extraordinary absorption rate that exceeds the performance of conventional desorbers by more than a factor of 10, and we expect to improve this level of performance significantly.

- Regenerative Heat Exchanger - The regenerative heat exchanger consists of arrays of microchannels with channel widths between 100 and 300 microns and channel depths up to 1 mm. Extensive experimental investigations of single-phase microchannel heat transfer have been published by PNNL (Ravigururajan 1995). Convective heat transfer coefficients of 1.0 to 1.2 W/cm^2-K are attainable. These heat transfer coefficients exceed conventional regenerator performance by a factor of 3 to 6.

- Combustor - PNNL has demonstrated a microchannel combustor for the Department of Defense Advanced Research Projects Agency (DARPA). The microchannel combustor can produce thermal energy at a rate of at least 30 W/cm^2, with a thermal efficiency between 82 and 85% (Drost et al. 1996). For use with a hot water or steam system, the combustor would not be needed.

- Solution Pump - PNNL has qualified several small, commercially available pumps for application in miniature LiBr/H_2O systems. While significantly larger than needed, these pumps are adequate for a proof-of-principle demonstration of the miniature absorption heat pump.

HEAT PUMP PERFORMANCE

We have not analyzed a compact heat pump for applications with a hot water/steam loop as the heat source and with an air-cooled evaporator, so we will present results for a similar 350 W (1195 Btu/hr) manportable cooling system. Based on the experimental data we have collected to date, a prototype manportable cooler has been designed. This section presents the predicted performance of a single-effect, LiBr/H_2O absorption heat pump sized to provide 350 W of cooling. The system includes a water-cooled condenser and absorber, a water heat source for the evaporator and a microchannel combustor with exhaust gas at 250°C as the desorber heat source. In many applications, water-cooling for the absorber and condenser will be available (i.e., a cooling tower for space conditioning). In other applications, such as manportable cooling, an air-cooled heat exchanger will be required for ultimate heat rejection from the system.

Based on our component testing results and simulation, we predict that a manportable cooling system would weigh approximately 650 g and have a coefficient-of-performance (COP) of 0.68. The COP of a system using a hydronic loop as a heat source would be somewhat lower because of the relatively low temperature of the thermal energy available. COP is the ratio of the amount of cooling provided divided by the thermal energy supplied to the desorber. A COP of 0.68 for a heat-actuated heat pump is comparable to a COP of 2 to 2.5 for a conventional vapor-compression heat pump where primary fuel must be used at a power plant to produce electricity.

Based on these results, we estimate that a 1-kW (3400 Btu/hr) air conditioner will have dimensions of 15 cm by 15 cm by 6 cm and will weigh approximately 2 kg (4.4 lb). Compared to a macroscale absorption heat pump, this represents a reduction in volume by a factor of 60.

These device characteristics are a compelling example of the advantage of devices in the miniature size range. The specific cooling (cooling per unit volume) of the miniature heat pump is higher than that of a conventional macroscopic absorption heat pump by a factor of 60 (1.25 W/cm^3 compared to 0.02 W/cm^3) for a macroscale device.

CONCLUSIONS

By taking advantage of the high rates of heat and mass transfer attainable in microstructures, PNNL developed a miniature absorption heat pump with a cooling capacity of a 1 kW having dimensions of 15 cm by 15 cm by 6 cm and a weight of approximately 2 kg. Compared to a macroscale absorption heat pump, this was achieved with a reduction in volume by a factor of 60. By enabling the use of distributed space cooling with relatively low temperature thermal energy, this technology may be the key to providing space cooling with oil-fired equipment.

REFERENCES

Cuta, J.M., C.E. McDonald, and A. Shekarriz. 1996. "Forced Convection Heat Transfer in Parallel Channel Array Microchannel Heat Exchangers." Advances in Energy Efficiency, Heat/Mass Transfer Enhancement PID-Vol.2 HTD-Vol.338, American Society of Mechanical Engineering, New York.

Drost, M.K. C.J. Call, J.M. Cuta, and R.S. Wegeng. 1996. "Microchannel Integrated Evaporator/Combustor Thermal Processes." Presented and 2nd U.S./Japan Seminar in Molecular and Microscale Transport Phenomena, August 8-10, Santa Barbara, California.

Ravigururajan, T.S., J. Cuta, C. McDonald and M.K. Drost. 1996. "Single Phase Flow Thermal Performance of a Parallel Micro-Channel Heat Exchanger." Presented at American Society of Mechanical Engineers 1996 National Heat Transfer Conference.

Paper No. 98-03

High-flow Fan Atomized Oil Burner (HFAB) Development

Richard F. Krajewski, P.E., BNL, Dr. Thomas A. Butcher, Ph.D., BNL, Yusuf Celebi, BNL, and Gang Wei, BNL

High-flow Fan-Atomized Oil Burner (HFAB) Development

Richard F. Krajewski,BNL Thomas A. Butcher, Ph.D., BNL
Yusuf Celebi,BNL, and Gang Wei, BNL

Abstract

BNL's recent approach to achieving low firing rates in residential oil burners, has been an adaptation of the Fan-Atomized Burner (FAB) technology. While the FAB technology has been a break-through in burner design the continued effort for cost reduction and improved performance has led to a new design. This new design is different in that the secondary and tertiary air flows have been eliminated and 100% of the combustion air flow is utilized in more effective atomization of the liquid fuel. This new approach has been termed the High Flow FAB or HFAB. The benefits of the HFAB concept are lower manufactured cost together with improved performance and lower emissions. The evolution of the HFAB design has been positive through testing with practical solutions to issues of head temperature, soot formation, and ignition. The current design is one which matches the need for low output at low excess-air and reduced emissions with low CO and NO_x emissions.

Introduction

In preceding designs BNL's approach to achieving low firing rates in residential oil burners has been the application of the Fan-Atomized Burner (FAB) technology.[1] In this design the fan air pressure is used to atomize the liquid fuel. Along with low firing rates the FAB design has been able to eliminate the effects of nozzle off-cycle coking and to reduce on-cycle emissions. In the FAB, the burner head is designed to split the air flow from the combustion air fan in three ways. About 60% of the combustion air flows into a special nozzle to atomize the liquid fuel. The remaining 40% of the combustion air is split between secondary and tertiary air flow that is provided directly into the flame zone. A number of configurations of the FAB have been tested at BNL. A commercial residential application of this technology is incorporated in the Pioneer burner.[2] This burner, which is manufactured by the Heat Wise Inc., has been through UL testing and is undergoing field trials during the 1997/1998 heating season.

Mechanical Design - Air Handling

The design of the burner is different from the FAB in that the secondary and tertiary air flows have been eliminated. Now, 100% of the combustion air flow is utilized in the atomization of the liquid fuel. Hence, the name High-flow Fan-Atomized Burner (HFAB) is applied to this design. The BNL nozzle design, development work, and test results for the HFAB are described in detail in an informal report.[3] Expected benefits (which led to the initiation of this development effort) for this new arrangement, include:

A. Improved atomization with higher atomizer flows
B. A simpler, lower cost burner head
C. Lower NOx emissions.

With the use of 100% of the combustion air flow through the nozzle the flow in the flame zone is essentially a single, swirling jet with higher velocities than earlier designs. This arrangement provides great opportunity to recirculate combustion product to the root of the flame. The higher velocities can drive very high recirculation rates, leading to lower peak flame temperatures and reduced NO_x.

In the original development work, the burner was configured so that the combustion air fan was directly coupled to the air atomizing nozzle through a 1 ½ inch diameter tube. The mechanical attachment to the appliance was accomplished through the use of a cylindrical outer holder which permitted a conventional flange attachment to be used for mounting. The nozzle assembly was mounted in a donut of refractory material concentric to the mounting cylinder. Another protective refractory ring was inserted co-planer with the front of the nozzle assembly.

In a later design, the refractory donut was replaced with steel rings but the front protective refractory ring was retained. Still later, the design included a steel flame shield which was intended to protect the front of the nozzle and refractory was added back between the flame shield and first steel ring. In all these early designs the combustion air was directly channeled to the nozzle assembly.

A final prototype of the HFAB has been developed and is currently being evaluated at BNL. The objectives of the design of this burner were simplicity and servicablity. At the same time we wanted to demonstrate non-conventional arrangements. In this design the combustion air fan pressurizes an air tube which in turn supplies air flow to the nozzle assembly. This all-metal configuration for the HFAB has been designed to outwardly mimic a conventional burner. In addition to all the parts required for fuel handling, ignition, and controls, it basically consists of a fan, an air tube and a slotted flame tube with a solid choke ring. Inside the head, held concentric to the air tube by a support plate, is an assembly, which consists of the nozzle, electrode holders, a CAD cell (flame sensor) holder, and a shield plate. This assembly is secured in a retainer. The shield plate seals against a stop ring mounted to inside the air tube. Figure 1 shows an isometric view of the prototype HFAB head and it's components. For service the fuel line, nozzle assembly, retainer, and shield are all easily slid together back out of the air tube.

Combustion air from a high pressure fan is introduced at the beginning of the air tube and flows into the nozzle assembly. Some air flow around the nozzle retainer provides convective cooling to the rear of the shield plate. Holders for high-voltage ignitors and a flame sensor are mounted rigidly to the shield plate and pass back through the retainer. Ignition and flame sensor wiring pass back through the air tube and exit the assembly though the rear support plate. Currently, a small DC fan/motor combination are being used to provide atomization/combustion air.

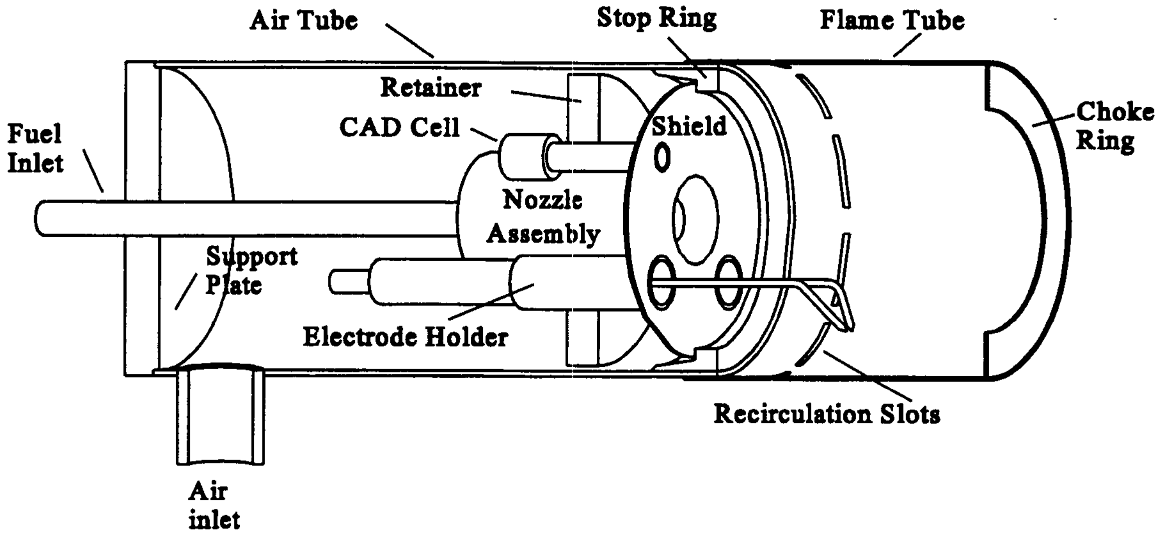
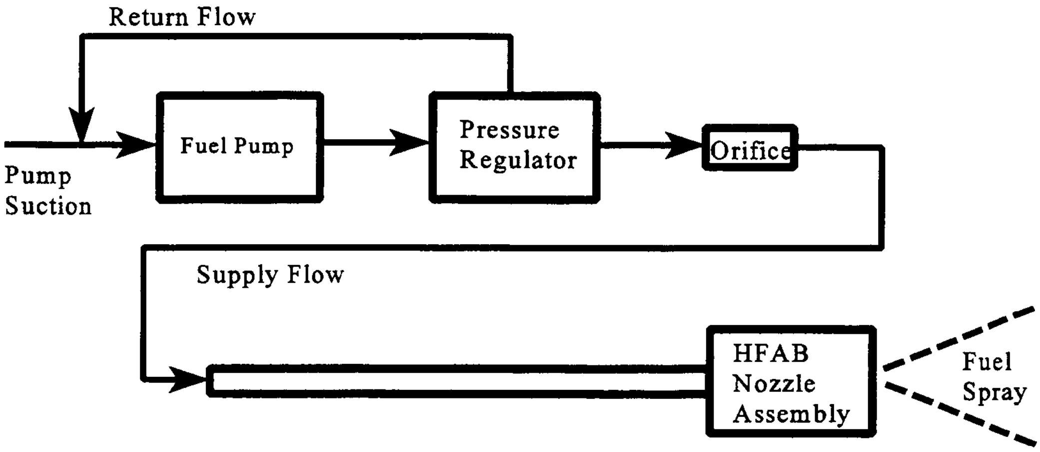


Figure 1 - Mechanical configuration of prototype HFAB air tube and combustion head. (not to scale)

Source File: [illegible].dwg

Mechanical Design - Fuel Handling

There are many ways to configure the system. For the current "concept" burner a non-conventional approach was taken. The fuel system consists of a low pressure pump delivering fuel through a regulator and orifice to the air atomizing nozzle . The fuel pump, is different in design from the more common motor driven gear pump type found on conventional burners. This pump is a solenoid actuated piston and check-valve design which supplies fuel at a maximum pressure of 12 psi. The regulator is adjusted to about 8 psi and the orifice is sized to 0.008 inches diameter to establish a fuel flow of 0.25 gph. Power to the pump is a pulsing DC supplied through a half-wave rectifier directly from a 120 VAC source. Nominal power draw of the pump is 15 watts. The flow capacity of the pump exceeds the fuel rate requirement of HFAB and so a part of the flow is bypassed from the regulator discharged back to the suction side of the pump. Figure 2 is a block diagram representation of the fuel supply system for the HFAB.



Source File: ohconf98\hfabfuel.wpg

Figure 2 - Fuel System block diagram schematic for prototype HFAB

Development Test Results

The preliminary test plan for the prototype HFAB has been developed along exploratory lines with attention to potential problem areas. The plan included study of issues such as: combustor sooting, surface temperatures, performance (excess-air, CO, NO_x), and ignition.

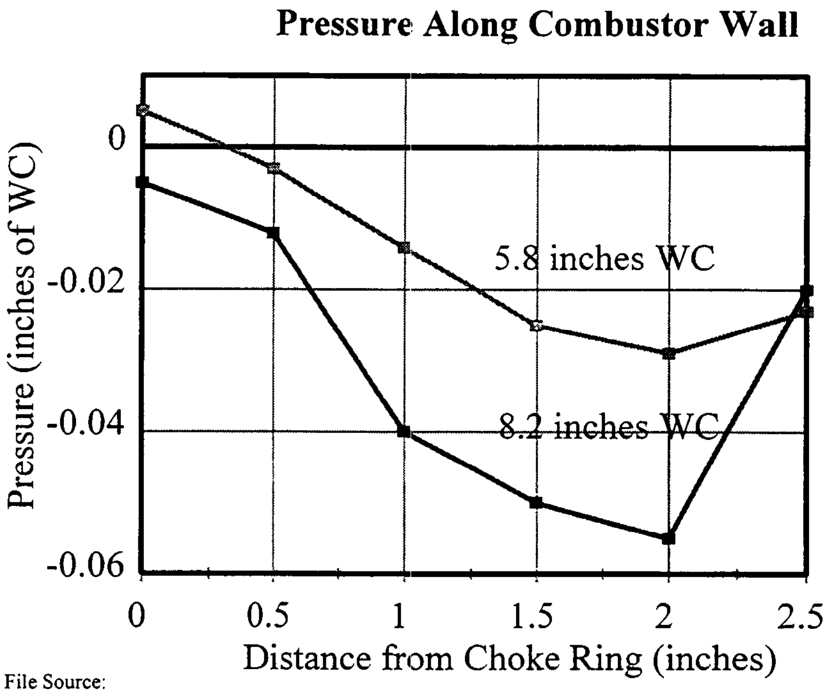
In the early tests of the HFAB prototype in the quartz cylinder test chamber at BNL, there was some concern about material temperatures associated with the shield plate. These temperatures, with the shield in contact with the stop ring, were lower than expected at about 800 - 900°F. Of larger concern were issues of the formation of soot on the combustor inner surfaces, and cold ignition at design fuel flow rates slightly below 0.25 gph. Parametric studies were done to evaluate effect of the flame tube length and choke ring size on performance. Increasing the length of the flame tube or increasing the size of the choke ring improves flame stability but also increases NO_x emissions.

The next series of tests were run in a low mass boiler. The results were gratifying in that the HFAB was able to operate at excess-air levels of 18-47% (about 3.0-7.0% O_2) with reduced levels of soot on the combustor surfaces. The shield temperature was now about 1300°F and some distortion of the shield material was observed. Three holes were added through the retainer to enhance the convective cooling on the back side of the shield. Subsequent tests were conducted with small changes of combustor length. The range of test resulted in an excess-air range of 18-25% (3.0-5.0% O_2) with light sooting of the combustor interior and a flame shield temperature of about 1100°F.

With the combustor length at it's shortened configuration, slots were added to the choke ring. The addition of recirculation slots to the flame tube or choke ring reduces NOx emissions and tends to keep the flame tube wall cleaner. The effects of these slots are very dependent upon size and location. With very large slots flame stability can be affected.. The choke ring slots (about 0.625" long) in these tests were equi-spaced with each occupying about 20^{o} around the outer periphery of the choke ring. The configuration was tested at excess-air of about 20% (3.5% O_2) and resulted in a light soot formation of the combustor interior and a flame shield temperature of about 1100^{o}F.

Pressure measurements were made inside of the flame tube, along the wall, under firing conditions at two combustion air fan pressure levels, 5.8 and 8.2 inches WC. The results of this exploration are shown in Figure 3.

With the pressure profile largely negative within the combustor, as shown in Figure 3, and slightly positive in the chamber, recirculation flow from the combustion chamber was expected back through slots in the choke ring. Several combustion experiments were conducted, each at two levels of combustion air fan pressure and varying O_2 levels. At various stages, modifications were made to the choke ring which involved enlargement of the slots in terms of width and length along the choke ring periphery.

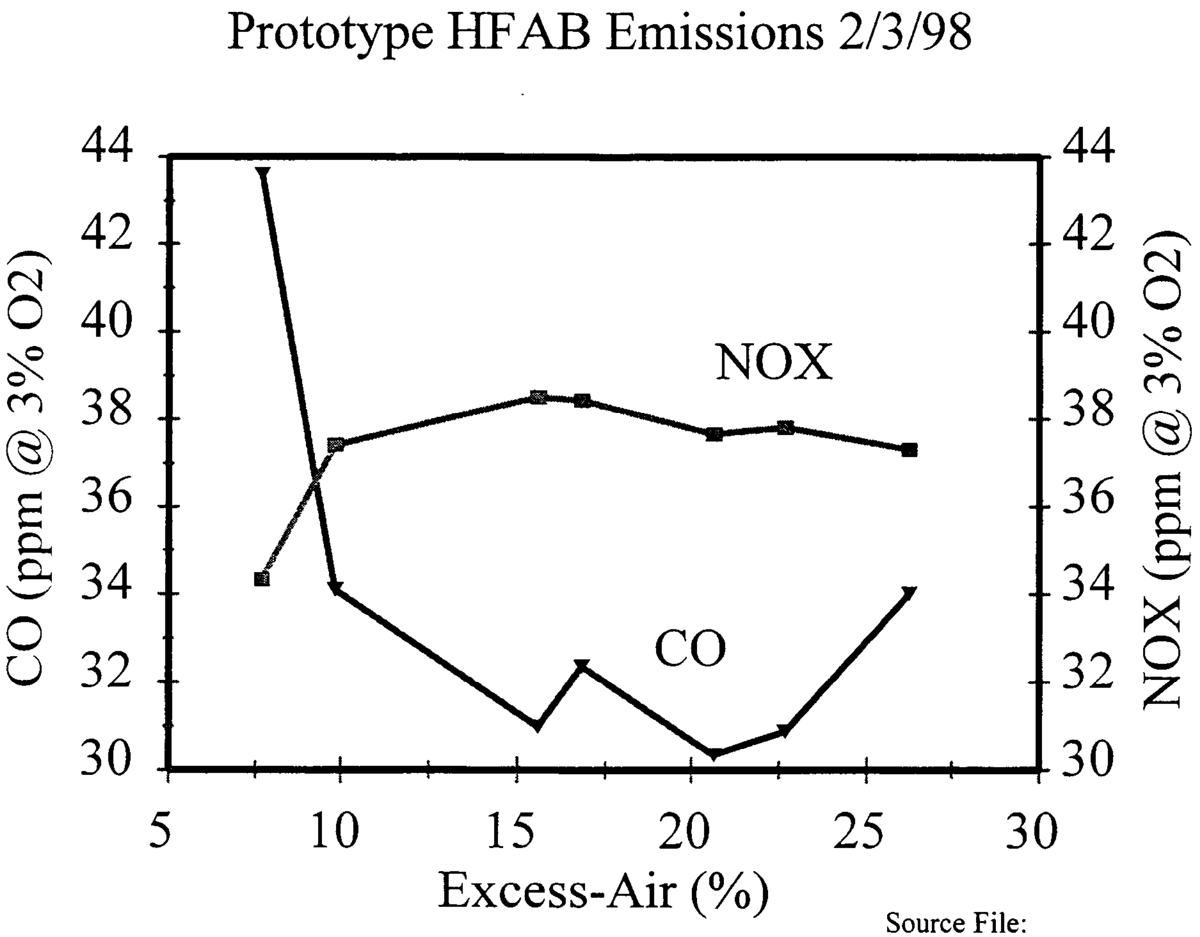


File Source:
walpress.wb2

Figure 3 - Combustion wall pressure inside of the flame tube at various distances from the choke ring. Data taken during burner operation.

As of the present time testing of the HFAB prototype is continuuing primarily to determine the location of the recirculation slots which provides the best compromise between flame stability, NO_x, low excess air capability, and head soot deposits.

Emission testing of HFAB is conducted as a matter of course in this work.. Accurate measurements of excess-air (flue gas O_2), CO, and NO_x were taken over a range of burner operating conditions. The results with one recent configuration, firing into a two-section cast iron boiler are plotted in Figure 4.



Source File:
hfab2398

Figure 4 - Plot of CO and NO_x as a function of excess-air for the prototype HFAB

Future Development

Further exploration of the HFAB operation and application is planned. Ignition is an important issue and optimal positioning of the electrode system is key to resolving this for reliable operation. Fuel system design features that require exploration include low electric power requirements and long term reliability. The design is at a point where packaging of the prototype configuration for demonstration is complete. Application testing is starting that will include furnace, boiler, and water heating equipment. This may include non-integrated burner applications such as combustor/inducer in furnace and boiler packages. We are also planning to scale up the results very shortly to 0.4 gallons per hour and conduct some limited field testing.

References

[1] Butcher, Thomas A., Advanced Oil Burner for Residential Heating - Development Report, Informal Report BNL-62077, July 1995

[2] Butcher, T.A., Krajewski, R.F., Leigh, R., Celebi, Y., Fisher, L., Kamath, B., Residential Oil Burners with Low Input and Two-Stage Firing, ASHRAE Paper PH-97-13-4, January 1997

[3] Butcher, T.A., Development of a Low Pressure, Air-Atomized Oil Burner with High Atomizer Air Flow, Informal Report BNL [Draft]

Paper No. 98-04

Progress in the Development of Self Tuning Oil Burners

Roger J. McDonald, BNL, and Richard Krajewski, P.E., BNL

Progress in the Development of Self-Tuning Oil Burners

Roger J. McDonald, BNL Project Engineer
Richard F. Krajewski, BNL Project Engineer

Introduction and Background

BNL has initiated a project with the target of developing a self-adjusting (automatic tuning) oil burner. In defining this project several approaches have been given consideration. At present, the project has been restricted in scope by the over riding cost issues attached with different concepts. Even in looking at the problem in this way, cost will ultimately be a major hurdle to any concept proposed in the price sensitive field of residential oil burner manufacture. The concept is not new and has been discussed by many members of the oil heat industry over the years. It is however very difficult to develop an affordable technology with a high level of reliability and dependability.

In larger systems, commercial and industrial scale, the idea has become a reality. The savings in maintenance and fuel costs associated with combustion systems used in industrial manufacturing facilities, hospitals, and commercial buildings are such that systems designed for automated control are now practical and cost effective. In general, these concepts have taken the approach of monitoring the oxygen content of the combustion products and adjusting the burner by means of a electro-mechanical actuator to adjust the air-fuel ratio of the combustion process. Various sensors and systems have been designed by different manufacturers to measure the oxygen content in the exhaust stream. Likewise, different means are employed to adjust the burner to reach the desired air to fuel ratio. These oxygen based systems require either a sampling system or a oxygen probe be placed into the exhaust gas stream. One manufacturer has very recently introduced a system that uses a unique optical scanner to monitor the flame using a controller that can interface with the burner via a linear linkage activator component. This system looks right into the flame through a sight port. It monitors two constituents in the targeted flame and the system maintains the efficiency ratio.

Oil Heat Equipment Manufacturer's Viewpoints

BNL has gathered guidance and direction from the oil heat industry including responses to an oil heat trade journal's survey of several leading oil heat equipment manufacturers regarding the self-adjusting system concept. The following quotes are from that survey as published by the Yankee Oilman Magazine.

The first question was, **"Do you feel that self-adjusting controls will be accepted in the market place?"** The responses ranged from a simple, "Yes. Must be simple and reliable." to comments such as, "Yes. The acceptance of such a *self-adjust* control would depend partly upon its simplicity - should be able to be installed and/or set up by an average plumbing contractor; its reliability - must be essentially 100% (IE., fail in the safe mode), and its cost should show a quick payback." The issue of who pays for the technology was brought out more than once. Should it be the consumer, the refinery, or the oil dealer. "Does the consumer pay the price for varying service or inconsistent oil quality? Or does the refinery or dealer absorb the costs to remain competitive?"

The second question was, **"What do you see as the advantage / disadvantage of self-adjusting controls?"** "Advantage is maintaining clean and proper combustion. Disadvantage will be control reliability." "It would make it practical to run closer to a stoichiometric air/fuel ratio thus saving energy, and in the long run for soot and for corrosion of heating equipment. Also hopefully eliminating litigation for soot cleaning of homes." "It would allow the fuel oil industry to compete with other fuels by reducing emissions and reduce operating and maintenance costs to the consumer." "The greatest advantage is control over the unknown. Once the unit is installed or has its annual service, nothing is known until a problem arises - a lockout or worse. A heating system should operate trouble-free and this type of device would aid in this area."

The last question was, "**What kind of engineering hurdles have to be overcome in order to make the system safe and practical for homeowner use?**" The responses included, "Field experience." "The hurdles to overcome are: 1. Develop a reliable sensor with little or no drift to measure air / fuel ratio; 2. Develop reliable servo system to respond to the air / fuel changes; 3. Keep the cost down to be reasonably affordable by the homeowner; 4. Keep the control system simple." "Engineering hurdles should not present a problem, not with the resources that are available to us. Education and technical (knowledge) will be our prime concern as an OEM." "Nothing. Other than typical testing in the variety of appliances and combustion chambers we see to ensure across the board utilization (or point out where it won't work), plus UL approval and field acceptance."

The consensus of the responses being that yes it can be accomplished. The benefits can be significant. The questions remain: can it be done at reasonable cost and in a simple easy to implement design? There are reasons why it hasn't yet been done. If it was simple it would already be in the marketplace.

BNL has planned the project accordingly and will attempt to resolve these questions and issues in a logical sequence of smaller steps. First will be sensor technology. Second will be issues of mechanical actuators (servo systems). Third will be the question of controlling the process. Cost will be factored through-out the process. However, cost will not necessarily be a considered factor that will cause BNL to kill a concept prior to engineering developmental tests. An example would be the use of a prototype sensor technology that can not be had for a reasonable price because it has not yet been sold in sufficient quantities to account for quantity price reductions.

Oxygen Measurement System Selection

In selecting an oxygen measurement system BNL has, in the past, considered various sensor technologies including processes based on paramagnetic, electro-chemical, and zirconium oxide detection. The paramagnetic is the most accurate and dependable but not very practical due to the cost, sampling system, and complexity limiting it to only those types of applications where higher cost and sampling system maintenance are not at issue. The electro-chemical approach is quite accurate but requires periodic replacement of the sensor cell which is slowly consumed (oxidized) over its lifetime of about one year of intermittent use. Most portable flue gas analyzers use the electro-chemical type of oxygen sensing technology. The last category of common oxygen sensors are those based on zirconium oxide. The type used in the automotive industry.

Zirconium Oxide Oxygen Sensor Characteristics

The basic output characteristics of a zirconium oxide sensor are illustrated in Figure 1. A sensor nominally consists of a pair of porous platinum electrodes separated by a layer of zirconium oxide. At high temperatures the solid zirconium ceramic becomes conductive to oxygen ions ($O^=$). An external voltage is produced which is related to the flue gas oxygen content, the reference gas oxygen constant, and the temperature by the Nernst equation. At stoichiometric fuel/air ratio (0% flue gas oxygen) there is a large change in the output voltage, termed the lambda jump, which is somewhat insensitive to sensor temperature. This behavior is used in automotive applications to control the air/fuel ratio near stoichiometric in engines equipped with catalytic converters. These systems can be designed with heaters (used with lean burn engines) or without.

In looking at the problem of developing a self-tuning burner BNL has recently investigated four candidate oxygen senors based on zirconium oxide technology. These included an unheated automotive lambda sensor, a heated automotive lambda sensor, a duel chambered Honeywell-Gasmodul heated sensor, and a system with temperature compensated probe made by Australian Oxytrol Systems Pty. Ltd..

The oxygen sensors under examination are of a design applied to current automobile and combustion system emission controls. These take advantage of one of two electrochemical mechanisms of Zirconium Oxide (ZrO_2) when the material is heated or exposed to a gas stream at elevated temperatures. The automotive sensors are commonly provided in the un-heated configuration but the addition of a heating element within the sensor allows for the application in colder regions of the engine exhaust stream. The gas stream temperatures range from below 300 C (572 F), with heat added to the cell material, to above 650 C (1202 F), without heat added to the material.

One of the characteristics is that at high temperature the material partly dissociates to produce mobile negative oxygen ions which normally move at random. When a DC voltage is then applied across the material, the ions can be transported through it, liberating oxygen at the anode. The application of this characteristic is as a pump cell to transfer oxygen ions.

Another characteristic of ZrO_2 at high temperatures is that any difference in oxygen pressure across it generates an electrical potential, known as a Nernst voltage. The Nernst equation is:

$$V=0.0119 \times (T) \times [\ \ln\ (pO_2)R/(pO_2)F\ ]$$

where

V = output voltage
T = temperature (° R)
$(pO_2)R$ = oxygen partial pressure on the reference (ambient) side
$(pO_2)F$ = oxygen partial pressure on the flue gas side

This voltage is proportional to the natural logarithm of the ratio of the oxygen partial pressures on either side of the material. The application of this characteristic is as a Nernst-concentration cell to measure the relative oxygen concentration of two gas mixtures, one normally is the ambient air (20.9 % O_2) and the other is the mixture of unknown oxygen content in question.

Two Wire (Unheated) and Three/Four Wire (Heated) Sensors

These sensors have been called the lambda sensor and used to measure the relative concentration of oxygen in combustion gases when compared to that of ambient air. Lambda (λ) is the fuel independent Air-Fuel (A/F) ratio. As is illustrated in Figure 1, an output voltage, called the Nernst voltage equal to about 0.8 volts, is generated by the sensor in a fuel rich exhaust stream where λ = 0.6. At about λ = 0.95 and 0.75 volts there is a downward knee in the (voltage versus λ) output and the voltage falls rapidly to about 0.4 volts at λ = 1.0 or stoichiometric conditions. At the early fuel lean conditions, as about λ = 1.05 at 0.15 volts, the output again goes through a knee and levels off to a λ = 1.3 and a voltage of 0.1 volts.

Dynamic Oxygen Sensor (GMS-10, Honeywell-Gasmodul BV)

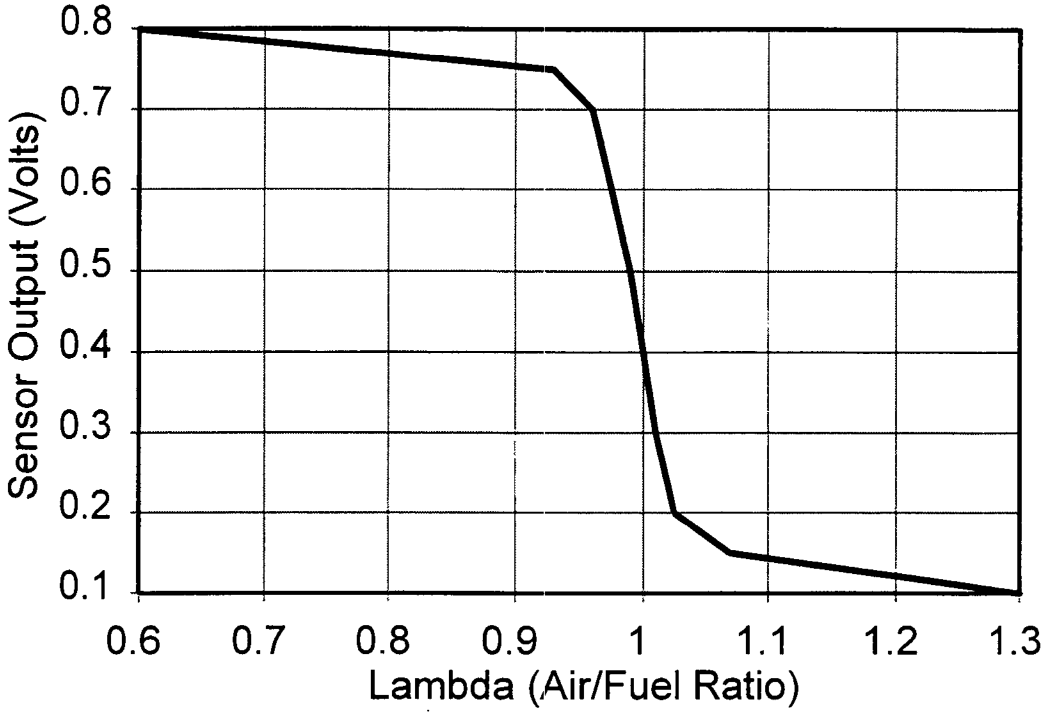
The sensor consists of two identical ZrO_2 disks with porous platinum electrodes and three platinum rings sandwiched alternately together, Figure 2. The outer platinum rings, which provide the sensors electrical contacts, are each covered by AL_2O_3 (alumina) filters, and the entire assembly, with a heating coil, is housed in shell of porous stainless steel.

The sensors operation is cyclic. One of the two ZrO_2 disks is connected to a reversible current source. Working as an oxygen pump, it evacuates the oxygen from the chamber between the disks. Starting at some level (first reference level), a Nernst voltage is generated by the other ZrO_2 disk which increases as the pump evacuates the chamber. At a second pre-set voltage level the current to the pump is reversed and the chamber is re-pressurized until the Nernst voltage drops to the starting level at which the cycle is repeated. The Nernst voltage across the sensing ZrO_2 disk is used to both control the sensor and to generate its output to the control system which detects the duration of the pumping cycle between voltage reference levels. This duration is a measure of the partial pressure of the ambient (combustion product) oxygen. The dynamic oxygen sensor is small, measuring 2 x 2 x 1.5 mm.

Temperature Compensated Sensor (Type DL, Australian Oxytrol Systems Pty. Ltd.)

The sensor consists of a special ZrO_2 pellet sensor with a Type-R, platinum-13% rhodium / platinum, high temperature thermocouple. The pellet is bonded permanently to an impervious alumina tube by a high temperature eutectic welding operation. The protruding portion of the special pellet is coated with porous platinum and carries circumferential grooves to facilitate the attachment of the external electrode. Likewise the pellet end within the sensor is also coated with porous platinum and connected to the inner electrode. The thermocouple is mounted inside the alumina tube with the tip spring loaded against the pellet for measurement of the sensor temperature.

Figure 1 - Typical (Oxygen) Sensor



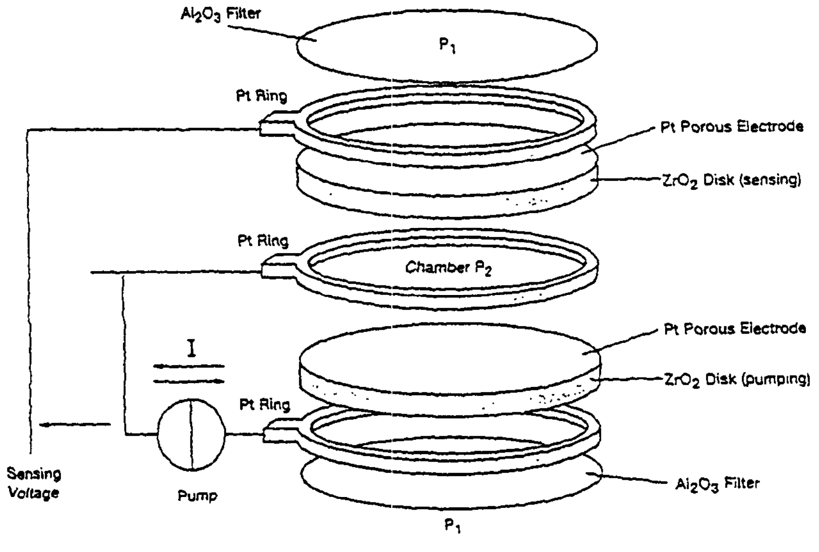


Figure 2: Honeywell-Gasmodul BV Dual Chamber Zirconium Oxide Oygen Sensor

Preliminary Oxygen Sensor Test Results

The Australian Oxytrol system was evaluated by BNL. The tests results indicated that the oxygen levels determined by the probe were consistently lower than those measured with the laboratory's standard paramagnetic oxygen measurement system. The unheated automotive oxygen sensor was tested by installing one directly in the combustion chamber of a cast iron boiler. The sensor required over five minutes of burner operation to heat up before useful signals were obtained. The operation once steady state conditions were established was quite reasonable but the time constant of the sensor was deemed to be too slow to provide a useful and reliable input for a self-tuning system. The heated automotive sensor can be made to work but is quite expensive and is already in mass production so future cost reductions are unlikely. Test results with the Honeywell Centra GMS-10 and Oxymac control circuit were excellent and BNL elected to pursue this option in its initial development efforts towards a self-tuning oil burner.

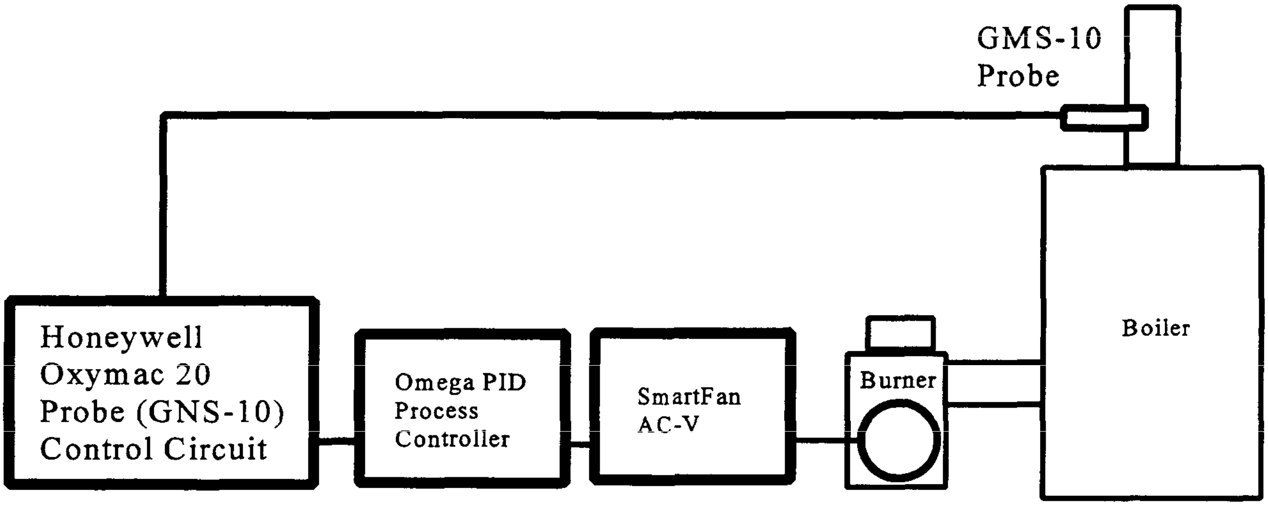


Figure 3: Self Tuning Oil Burner Diagram

Self-Tuning Oil Burner Prototype Development

While research was progressing on the BNL Fan Atomized Burner development, work on the self tuning project was focused on the concept of a self tuning conventional burner using a flame retention head oil burner. The concept pursued was the use of the Honeywell Centra GMS-10 zirconium oxide sensor and control circuit linked by a microprocessor based PID control unit manufactured by Omega Engineering feeding a control signal to a fan speed controller made by Control Resources Incorporated, SmartFan AC-V which in turn provided the power for the PSC motor of a modern high static pressure flame retention head burner as shown in Figure 3.

The first step was to determine the characteristics of the SmartFan AC-V control when coupled with the burner. Figure 4 is a plot of the AC voltage supplied to the oil burners PSC motor plotted on the Y1 axis and also the corresponding flue gas percent oxygen plotted on the Y2 axis. This data was obtained as a function of input DC voltage to the controller using a regulated variable DC voltage source. This test was conducted with the burner properly adjusted within the output voltage range of 77 to 120 volts AC. At a voltage output of 60 volts AC the smoke level was measured between a trace to number one on the Bacharach scale and at 50 volts AC the smoke was measured to be a Bacharach number 1. When a voltage below 2.65 DC volts was input there was an insufficient AC output, less than 50 volts, from the AC-V controller to keep the oil burners motor operating.

The operating characteristics of the Honeywell Centra GMS-10 probe and Oxymac 20 control circuit are presented in Figure 5. The oxygen probe and controller circuit provide excellent agreement with the laboratory paramagnetic analyzer when corrected for wet (GMS-10) versus dry (paramagnetic) measurements. The GMS-10 probe has a response time of less than eight seconds to a step change in oxygen content.

The process controller provides for inputs of a process variable, in this case the % oxygen signal from the GMS-10/Oxymac 20 system, a reference set point variable, and a control output, the DC voltage signal which is used as an input to the SmartFan AC-V controller. The output of the controller is a function of the error which is the deviation between the process signal (%oxygen voltage signal) and the set point value. The Omega PID controller was one that could be used in any of three basic functions. The proportional controller could be used with the integral and derivative functions either turned on or off. Along with many other functions which could be turned on or off, the main variables of the controller, the proportional band value, integral reset value, and derivative rate value could all be varied over a wide rand of settings.

Once the entire system was assembled the major issue was one of gaining some level of understanding the PID controller. The self tuning burner system tends to result in either a saturated control mode or a unstable operating condition. In the saturated mode the system can not reach the set point value because it is either too high or too low. The result being the oil burner motor remains at a constant high or low speed. In the unstable mode the motor speed cycles rather quickly between the full and minimum speed conditions. A major part of the problem is the very narrow oxygen range that can be obtained with the motor/control range.

There were many different test runs conducted with a rather limited level of success. The data contained on Chart 1 illustrates some of the more stable responses to a sudden restriction of the combustion air within the limits that the system could provide control. The control output signal is the top chart recorder trace and the process variable in the lower chart trace. In the first section of the chart a sudden removal of the restriction provides a controlled response that although swinging between high levels of motor speed and a saturation at the low end does provide a decay of the high speed levels that dampens out within 2 minutes to the minimum output level. In the second part of the chart a restriction is put in place and the controller responds in a more acceptable manner (no violent cyclic swings in speed control) within four minutes and then provides adjustment of the motor speed to maintain the process variable signal (% oxygen) at a fixed level. A subsequent experiment using the fixed voltage source to drive the AC-V control to furnish a constant fan speed provided some insight into the changes in the control output observed. The oxygen was changing slightly up and down over time due to changes in draft or other real physical conditions. The PID controller was compensating for these minor fluctuations. The conclusions drawn were that the PID controller was unable to provide the level of control desired based on the narrow range of the process variable signal (about a 1 % oxygen range) and the limited controllable range of the motor speed which is in fact rather non-linear and constrained by its design

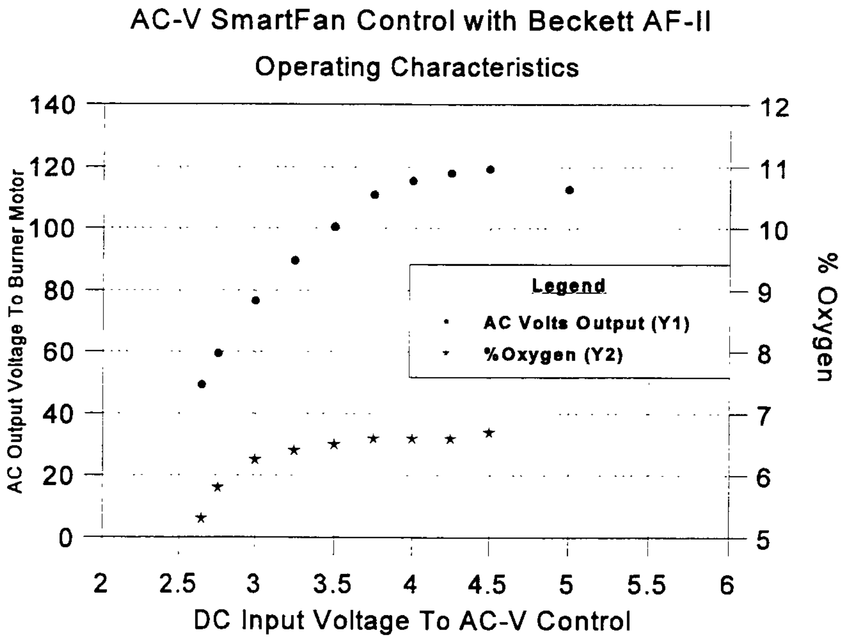


Figure 4: SmartFan AC-V Operating Characteristics AC Output & Burner % Oxygen

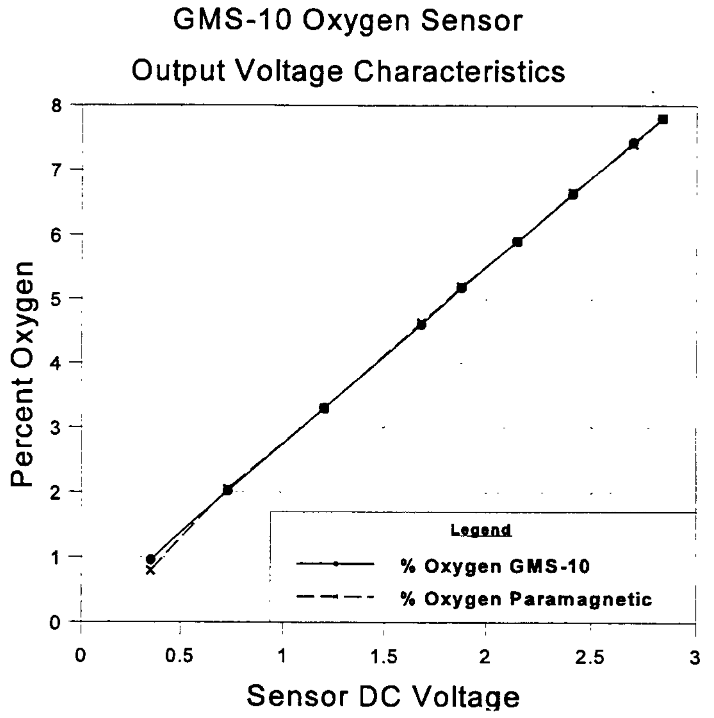
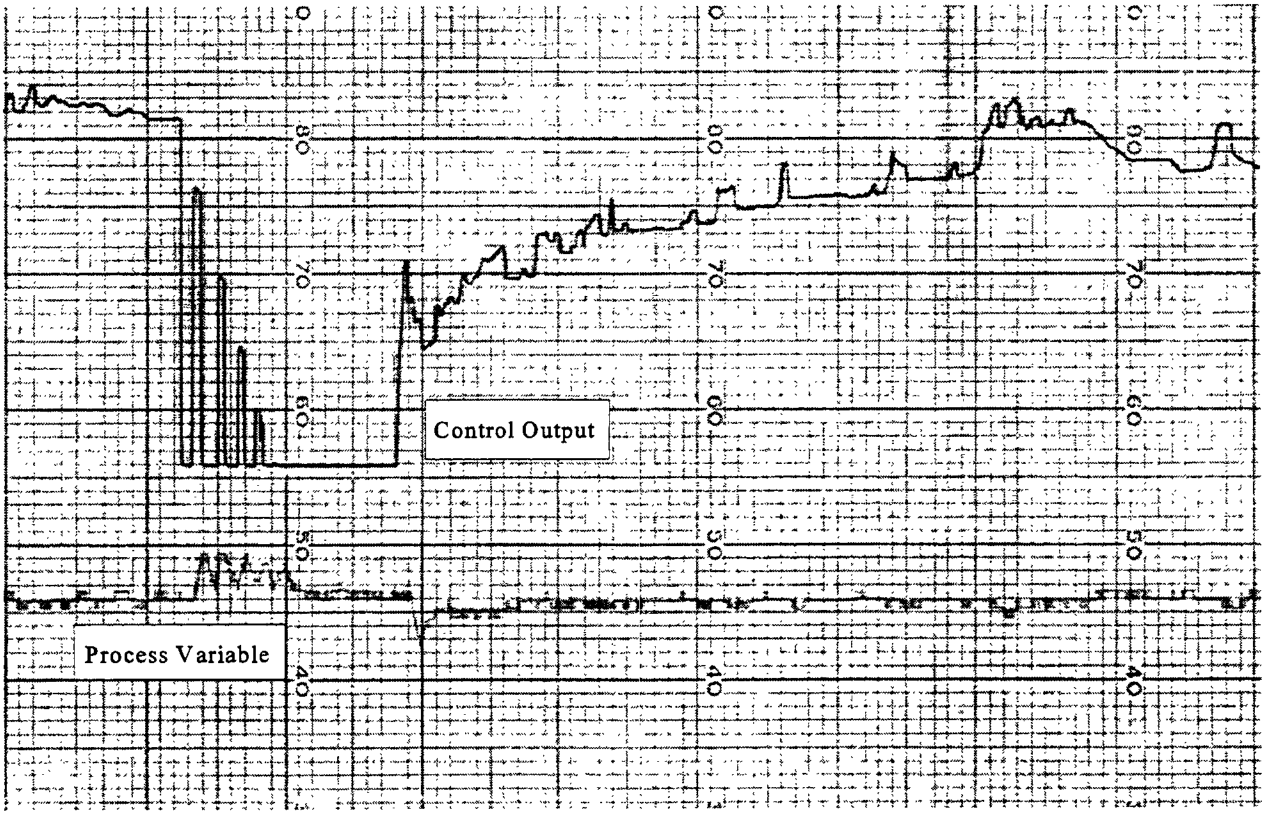


Figure 5: Honeywell Centra GMS-10 Oxygen Sensor Characteristics

Work in Progress

As the project continues, BNL is investigating alternative design approaches which based on what we now know should be more fruitful. In looking at the problems we encountered thus far it seems a wider range of control is necessary for stability in the control of the process. It appears this is unlikely to come on the air side of the equation. To accomplish this we are investigating mechanisms to provide an actuator that would throttle the fuel rather than the air. To do this we are looking into a gasoline type of throttle body injector as a means to control fuel flow. This in conjunction with an oil burner design, which incorporates a low pressure fuel atomization technique, should provide a wide range of fuel input rate. The burner should operate with a stable flame with a combustion process that is will not be sensitive to the changes in fuel flow rate.



[O-100% Chart Scale Translates to 0.0-5.0 D.C.Volt Range, Chart Image is Truncated]

Chart 1: Chart Recorder Output Self-Tuning Oil Burner Control Output and Process Variable

Reference:

Thomas A. Butcher, Ph.D., Performance Control Strategies for Oil-Fired Residential Heating Systems - Project Report, Formal report BNL 52250, July 1990.

Paper No. 98-05

Application of HFAB Technology to the Development of a 500 Watt Thermophotovoltaic (TPV) Power System

Dr. Thomas A. Butcher, Ph.D., BNL

Application of HFAB Technology to the Development of a 500 Watt Thermophotovoltaic (TPV) Power System

Dr. Thomas A. Butcher, Ph.D.

Introduction

Thermophotovoltaics (TPV) is a technology for making electric power from a high temperature heat source. Essentially, the source heats a surface which glows (emits light energy), the emitted light hits photocells, and power is produced. Oil and gas flames are obviously good heat sources for a TPV system. A great deal of important development work has also been aimed at the use of radioisotope sources in space applications.

Advantages of TPV over other methods of producing electric power include: no moving parts, low noise, light weight, and reliability. Work on TPV technology started in the 1960's and 1970's. Interest fell off after that time due to low conversion efficiency. At the end of the 1980's interest in this technology again became quite strong due, in part, to improvements in materials and photocells. With fuel-fired TPV systems there are currently two basic applications receiving attention. The first is small, remote and/or portable electric power generation primarily for electronics, the second is residential heating appliances with integral power generation [1,2]. This second application is sometimes called microcogeneration or self-powered appliances.

The basic components of a fuel-fired TPV system include:

- burner
- emitter
- optical filter (in some systems)
- photocells
- heat recovery

Two basic types of emitter surfaces have been used. The simplest is often called a “black body” emitter (actually it’s closer to gray) which emits light over a very wide range of wavelengths. In this case only a portion of the emitted light is suitable for conversion to electricity by the photocell. An optical filter is used to prevent out-of-band light from hitting the photocells. This out-of-band radiation is reflected at the filter and returns to the emitter. The second type used is selective emitters which have a high emissivity in a narrow band, matched to the photocell characteristics. Familiar examples of selective emitters include limelights used in the 19th century for theater lighting and mantles commonly used in camping lanterns [3]. This mantle, like selective emitter materials used currently in TPV applications, is a ceramic oxide. Ytterbia oxide selective emitters have emissivity peak which matches well the response of low cost silicon photocells and these have been used in TPV systems.

In gas-fired TPV applications porous surface burners have typically been used with the selective emitter material integrated with the combustion surface. An advantage of this approach is high and uniform heat transfer rates from the flame to the emitter over the emitting surface.

With oil firing the flame can be contained inside of a non-porous combustion chamber which also serves as the emitter. Many of the systems currently under development involve firing rates much lower than those which can be achieved with conventional, pressure-atomized retention head oil burners. In past and on-going development projects advanced burner design methods have been employed to enable oil-firing at the very low rates required. This includes ultrasonic atomization, vaporizing systems, electrostatic atomization, and the Babington atomizer. Some background on these methods can be found in References 4 and 5.

For the photocells, low cost silicon photodiodes are popular candidates. Alternative options are available which provide better response at longer wavelengths and enable greater power densities. Figure 1 shows the emission curve from a black body emitter held at a temperature of 2600 F. Also shown are the response range for the common silicon cell and an alternative, a gallium antimonide (GaSb) cell. The GaSb cell response is shown to extend to longer wavelengths where the emission intensity is higher [6,7,8].

The total emissive power of a radiative source decreases with the absolute temperature raised to the fourth power. TPV systems can really only extract electric power at high temperatures, leaving exhaust gas from the TPV generator with a high energy content. Two approaches have been taken for recovering this exhaust energy. For self-powered heating appliances this energy is simply applied to the thermal load - space heating or hot water. In this case only a small portion of the input energy is converted to electric power. For example, assuming an oil-fired system with a firing rate of 1 gallon per hour, and only 5% conversion to electricity, power would be produced at a rate of 2 kW. The overall system efficiency would be as high as is typical for current heating appliances and depend primarily on the exhaust gas temperature and excess air.

The second approach to recovering heat after the TPV generator involves a recuperator to preheat incoming combustion air. This method is applied to generators which have electric power as the only output - portable generators for example.

Development of a 500 Watt TPV Generator

BNL is currently participating in the development of a 500 watt electric power generator system for military applications. This work is sponsored by the U.S. Department of Defense (DARPA /U.S. Army CECOM in Fort Belvoir, Va). Cooperating team members include EDTEK, Inc. in Seattle, WA and The Charters Group, Inc. in Friday Harbor, WA. The objective is the development of a portable unit to be used for recharging batteries during field operations. The target system will weigh less than 15 pounds, have an efficiency (fuel to electric power) over 15%, and be fired with diesel fuel.

The system selected by the team for development incorporates the following major features:

- combustion system based on the Fan-Atomized Burner developed at BNL [9];
- a silicon carbide, non-porous "blackbody" emitter/combustion chamber;
- EDTEK resonant metal mesh IR filters and GaSb cells [10];
- a high temperature recuperator.

An overall heat balance for the system is provided in Figure 2. The system as shown produces 500 watts of net power plus 95 watts for auxiliary components including a solenoid type fuel pump, a brushless DC combustion air fan, two small brushless DC fans which provide air over the back end of the photocells, and the controls. In this system, since power is being generated at fairly low efficiency, these auxiliary electric power requirements have a very significant impact on overall system efficiency. The level of 95 watts has been only estimated for this heat balance. The project team is working to select components which can minimize power draw and it is expected that the actual internal load will be about half of this level. In the photocells about 1/3 of the light energy which strikes the cell surfaces is converted to electric power. The remainder must be rejected to cooling air from the back of the cells. This load is 2 • (95+500) or 1190 watts. In the cell area additional thermal losses of 347 watts have been estimated.

Silicon carbide has been selected as the emitter material because of its high temperature capability, high thermal conductivity, high emissivity, and resistance to damage under thermal shock. The design operating temperature for the emitter is 2550 F. Based on heat transfer estimates within the combustion chamber it has been estimated that the gas temperature exiting the chamber and entering the recuperator will be 2732 F. The table included as part of Figure 1 shows overall system performance parameters as a function of recuperator effectiveness. Effectiveness is defined as the rate of heat transfer in the recuperator divided by the maximum theoretical recuperator heat transfer. The maximum heat transfer rate occurs when the air temperature leaving the recuperator is equal to the gas temperature entering and this would occur only in a perfectly insulated recuperator with infinite heat transfer area. In actual systems the recuperator effectiveness can be calculated as:

$$\varepsilon = \frac{(Tairout - Tairin)}{(Tgasin - Tairin)} \cdot 100$$

where:

Tairout =	temperature of preheated air leaving the recuperator and entering the burner
Tairin =	temperature of ambient air
Tgasin =	temperature of combustion products leaving the combustion chamber and entering the recuperator

From the table in Figure 2 it is clear that overall system efficiency can be increased by increasing the area of the recuperator and so increasing effectiveness. This has very serious consequences, however, for the materials used in the recuperator. With ε below about 70%, and air preheat temperatures under 2000 F it is possible to consider use of high temperature metal alloys. Higher levels of preheat will require ceramic heat exchangers. The current design approach in the program calls for a metal alloy recuperator with ceramic protective inserts at the hot end to keep metal temperatures within acceptable limits. The recuperator consists of simple concentric annular passages and flow is laminar.

As shown in Figure 2 the firing rates required are very low - about 0.07 gallons per hour, (about ½ of a pint per hour). The burner to be used is a modification of the FAB burner as discussed above. The combustion chamber (emitter) has a diameter of 4 inches and a length of 5 inches. The chamber is configured for reverse flow. The burner is located on the axis of the cylinder and exhaust gas ports are located concentrically around the burner on the same wall. A very important consideration in the development of the system is the heat flux between the flame and the inner surface of the cylindrical emitter. The average flux must be high enough to match the design power draw from the cells. In addition the flux must be uniform along the emitter length to provide uniform current in the cells. BNL is using CFD simulations to assist in the design of the chamber internal geometry to meet these goals.

While the design firing rate, 0.07 gallons-per-hour is much smaller than conventional burners it only represents the maximum planned input for this system. In many cases the actual power draw from the system will be less than 500 watts and some consideration is being given to operation of the burner at lower rates. A major challenge for any burner to be used in this application is to be able to fire into an extremely hot combustion chamber with such high levels of air preheat. A continuous fuel cooling loop is used in our current design to prevent coke formation at the nozzle tip.

Currently the system design is being developed in parallel with prototype testing. A first complete system test is scheduled for summer of 1998. In combustion trials done to date prototype burners have been operated and found to perform well with a turndown of 2 to 1.

Conclusions

Thermophotovoltaics technology is an interesting area which is rapidly developing and could lead to the commercialization of some very innovative heating appliance concepts. While much of the effort is being placed on gas-fired systems, oil can also be used in these systems. In remote or portable applications oil is the fuel of choice. While TPV is likely to require a significant time before development work leads to commercial heating products the ongoing R&D work can have important benefits in the near term for the oil heat industry. The most relevant areas here may be the increased understanding of oil combustion processes and development of advanced, novel burner concepts.

References

1. Block, L., Daugirda, P., and Goldstein, M. Thermophotovoltaics: A new cogeneration technology for gas appliances, IEEE Transactions on Industry Applications, 28,1 (1992).

2. Krist, K. GRI Research on thermophotovoltaics, The first NREL conference on thermophotovoltaic generation of electricity - AIP conference proceedings 321, American Institiute of Physics, Woodbury, N.Y. (1994).

3. Nelson, R.E. Thermophotovoltaic emitter development, The first NREL conference on thermophotovoltaic generation of electricity - AIP conference proceedings 321, American Institiute of Physics, Woodbury, N.Y. (1994).

4. Locklin, D.W., Hazard, H.R. Technology for the development of high-efficiency oil-fired residential heating equipment, Battelle Colombus Laboratories for BNL, BNL 51325, June 1980.

5. Krishna, C.R., Butcher, T. and McDonald, R. Review of atomization and soot formation for advanced residential oil burner systems. BNL 52173, December 1987.

6. Day, A.C., Horne, W.E., and Morgan, M.D. Application of the GaSb solar cell in isotope-heated power systems, IEEE (1990)

7. Fraas, L., Ballantyne, R., Samara, J., and Seal, M. A thermophotovoltaic electric generator using GaSb cells with a hydrocarbon burner, First WCPEC, Dec 5-9, 1994, Hawaii IEEE (1994)

8. Couts, T.J., Wanlass, M.W., Ward, J.S. and Johnson, S. A review of recent advances in thermophotovoltaics, 25th PVSC, May 13-17, 1996 Washington, D.C.

9. Butcher, T. Advanced oil burner for residential heating - development report, BNL Informal Report BNL-62077 (July 1995).

10. Horne, W.E., Morgan, M.D., and Sundarum, V.S. IR filters for TPV converter modules. The second NREL conference on thermophotovoltaic generation of electricity - AIP conference proceedings 321, American Institiute of Physics, Woodbury, N.Y. (1995).

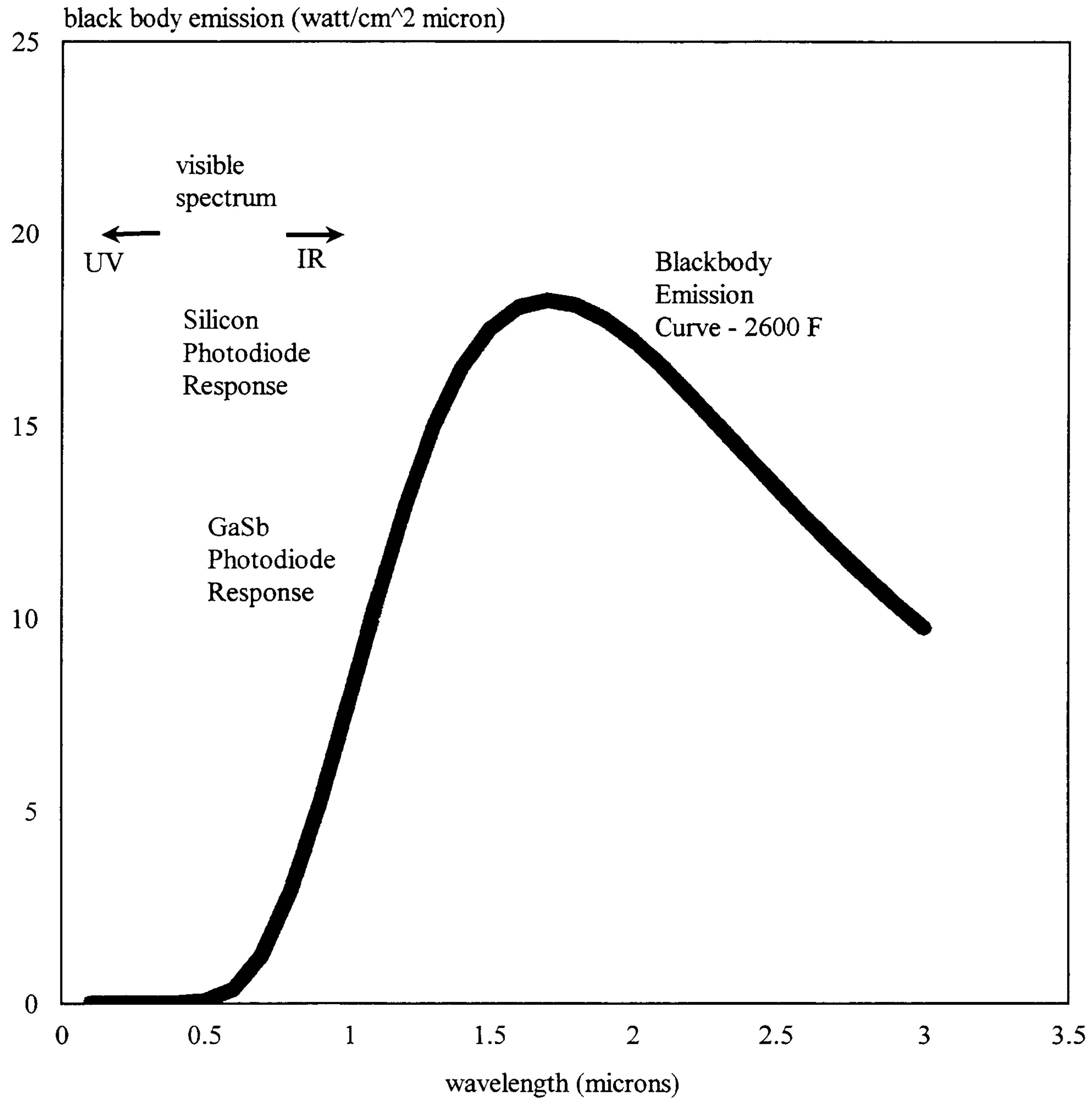
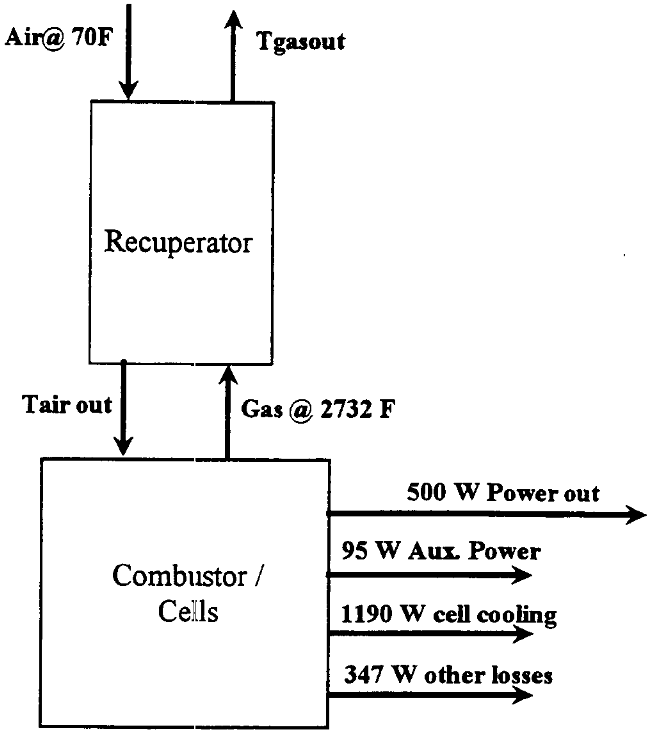


Figure 1. Illustration of black body emission curve at 2600 F and wavelength range over which silicon photodiodes and GaSb photodiodes respond



Recuperator effectiveness (%)	T air out (F)	T gas out (F)	Thermal Eff. (%)	input (W)	input (Btu/hr)	input (gal/hr)	System Eff. (%)
60	1670	1300	64.6	3300	11263	0.081	15.2
70	1936	1058	70.3	3033	10351	0.074	16.5
80	2201	820	75.9	2809	9587	0.069	17.8
90	2467	580	81.6	2613	8918	0.064	19.1
95	2599	460	84.4	2526	8621	0.062	19.8
100	2732	303	88.2	2417	8249	0.059	20.7

Figure 2. Energy balance on a 500 watt , oil-fired TPV power system. Impact of recuperator effectiveness on performance.

Paper No. 98-06

Field Tests of the HeatWise *Pioneer* Oil Burner and Insight Technologies *Advanced Flame Quality Indicator (AFQI)*

Yusuf Celebi, BNL, Dr. Thomas A. Butcher, Ph.D., BNL, Roger J. McDonald, BNL
&
Dr. Bola Kamath, Ph.D., President
Heat Wise, Inc.
P.O. Box 662
Ridge, NY

Field Tests of the Heat Wise *Pioneer* Oil Burner and Insight Technologies *Advanced Flame Quality Indicator (AFQI)*

Yusuf Celebi, BNL, Dr. Thomas A. Butcher, BNL, Roger J. McDonald, BNL and
Dr. Bola Kamath, HeatWise, Inc.

Introduction

The HeatWise *Pioneer* oil burner is the first commercial embodiment of a new technology, the Fan Atomized Burner (FAB), which was has been developed at Brookhaven National Laboratory over the last several years. The *Pioneer* FAB is approved by Underwriters Laboratories (U.L.) to burn No. 2 fuel oil in a range from 0.3 to 0.65 gallon per hour (40,000-90,000 Btu/hr). The Insight Technologies' *Advanced Flame Quality Indicator (AFQI)* is a new product line available to the oil heat marketer to provide automatic monitoring of customer's oil heating systems which was also based on a development of BNL's Oilheat R&D Program, the patented Flame Quality Indicator. Insight Technologies has expanded upon the features originally included in the patent, which is held by the United States Department of Energy (DOE), to include remote fuel system monitoring, fill status, as well as filter condition. During the 1997 / 1998 BNL together with HeatWise and Insight Technologies initiated an extended field trial of the *Pioneer* burner using the *AFQI.*

Background

The *Pioneer* burner is the first practical burner design that is designated for use in small capacity heating appliances matching the needs of modern energy efficient homes. Firing in the range stated above it allows for new oil heating appliance designs to compete with the other major fuel choices in the small design load residential market. This market includes energy efficient single family houses, town-houses, condominiums, modular units, and mobile homes. The firing rate range is also wide enough to cover a large percentage of more conventional heating equipment and home designs as well. Having recently passed Underwriters Laboratory certification tests the burner in now being demonstrated in field tests in several homes and samples are being made available to interested boiler and furnace manufacturers for product development and application testing. At Heat Wise, the Pioneer burner production started on a limited basis in 1997, before the heating season. Currently each burner is test fired in small boilers near the production area. In parallel with the field test effort, Heat Wise is subjecting burners in the plant to a wide variety of possible field upset conditions.

The *AFQI* system is a package consisting of a central monitoring station (PC computer) with a dedicated phone line to receive incoming phone calls from individual *AFQI* units installed on oil fired hydronic boilers or furnaces and / or water heaters in the oilheat customers homes. The *AFQI* can be used to monitor the oil burner flame condition, fuel tank level, fuel filter condition, fuel delivery status and the homes k-factor (used to schedule fuel delivery), low temperature conditions in the home, primary safety control, and water spillage in the boiler run (pressure/fill valve release for example).

Test Plan

The initial plan was to install as many as ten of the Heat Wise Pioneer burners in the homes of BNL staff who utilize oil heat to provide space heating comfort in their homes. In these cases BNL would provide detailed support to the field test sites by providing instrumentation, monitoring, and service related maintenance in case of any unexpected problems. Heat Wise would build and pre-test the units prior to installation in the field. The tests would be conducted under the sponsorship of the Co-operative Research and Development Agreement (CRADA) formed between the New York State Energy Research and Development Authority (NYSERDA), DOE and BNL.

Description of Extended Field Tests Evaluation

The availability of the AFQI system was a natural for BNL to select for use in the extended field trials of the Heat Wise *Pioneer* burner. Insight Technologies and NYSERDA agreed to provide the hardware and software needed and even kindly provided BNL with a central monitoring station for the duration of the tests. BNL provided the engineering, technical talent, field test sites, and a dedicated phone line for the project. Tests in four homes were initiated in December 1997.

Early Experience Gained During Field Trials

In selecting sites for field tests an emphasis was placed on locations which are compatible with the low firing rate capability of the Pioneer burner. This includes boilers with ratings on the low end of the normal range for oil appliances to prevent condensation of flue products in the stack. Also, systems with indirect water tanks are considered the best candidates although most of the sites have, in-fact, had tankless coils for domestic hot water production. In these cases the burners were set up in advance to operate at the high end of the Pioneer range (0.5 to 0.6 gph) and no problems with capacity have been reported.

As with any new technology the major benefit of conducting a field trial the identification of areas where improvements are needed before full commercialization can proceed with a high level of product reliability. Several important lessons were learned early in this test program.

For this field test a small test production run was made to produce the various burner parts. Prior to the completion of this run and the formal start of the field tests one of the original pre-production burners was operated in the field for several months at a firing rate of 0.37 gph without problems. Some of the production components were not made exactly the same as in the original design and a decision was made to reproduce these to ensure the best burner performance. These types of common early production concerns caused some delays in the field test program.

Fuel oil delivery is another important factor in the Pioneer as with any burner. The supply of clean fuel to the burner has been assured with the use of 10 micron filters. Good results are obtained using styrene filter elements which are marketed for a reasonable price. The second part of fuel delivery is constant delivery pressure. In the tested version of the Pioneer burner a SUNTEC PRV valve or

WEBSTER OSV valve is used to maintain steady pump inlet pressure. The pressure regulator in the Pioneer system is referenced to pump suction pressure and the use of a vacuum regulating valve of this type eliminates effects of modest system changes.

Heat Wise listed the Pioneer burner with UL with very low pressure pumps (5-15 psi) developed by SUNTEC with integral solenoid valves. One of the burners in the field showed a sluggish piston and ultimately stopped. Another burner operated for four months in the heating season and slowly showed a drop in stack temperatures. When the unit was opened for inspection at the end of this period a small layer of uniform paste material had deposited on the nozzle strainer. This material had created a 2 psi pressure drop. With a low pressure fuel delivery system this is enough to affect the firing rate. Table 1, extracted in part from the Pioneer burner manual, make a comparison of the influence of pressure on firing rate. Any burner with a low pressure fuel supply system is affected to a greater degree by pressure changes.

Another area where improved performance might be readily achieved is in startup and shut down transients. Recently several nozzle shut-off devices have been introduced to the market. and these can give dramatic performance in a very efficient burner. After installation on a conventional retention head burner using Hago's new ECO valve, tests conducted by Heat Wise showed small startup and shutdown peaks in the first cycle, smaller peaks in the second cycle, and no peaks at all in subsequent cycles. The situation in the Pioneer burner is similar is ways to that in conventional, high pressure burners. This performance is due to trapped air bubbles in the line between the pump cut-off and the nozzle tip. Also, an inventory of oil stays behind after the burner is shut off in the same region. If the draft is zero and the application involves a hot chamber, dribbling of oil out into the chamber becomes a greater issue. In some appliances this problem is avoided using post purge controls of 2 minutes or even longer.

Based on field experience to date, Heat Wise has been exploring the use of a standard, 100 psi pump in combination with an in-line metering orifice and a nozzle shut-off valve. The high pressure pump will not require a separate solenoid valve. Even if the piston is slightly sluggish the flow rate will not change drastically. The oil pressure gauge and suction regulating valve can be eliminated. The accumulation of minute amounts of dirt on the nozzle strainer will not be as important a factor in reliability. With the nozzle shut-off valve transient performance can be significantly improved. Finally, use of a conventional pump has huge advantages in service - the need to carry another pump and concerns about misapplication are eliminated.

The Insight Technologies' *AFQI* system was extremely useful in allowing BNL to gauge the problem in real time as developed in the field rather than wait for a failure to occur before stepping in to diagnose the problem. In addition to providing the oilheat marketing industry with an important new tool to enhance the image of oilheat as a modern service friendly energy choice it proved itself very valuable to the equipment manufacturing industry. It provides the manufacturer with a tool to track the performance of new heating technologies during the field trial period of development which can rapidly tell you what is happening on a moment to moment basis.

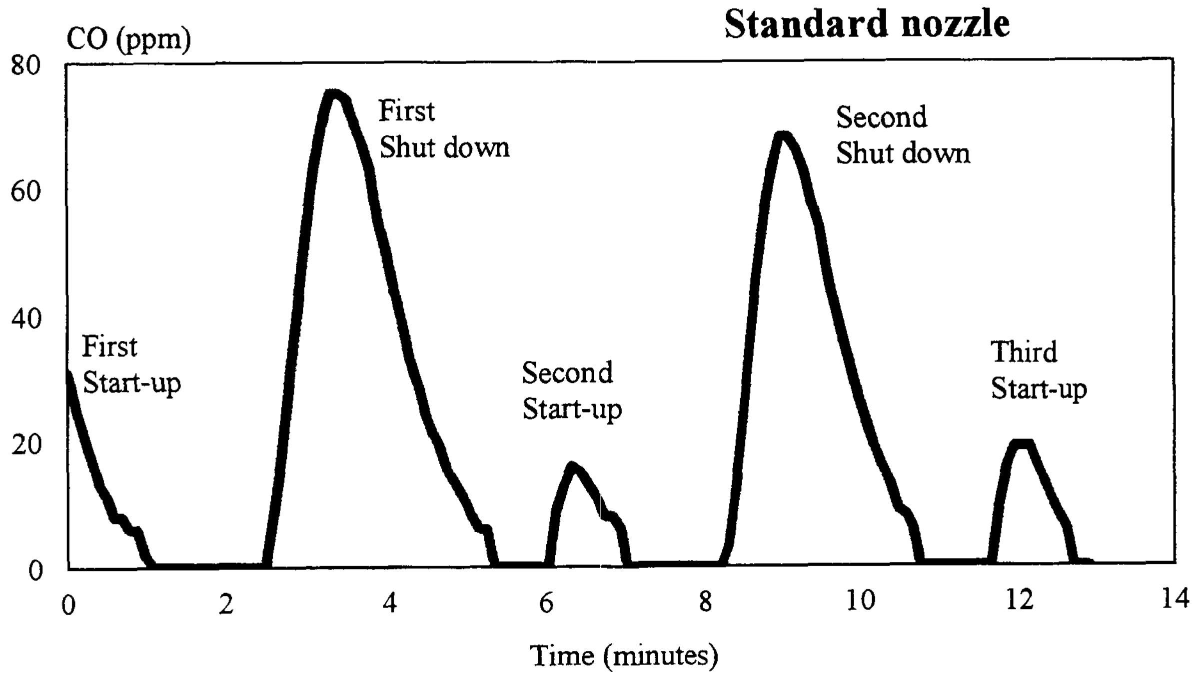
Future Plans

Field testing with the Pioneer burner is continuing through the 1997/1998 heating season and will, in fact, continue into the next heating season. Heat Wise is committed to bring this technology and the burner to the market. Various appliance manufacturers have expressed strong interest and have already made plans to develop heat exchangers specifically for low firing rates. Heat Wise has started a dealer training program and expects to begin limited installations in selected service organizations.

Table 1. Effect of Pressure on Firing Rate - Pioneer Low Pressure Nozzle and Conventional (Simplex) High Pressure Nozzle.

Pioneer Nozzles				***Simplex Nozzles***			
Two Hole Fuel Distributor		Three Hole Fuel Distributor					
PSIG	GPH	PSIG	GPH	PSIG	GPH	PSIG	GPH
2	.244	3	.45				
3	**.3**	4	.474				
4	.34	5	.53	95	.292	95	.389
5	.38	5.5	.597	**100**	**.3**	**100**	**.4**
6	.42	6.5	.605	105	.307	105	.42
		7.5	**.65**	110	.314	110	.43
		8.5	.69				
		9.5	.722			95	.633
		10	.75			**100**	**.65**
		10.5	.769			105	.67
						110	.68

Note: Numbers in bold indicate rated conditions.



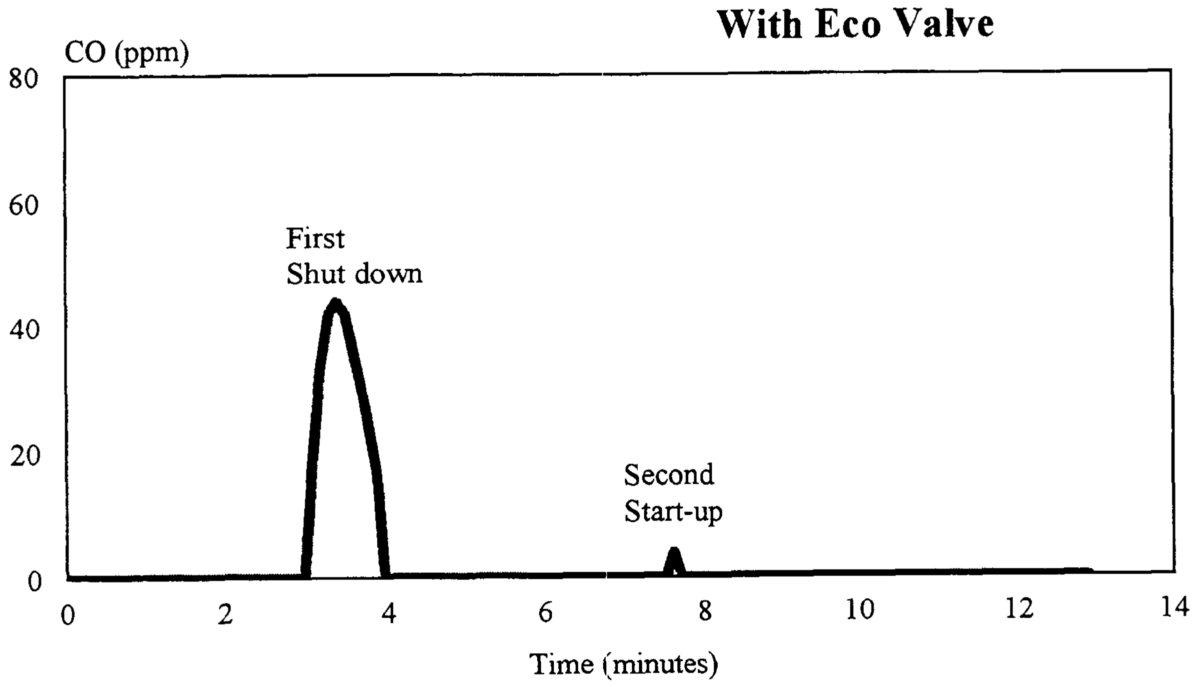


Figure 1. Comparison of startup and shut down CO transients with and without a nozzle valve. BK-1 retention head burner.

Paper No. 98-07

Expanded Use of Residential Oil Burners to Reduce Ambient Ozone and Particulate Levels by Conversion of Electric Heated Homes

John E. Batey, P.E., President
Energy Research Center, Inc.
35 Fawn Road
Easton, CT 06612

EXPANDED USE OF RESIDENTIAL OIL BURNERS TO REDUCE AMBIENT OZONE AND PARTICULATE LEVELS

John E. Batey, PE

1. SUMMARY

The information presented in this summary report is based on recent publications by the US Department of Energy, the US Environmental Protection Agency, National Laboratories, and other well-documented sources. Key points include the following.

- Recently revised USEPA Ambient Air Quality Standards for **Ozone** and **Particulate Matter** will require actions by many states to comply with the more stringent regulations. Each state environmental agency must carefully plan their actions in response to these new standards to avoid unnecessary negative impacts on consumers.
- Air emissions from residential oil burners are much lower than most other combustion sources in the US both in terms of RATE and TOTAL annual emissions, and are negligible quantities.
- Nitrogen Oxide emissions from residential oil burners are much less than most other combustion sources, and on-going activities by the oilheat industry promise to lower these emissions even further.
- Particulate Matter emissions from residential oil burners are also much less than most other combustion sources, and are now similar to emissions from gas burners based on recent USEPA publications. In fact, when all man-made and natural particulate sources are considered, home oil burners produce only 0.007% of the annual total. This is an insignificant amount.
- Voluntary actions by the oilheat industry have reduced oil burner PM emissions lower than USEPA reduction goals, and on-going activities will continue to lower emissions even further.
- Meaningful emission reductions and energy cost savings are produced by converting homes with electric heat and hot water to home heating oil. Typical reductions follow:
  - Nitrogen Oxides are reduced by **85% to 90%** with potential reductions nationwide of **765,000 tons per year** (3.5% of total US emissions in 1995)
  - Particulate emissions are reduced by **90% to 94%** with potential reductions nationwide of 30,000 tons per year
- Simply replacing an electric hot water heater with an oil powered model can lower average water heating costs by $485 a year, lower greenhouse gases by 2 tons per year (for each conversion), and produce a 50% to 100% return on investment for homeowners.
- Converting from electric space heating and hot water to oil powered equipment reduces energy costs in a typical home by **$35,000 to $70,000** over 20 years. Good to excellent payback periods are generated that often vary from 2 and 3 years, and can be less than one year in some homes.

Public policies that encourage homeowners to switch from electric to oil powered heating equipment can reduce Nitrogen Oxide and Particulate emissions generated for home heating by more than 90%, lower greenhouse gas emissions by 50%, and produce 20-year energy cost savings for typical homeowners of tens of thousands of dollars.

Recommendations: Oil marketers and state oilheat associations must begin active programs to present the information contained in this report to State Departments of Environmental Control, State Legislatures, and other decision making agencies to encourage pro-oil policies to reduce Ozone and PM emissions.

2. INTRODUCTION

Recently, the US Environmental Protection Agency (USEPA) revised the National Ambient Air Quality Standards for Ozone and Particulate Matter (PM). The new USEPA standards will require that each state develop an implementation plan that demonstrates how the state will reduce its emissions. This has created a need for updated information on the relative emissions from all combustion sources. Oil heat industry associations produced this report which is based on the best available up-to-date information regarding emissions of ozone-related pollutants, particulate matter, and other air pollutants from oil burners and other combustion sources.

The objective of this report is to :

- Provide State Environmental Agencies, Legislators, and other interested parties with accurate and well-documented information on emissions from oil burners,
- Indicate recent trends in oil burner emissions and on-going activities that will lower future oil burner emissions without new regulations, and
- Recommend actions that can assist each state to lower Ozone and Particulate levels in the ambient air as needed to meet the new USEPA standards.

This report presents current emission data for oil burners and other combustion sources in the US, based on research and reports published by the USEPA, National Laboratories, the oil heat industry, and other independent sources. References are available to fully support this information. This up-to-date information must be presented to each state so that state decision-makers can develop strategies and policies for lowering emissions with minimum impact and cost to consumers.

3. OVERVIEW OF REVISED NATIONAL AMBIENT AIR QUALITY STANDARDS

Ozone

The new USEPA ambient air standard for ozone will effect many combustion sources in the next five to ten years. Many regions of the US were out of compliance with the old standard (0.12 parts per million). The revised standard is more restrictive (0.08 parts per million) and it will force state environmental agencies to control even smaller combustion sources in the future. **Ozone** is believed to produce adverse health effects in the lower atmosphere that include: damage to lung tissue, reduced lung function, increased sensitivity to other lung irritants, and permanent structural damage to lungs even at very low concentrations. Ozone and related oxidants are also believed to be responsible for crop damage totaling several billion dollars each year according to USEPA estimates.

Ozone is a "secondary pollutant" that is not directly emitted by most combustion sources. It is formed by chemical reactions in the lower atmosphere with other air pollutants from combustion sources that include Nitrogen Oxides and Volatile Organic Compounds (hydrocarbons that react in the atmosphere). The following simplified steps summarize how ozone is produced:

- Combustion sources produce and emit Nitric Oxide (**NO**) into the air
- **NO** is then oxidized in the air to form Nitrogen Dioxide ($\mathbf{NO_2}$).
- $\mathbf{NO_2}$ absorbs sunlight and breaks apart into Nitric Oxide (**NO**) and oxygen atoms (**O**)
- Some of these oxygen atoms (**O**) combine with Oxygen in the air ($\mathbf{O_2}$) to from Ozone ($\mathbf{O_3}$).

NOTE: Ambient Ozone and oxidant levels are reduced by lowering Nitrogen Oxide (**NO** and **NO_2**) emissions from all sources.

Recent discussions with the Chief of Stationary Sources in one state environmental agency indicated that most of the areas in that state will go from complying at 0.12 ppm to non-complying at 0.08 ppm. State Environmental Agencies have indicated that control of smaller sources (including gasoline powered lawn mowers, for example) will be considered after the proposed regulation is enacted. Clearly, more research is needed to quantify the health and welfare benefits produced by restrictions on combustion sources compared to the costs of these measures and the lifestyle changes that are created.

Particulate Matter

Particulate matter includes *dust, dirt, soot, smoke, liquid droplets*, and *particles* formed in the air from condensation or chemical reaction of sulfur oxides and organic compounds (including unburned hydrocarbons). Suspected adverse health effects in humans include: respiratory and cardiovascular disease, reduced defense against foreign matter, damage to lung tissue, cancer, and premature death. Particulate matter may also interact with other pollutants (such as sulfur oxides, nitrogen oxides, and ozone) to increase their adverse health effects, and to reduce atmospheric visibility.

The **new** PM regulation keeps the existing **PM10** levels (for particles with diameters below 10 one-millionth of a meter) and **ADDS** to them a restriction on **PM2.5** particulates with diameters that are 2.5 one-millionth of a meter or smaller.

Common sources of particulate matter include: fuel combustion, industrial processes, waste disposal and recycling, cars and trucks, and off-highway vehicles. However "naturally occurring sources" include agriculture, construction, fires, and wind blowing that account for **6 to 8 times more PM10 particulates each year than combustion and process-related sources**. Severe restrictions on combustion source emissions will only produce a trivial reduction in ambient particulate levels with minor health benefits, if naturally occurring sources are not reduced also.

Research by Brookhaven National Laboratory and Canadian investigators has found that particulates from residential oil burners are a combination of soot (unburned carbon) and sulfates (including sulfuric acid). The total mass of particulates from oil burners will depend on burner design, burner adjustment, and sulfur content of the fuel. Fuel oil with lower sulfur content (which is the current industry trend) is expected to produce less particulate matter. Therefore, lower particulate emissions are expected in the future.

Implementation Concerns

The revised USEPA ambient air quality standards set new lower limits for ground level ozone and fine particulate matter that must be met by each region of the country. Each state must develop its own State Implementation Plan (SIP) which describes how these reduced ambient levels will be achieved. Specific concerns include:

- Ambient pollution is created by a combination of local sources within a state and by transport of pollutants across borders from other states. Therefore, reaching USEPA ambient air levels is a complex matter which involves **interstate transport of pollutants** which cannot always be controlled by SIPs produced by individual states.
- **Non-uniform regulations may be produced** by each state requiring combustion equipment manufacturers to produce a range of burners with varying emission levels.
- **Adverse economic impacts can be produced by some new regulations.** For example, in one New England state, past regulations reduced the use of #6 fuel oil even though this action reduces annual

nitrogen oxide emissions by less than one-half of one percent. This may increase the price of interruptible natural gas which is historically based on the prevailing price of #6 oil.

- **Smaller Sources will be Controlled by States to Meet the New Regulation -** in some states gasoline powered lawn mowers were one smaller source that was specifically mentioned.
- **Actual Emissions for some sources are much less than perceived values.** For example, particulate emissions rating for modern oil burners is much less than older models and are now similar to gas-fired equipment. However, most national and state environmental agencies are not aware of these recent changes.

Clearly, state environmental agencies must carefully plan their actions in response to the new USEPA ambient air standards so that emissions can be lowered without causing severe negative impacts on consumers. Detailed cost-benefit analyses are essential for each state that are based on quantified values before State Implementation Plans are completed. Furthermore, the practicality and impact on consumers of each proposed measure to reduce ozone and particulate levels must be fully examined. The information contained in this report is intended to supply some of the data that is required to make informed decisions.

4. AIR POLLUTANT EMISSIONS FROM RESIDENTIAL OIL BURNERS

Air pollution emissions from residential oil burners are much lower than emissions from most other combustion sources in the U.S. and do not produce a significant negative impact on the environment. Both the rate of air emissions and total emissions released by oil burners are low. Brookhaven National Laboratory Report 52249 concluded: "**Residential oil burners generally, and modern equipment specifically, are not significant national emission sources**". The environmental cost produced by oil burners is much less than other combustion sources including electric heat, heat pumps, and residential wood stoves. Modern oil burners now produce air emissions at rates that are similar to natural gas burning equipment.

The **RATE** of air pollutant emissions from residential oil burners for five key air pollutants is much less than other combustion equipment in the U.S. and ranges from only **1/4th** to **1/43** of the average combustion source based on USEPA emission factors for oil burners. **Particulate** emissions from home oil burners are 35 time lower than the average combustion source, and **Nitrogen Oxide** emissions are only one-fourth of the average. Tests by Brookhaven National laboratory also show that **Hydrocarbon** emissions from oil burners now average only 0.00174 lbs/MMBTU, or only **1/123** of the average U.S. combustion source. This is lower than residential natural gas burner emissions. **Sulfur Oxide** emissions vary from **1/10 to 1/2** of the average US combustion source depending on the sulfur content of the fuel oil. Lower sulfur fuel oil is now available with only 0.05% sulfur as required for on-highway use and the current industry trend is toward lower Sulfur fuel oil. It is clear that the rate of air pollutants released by residential oil burners is very low when compared to other sources in the U.S.

TOTAL air pollutant emissions by oil burners each year are also very low when compared to the average U.S. source. Oil burners account for only **0.04 percent** to **0.69 percent** of each of the air emissions shown. This is based on data from the U.S. Department of Energy and U.S. Environmental Protection Agency as contained in a report by Brookhaven National Laboratory.

It is clear from these emissions data that residential oil burners are not a significant source of air pollution in the U.S. Oil burners are one of the cleanest combustion sources and produce much less than one percent of the TOTAL annual emissions.

5. OZONE AND ITS FORMATION BY COMBUSTION SOURCES

Ozone (O_3) and related oxidants are not a primary pollutant released by combustion sources, but they are created in the lower atmosphere by other primary pollutants that include Nitrogen Oxides (**NO** and **NO_2** sometimes called **NOx**) and Volatile Organic Compounds (**VOC**) which are produced by combustion equipment.

Nitrogen Oxide Emissions from Residential Oil Burners

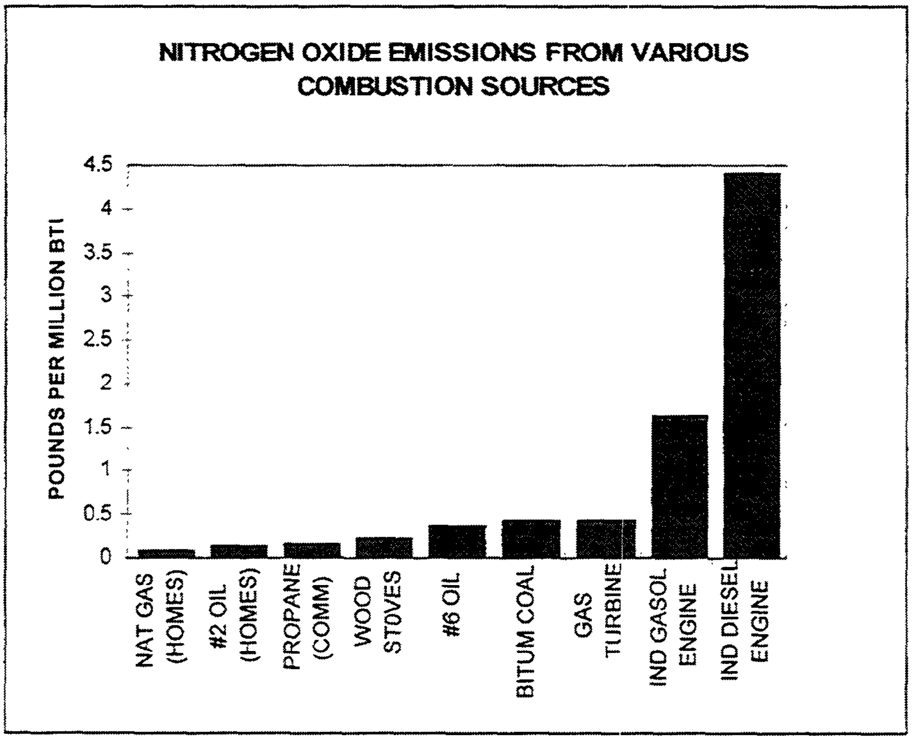
Nitrogen Oxide emissions from residential heating equipment vary depending on burner design, combustion chamber insulation, fuel firing rate, heat exchanger design, and several other important variables. While comprehensive testing to characterize NOx emissions has not been completed for residential oil burners, tests conducted to date by Brookhaven National Laboratory and other researchers indicate a typical flue gas concentrations ranging from approximately 75 to 120 parts per million. This equals **0.10 to 0.16** pounds of NOx per million BTU of fuel consumed.

Nitrogen Oxide emissions (thermal NOx) increases as the peak temperature in the combustion chamber rises. Conditions that tend to increase NOx emissions include:

- Highly efficient burners with elevated flame temperatures
- Furnaces and boilers with high fuel firing rates (higher combustion temperatures)
- Refractory-lined combustion chamber where heat is not removed from the flame
- Boilers and furnaces where only a small part of the flame is exposed to heat transfer surfaces

Additional testing is needed to fully develop this relationship for a range of boiler and furnace designs, but the recent trend in boiler and furnaces toward non-refractory-lined combustion chambers is expected to lower the NOx of future oil heating equipment.

Comparison of Nitrogen Oxide Emissions From Various Sources



The chart on the left shows the RATE of NOx production by various combustion sources as presented in USEPA Publication AP-42 (October 1996). Residential natural gas and oil burners and commercial propane burners are among the lowest emitters, with average emission factors of 0.094, 0.13, and 0.15 pounds per million Btu of fuel consumed, respectively.

When compared to residential oil burners, most other combustion equipment emits much higher NOx levels:

- **Wood stove** Nitrogen Oxide emissions are about **70% higher,**
- **Heavy oil (#6 fuel oil)** burners are **1.8 TIMES higher**,
- **Bituminous Coal** burners are **2.3 TIMES higher**
- **Industrial Gasoline Engines** are **12.5 TIMES higher**, and
- **Industrial Diesel Engines** are **33.9 TIMES higher** than residential oil burners.

If all combustion sources in the U.S. produced nitrogen oxide levels as low as residential oil and gas burners, the air quality problems (including photochemical pollutants and ground level ozone) would be significantly reduced. Furthermore, new oil burner designs now under development by BNL and by burner manufacturers can reduce nitrogen oxides emissions by 50% or more compared to present oil burning equipment.

A comparison of TOTAL emissions of Nitrogen Oxides by all source in the US are presented by the USEPA in the "National Air Quality and Emissions Trend Report, 1995", published in October 1996. Transportation accounted for 48.7% of all the NOx emissions in the US primarily from automobile and truck gasoline and diesel engines. Electric power utilities are the next highest source which is 28.6% of the annual emissions. Together these two source comprise more then three-fourths of the total.

Industrial fuels and industrial processes are next highest at 14.4% and 4.0%, respectively. Residential oil burners produce **less than 0.5% of the total** which is a negligible quantity. Furthermore, most of the home heating oil is consumed during the heating season from mid-October to the end of April and not during the "Ozone Season" which runs from May through September. The only residential fuel oil used during the Ozone Season is for domestic hot water which occurs during the summer months and typically accounts for less than 10% of the annual oil consumption. This means that the total Nitrogen Oxide emissions from residential oil burners from May through September is much less than 0.5% of the total and may approach only 10% of the 0.5%, or 0.05% of ozone season NOx. Clearly, residential oil burners contribute only a minor percentage of the annual NOx emissions in the US, and a negligible quantity (0.05%) during the peak Ozone Season from May through September when emission controls are needed.

New Oil Burner Technologies

Brookhaven National Laboratory (BNL) has been operating an oil burner research program for the US Department of Energy for more than 20 years. Many important efficiency advances have been adapted by the oil heat industry directly through this program. Presently, BNL is developing a new residential oil burner, the Fan Atomizing Burner, that **substantially reduces nitrogen oxide and particulate emissions** while improving overall thermal efficiency. While still a prototype, it represents an important advance in oil combustion which may someday be incorporated (completely or in part) in commercially-available products. It may offer an important alternative to blue flame burners with lower costs.

On-going Oil heat Industry Activities Contributing to Lower NOx

Nitrogen Oxide emissions from residential oil burners vary widely as demonstrated by field measurements by the USEPA. Several activities and trends within the oil heat industry continue to contribute to lower NOx emissions. These include:

- **Lower Oil Burner Firing Rates** can also help lower NOx emissions by as much as 20% compared to earlier levels based on preliminary research that was completed by Brookhaven National Laboratory
- **Cooler Combustion Chambers** - Nitrogen Oxide emissions drops as the cold surface area exposed to flame increases

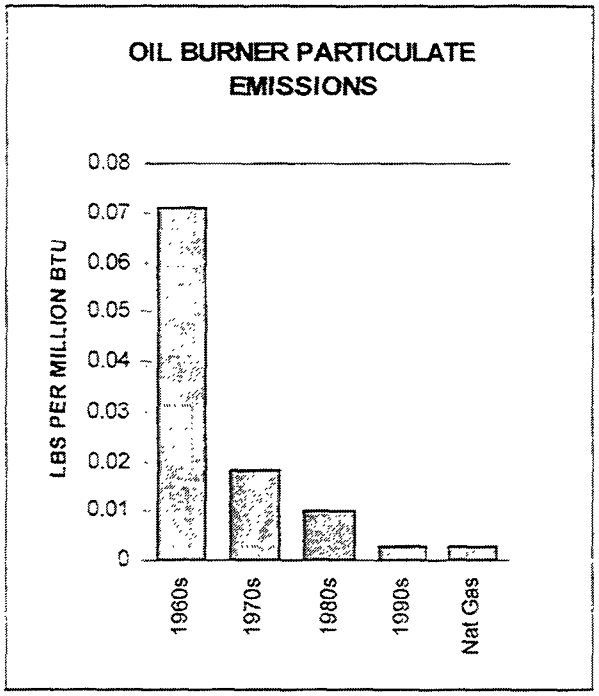
- **Oilheat Industry Technician Training and Certification Programs** also help to lower oil burners emissions through improved burner service and adjustment procedures.

6. PARTICULATE MATTER EMISSIONS FROM COMBUSTION EQUIPMENT

Particulate Matter is released by all fuel-burning equipment and includes smoke and soot that result from incomplete combustion of the fuel. Residential oil burners release particulates at a rate that is one of the lowest of all combustion devises as documented in USEPA publications.

Oil Burner Particulate Emissions

Particulate emissions from residential oil burners vary with the design of the burner, on-off cycling frequency, and burner adjustment. Tests conducted at Brookhaven National Laboratory in 1990 for the US Department of Energy found that properly adjusted flame retention oil burners from various manufactures produce very low particulates levels. PM emissions are less than **0.001 pounds per million BTU** (Lbs/MMBTU) of fuel burned during continuous operation. This is comparable to field tests of emissions from natural gas burners. During burner start-up and shut down, particulate emissions are higher because of changes in fuel-air ratio that occur when a burner starts and stops, and average **0.0027 Lbs/MMBTU** based on tests by Brookhaven researchers. This is much lower than most other combustion sources including older oil burners. It represents only several ounces of total smoke and soot a year which will not adversely effect system efficiency. Modern burners are now approaching near-zero smoke and soot levels when properly adjusted.



The reductions in oil burner particulate emissions that have occurred over the past 30 years are shown in the Figure on the left. This chart is based on information published by Brookhaven National Laboratory and the US Environmental Protection Agency. Residential oil burner particulate emissions have been lowered **by a factor of 20** and are now approaching emissions from natural gas burners. The reason for the lower oil burner smoke and soot is improved burner design that produces more complete mixing and burning of the air and fuel oil. Flame retention heads create recirculation of combustion gases within the flame for improved fuel vaporization, fuel-air mixing, and burning. This produces more complete combustion which lowers particulate emissions. Also, oil burner air pressures have increased by more than a factor of 60 during the evolution of earlier designs to modern flame retention models. This improves burner stability and helps keep burners "in tune" during the heating season as the chimney draft changes.

The US Environmental Protection Agency (USEPA) recently acknowledged that modern oil burners are much ***cleaner burning*** than older models. The updated (October 1996) USEPA emission factor for particulates from oil burners is **7-1/2 times lower than the previous rating**. Burner tests by Brookhaven National Laboratory and other sources were submitted to the USEPA by the Oilheat Manufacturers' Association, and an update to the oil emission standard was requested. The new USEPA emission ratings affirm that oil burners are now one of the cleanest combustion sources in the US. This revision is important because it corrects the common misconception that oil burners are "dirty". Also, while the new ambient air quality standards may restrict particulate emissions from combustion equipment in the future, residential oil burner PM emissions are now recognized as being much lower than the previous ratings. This makes it easier for them to comply with more stringent regulations in the future.

Particulate Emissions from Various Combustion Sources

When compared to other common US combustion sources, PM emissions from natural gas, home heating oil, and propane are the lowest. Wood fireplaces and uncontrolled burning of Bituminous Coal on spreader stokers emit particulates at a rate that is more than **500 times higher** than gas and oil home heating equipment. Compared to all these other sources, oil and gas burners used in homes produce near-zero particulate levels. The difference between residential natural gas burners (0.0002 lbs/MMBTU), oil burners (0.003 lbs/MMBTU), and propane burners (0.004 lbs/MMBTU) are trivial when compared to these other sources. In fact, home oil and gas burners now emit approximately **35 times less particulate matter** than the average combustion source in the US. If all combustion equipment operated as cleanly as these residential gas and oil burners, particulate emissions in the US would not be a serious problem.

When compared to home oil burner's low PM emissions :

- Wood Fireplaces are **900 TIMES HIGHER**
- Bituminous coal burners (spreader stokers) are **890 TIMES HIGHER**
- Industrial Diesel Engines are **100 TIMES HIGHER**
- Industrial gasoline Engines are **33 TIMES HIGHER**
- Gas Turbines (powered by natural gas) are **6 TIMES HIGHER**

A comparison of TOTAL Particulate emissions each year in the US in 1995 is summarized in the US Environmental Protection Agency's National Air Quality and Emissions Trend Report, 1995 (ref: EPA 454/R-96-005). PM generated by all fuel combustion, industrial process and transportation in the US in 1995 include: Industrial processes (37%), Transportation (27%) Residential Wood Burning (14%), and Electric Utilities (10%) account for 88% of all particulate emissions each year (excluding natural sources). Residential oil burners produce less than 0.12%. This is an insignificant quantity.

Furthermore, **Natural occurring** Particulate Matter (PM10) emissions are much higher than the combustion, industrial process and transportation amounts shown in the chart. This includes fugitive dust, from unpaved and paved roads and other sources which is more than 15 times higher than the total of all man-made sources. When naturally occurring PM sources are included, **home oil burners produce only 0.007 % of total emissions each year. Lowering PM emissions from residential oil burners will produce no discernible benefit for the environment.**

Voluntary PM Reductions by the Oilheat Industry Exceeded USEPA Goals

A USEPA report published in 1976 (ref: EPA-450/3-76-006) presented information on typical PM emissions and included goals for reducing emissions from residential oil heating equipment. At that time oil burners operated with an average **Bacharach Smoke Number of 3**, and particulate emissions of **approximately 0.018 pounds per million BTU** of fuel consumed, according to USEPA emission factors. The 1976 report proposed specific options for reducing PM emissions in various regions of US.

While these mandatory actions were not implemented, voluntary efforts by oil heat equipment manufacturers, fuel oil marketers, and national, regional, and state oil heat associations have produced PM reductions over the past 20 years that HAVE EXCEEDED THE GOALS SET BY THE USEPA. The average Particulate emission rate for new oil burners is now only **0.003 pounds per million BTU**.

This is 3 times less than the 1976 target of 0.01 lbs/MMBTU. Modern (flame retention) oil burner can now operate with Bacharach Smoke Numbers that are less than Number 1. Regular burner inspection and service is also promoted by oil heat equipment manufacturers and associations. National Certification Programs for oil heat service technicians include burner service procedures that improve efficiency and lower air emissions. These programs help to assure proper burner adjustment and operation with minimal particulate levels. This demonstrates that the oilheat industry in the past has exceeded USEPA emission reduction goals voluntarily without the need for regulatory action.

On-going Actions by the Oilheat Industry to Lower PM Emissions

Actions by the oil heat industry will continue to decrease the rate of Particulate matter from residential oil burner without added regulatory action. These include:

- **Fuel Oil with Lower Sulfur Content** - producing lower particulate emissions from oil burners
- **Fuel Nozzle Cut-off Valves** - The new fuel nozzle cut-off valves offer an effective and low cost option for substantially lowering oil burner smoke during start-up and shut down which can reduce total smoke and soot emissions by as much as two-thirds.
- **Oil Burner Advances** - Recent advances in oil burner design have drastically reduced oil burner particulate emissions as discussed earlier in this report. On-going developments can further reduce emissions
- **Self-tuning residential oil burners** are also under development at Brookhaven that could eventually produce equipment that automatically re-adjusts burners to assure continued clean operation.
- **Flame Quality Indicators and other Advanced Controls** - when a burner goes out of adjustment the FQI or Advanced FQI immediately signals that service is needed. Other advanced control concepts are also under development that can improve upon the FQI/AFQI devices and provide enhanced functions including automatic burner tuning and modulation.
- **Conversion of Homes From Electric Heat to Oil** - Annual emissions of Particulate Matter and all other air pollutants are substantially reduced by switching homes that now use electric resistance heat or heat pumps for space and water heating to oil heating equipment. Heating oil companies continue to convert electrically-heated homes to oil. Clearly, conversion from electric to oil heat can substantially reduce Particulate Emissions in the US. Similarly, conversion from electric to oil powered home heaters can lower other air pollutants as follows:
  - Nitrogen Oxides by a **FACTOR OF 7**
  - Unburned Hydrocarbons by a **FACTOR OF 60**
  - Carbon Monoxide by a **FACTOR OF 12**
  - Sulfur Oxides by a **FACTOR OF 6 to 12**
  - Carbon Dioxide by a **FACTOR OF 2**

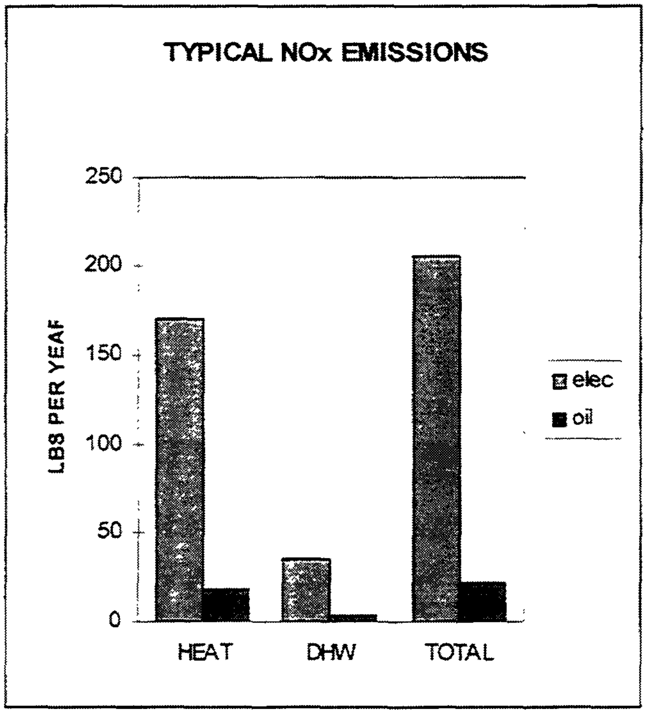
Federal and State programs and policies that accelerate the rate of conversion from electric to oil heating equipment can significantly lower Ozone and Particulate emissions and other air emissions in the US. In addition, heating costs savings are produced (typically 50% to 75%) which economically justifies conversion in most cases.

7. EMISSION REDUCTIONS AND COST SAVINGS BY CONVERTING HOMES FROM ELECTRIC HEAT TO OIL

Previous sections of this report compare the rate of emissions of **Nitrogen Oxide**, **Particulate Matter**, and **other air pollutants** from home oil burners and other sources. The information that follows summarizes the expected emission reductions by converting homes that use electricity for space and water heating to oil powered equipment. This includes Nitrogen Oxide, Particulate, and Greenhouse gas reductions. Annual cost savings and payback periods for converting from electric heat to oil are also presented for a range of heating costs and electricity and oil prices. Switching electrically heated homes to oil significantly reduces air emissions and reduces home heating costs. It is a good investment in most cases.

Nitrogen Oxide (Ambient Ozone) Reductions by Conversion to Oil Heat

The total Nitrogen Oxide release (a primary pollutant that produces ozone) from electric utilities in the US in 1995 was 7,135 thousand short tons, while the total electric energy generated was 2,994 billion kilowatt-hours (ref: DOE/EIA-0348(95)/2). This equals 1.32 pounds of NOx per million BTU of electric energy. If 10% is added for transmission, distribution, and in-home energy losses, this becomes **1.45 Lbs/MMBTU** of energy delivered to the home. Nitrogen Oxides from oil heating equipment in homes is 0.13 Lbs/MMBTU based on recent USEPA emission factors (AP-42). When typical heating equipment efficiency is included, this becomes **0.15 Lbs/MMBTU**, which is almost ten times less than the NOx emissions per BTU of heat delivered with electricity.



Home energy use includes space heating and production of domestic hot water. Typical fuel use in homes in oil heated regions of the US is about 850 gallons of oil a year (118 million BTU per year), and USDOE calculations indicate average energy use for domestic hot water is about 24 million BTU per year. Based on these usage rates and using median heating equipment and water heater efficiencies, the average reduction in Nitrogen Oxide emissions by switching from electric to oil space heating and hot water can be determined for a typical house.

The chart on the right summarizes expected reductions in Nitrogen Oxide emissions by converting a typical home from **electric space heat** and **hot water** to oil powered equipment. Conversion to oil reduces NOx emissions from 206 to only 21 pounds per year - a 90% reduction.

When an electric **air-to-air heat pump** with an *actual* Coefficient of Performance of 1.6 is replaced by oil equipment, NOx emissions drop from 142 to 21 pounds a year - an 85% reduction. Clearly, replacing electric home heating equipment is an effective way to substantially lower NOx emissions and ambient ozone levels in the US. National NOx reductions by converting homes from electric to oil powered heaters can be evaluated based on information published by a US Department of Energy (ref: DOE/EIA-0321(93)) which indicates that approximately 10 million homes are heated by electricity in regions where oil heat is also used. If all these homes were converted to oil powered equipment for space and water heater, Nitrogen Oxide emissions could be reduced by 1.5

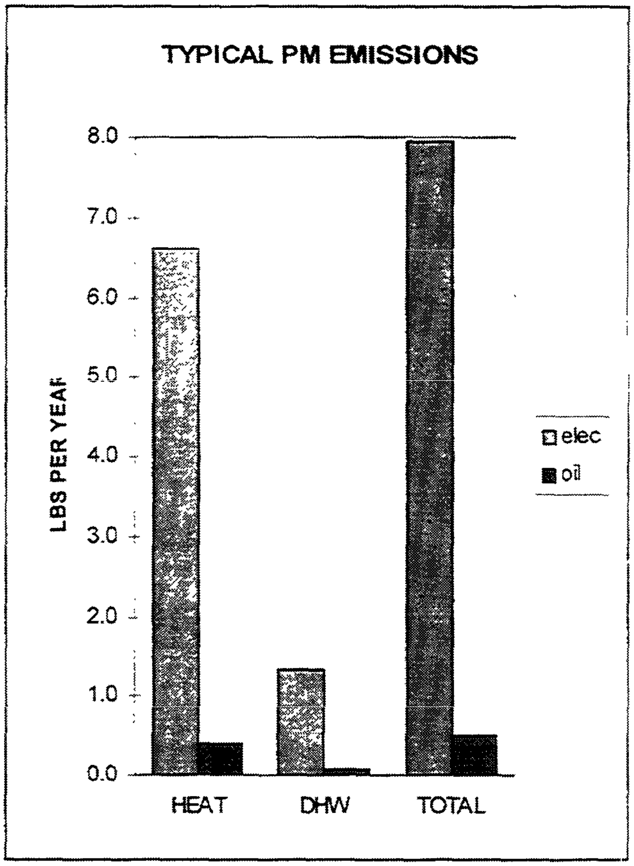
billion pounds or 765 thousand tons per year. This is a 3.5 percent reduction of total NOx emissions in the US for 1995.

Public policies that encourage switching electrically heated homes to oil powered heaters can reduce nitrogen oxide emissions and ozone levels in the ambient air. Homeowners also benefit from substantial energy cost savings each year.

Particulate Matter Reductions by Conversion to Oil Heat

The total release of particulates (PM-10) from electric utilities in the US in 1995 was 258 thousand short tons, while the total electric energy generated was 2,994 billion kilowatt-hours (ref: DOE/EIA-0348(95)/2). This equals 0.051 pounds of PM per million BTU of electric energy. When 10% is added for transmission, distribution, and in-home energy losses, this becomes **0.056 Lbs/MMBTU** of energy delivered to the home.

Particulates from oil heating equipment in homes is 0.003 Lbs/MMBTU based on recent USEPA emission factors (AP-42). When typical heating equipment efficiency is included, this becomes **0.0035 Lbs/MMBTU**, which is **16 times less than the PM emissions per BTU of heat delivered with electricity.**



For typical energy use for space and water heating in homes in oil heated regions of the US (118 million BTU per year for heat, and 24 million BTU per year for hot water), the average reduction in Particulate emissions by switching from electric to oil space heating and hot water can be determined for a typical house.

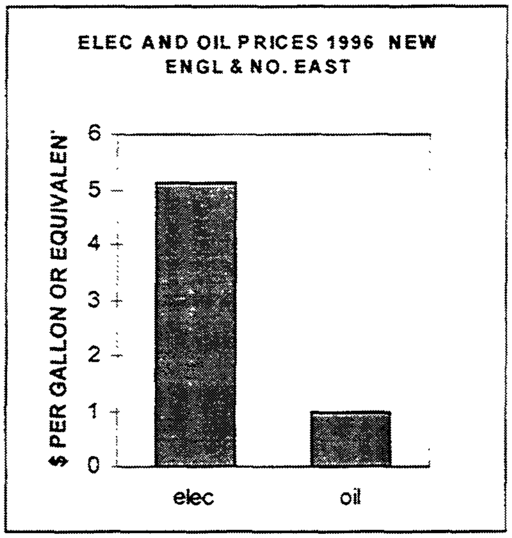
The chart on the left summarizes expected PM reductions by converting a typical home from **electric space heat** and **hot water** to oil powered equipment. Conversion to oil reduces PM emissions from 8.0 to 0.5 pounds per year - a 94% reduction. When an electric **air-to-air heat pump** with an *actual* Coefficient of Performance of 1.6 is replaced by oil equipment, Particulate emissions drop from 5.4 to 0.5 pounds a year - a 90% reduction. Replacing electric home heating equipment is an effective way to substantially lower emissions particulate levels in the ambient air in the US.

National Particulate reductions by converting homes from electric to oil powered heaters can be evaluated based on approximately 10 million homes that are heated by electricity in regions where oil heat is widely used. If all these homes were converted to oil powered equipment for space and water heating, Particulate emissions could be reduced by 60 million pounds or 30 thousand tons per year.

8. ENERGY COST SAVINGS AND PAYBACKS BY CONVERTING TO OIL

New England and the Northeast have the largest percentage of oil heated homes, and the average price of residential fuel oil in these regions in 1996 was $1.00 per gallon, while the price of electricity in these regions was $0.126 per kilowatt-hour. This is equivalent to $5.12 for the same amount of energy that is contained in one gallon of oil (ref: National Association of Regulatory Utility Commissioners, Residential Electric Bills - Winter 1995-96). See the chart on the right. Conversion of homes from electric heat and hot water to oil produces substantial energy cost savings.

The information that follows summarizes annual cost savings for homes that convert to oil from electric resistance heat, electric air-to-air heat pumps, and electric water heaters for a range of electricity prices and annual energy use rates. (See the complete report for more details.)



Conversion from **electric resistance heat** to oil offers the following advantages:

- Typical fuel savings of more than $3,000 a year are expected in New England and the Northeast
- Annual cost savings vary with house size but range from $896 a year to $7,934 a year in many cases
- Annual cost savings of $5,000 to $8,000 a year are expected in regions with larger homes where the electric rates are near $0.16 per kwh.

These cost savings produce excellent paybacks for homeowners and can be economically attractive.

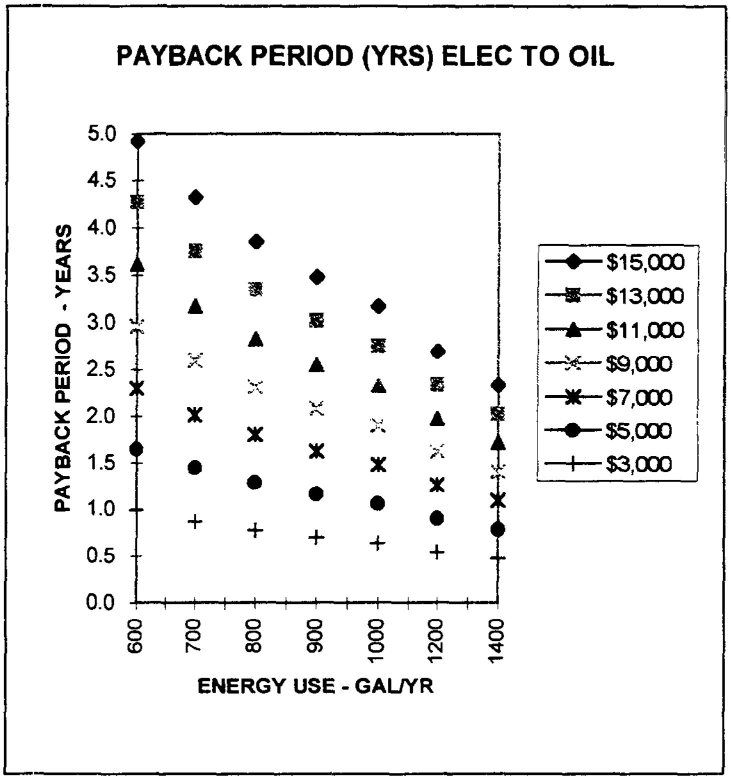
Annual cost savings from replacing electric **heat pumps** with oil heating equipment were evaluated for typical electric and oil prices, producing an average savings of $1,978 a year. Conversion costs for switching from heat pumps to oil is relatively low because the existing ductwork can be reused by the new oil heating equipment. Therefore, excellent playbacks for homeowners are often available for this conversion, especially when the electric rates are $0.10 per kilowatt-hour or higher.

Cost savings by converting from an electric to oil powered **water heater** range from about $100 to $872 a year depending on local electricity and fuel oil prices. An average cost savings for oil at $1.00 per gallon and electricity at $0.12 per kilowatt-hour is **$485 per year**. Actual savings are higher when hot water use within the home exceeds the USDOE average of 64 gallons per day. The cost of a new oil water heater is often in the range of $500 to $1000 depending on its size specific installation requirements. (Actual installed costs vary widely and can be less than $500 or more than $1,000). This produces a payback on the initial investment of within one to two years. **This is an excellent cost saving investment for homeowner that offers a 50% to 100% return on investment.** If a "tankless coil " can be added to the new oil boiler, the initial costs can be even lower than shown, and the payback can be less than one year.

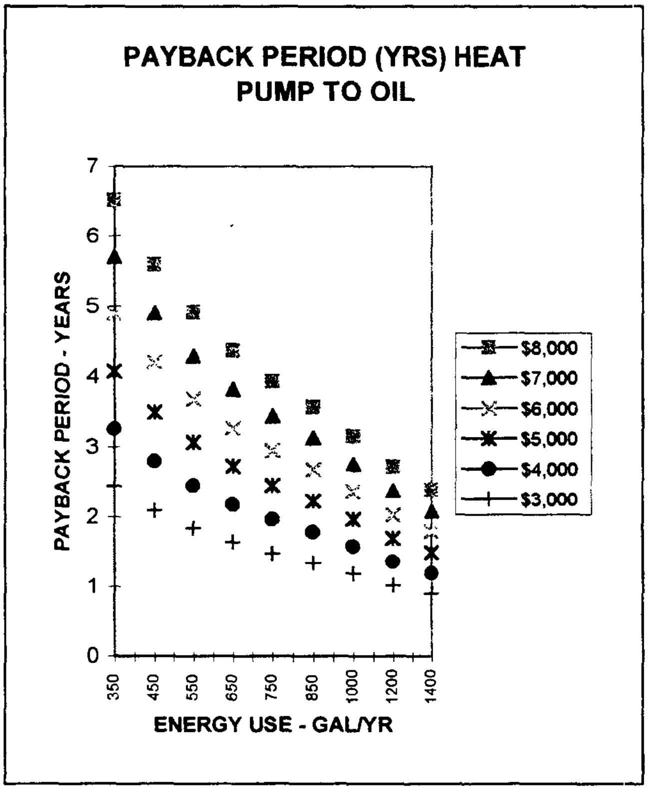
Paybacks for Converting Homes to Oil Heat

The PAYBACK PERIOD is the time that is required to pay for the cost of conversion ($) from energy cost savings ($ per year). The payback periods were calculated for converting from electric to oil powered space and water heating equipment using a range of conversion costs and annual energy use (house size). The charts that follow show payback periods in years for homes converted from **electric** space heat and hot water, and from electric **heat pumps** to oil powered equipment. Some key observations regarding these calculations include the following.

- <u>Good to excellent payback periods</u> ranging from only **one-half year to less than 5 years** are produced by converting to oil for electric and oil prices in New England and the Northeast.
- The lowest (best) **payback periods are one year and less** and occur for lower conversion costs of $3,000 to 5,000 (for example, conversion of a home with an electric furnace with existing ductwork), and for the higher energy use (larger homes).
- Mid-range values ($9,000 conversion cost and 900 gallons a year fuel use) produce **excellent payback periods of only 2 years**, which is a 50% return on investment.
- Even for the higher conversion cost of $15,000, paybacks are **within 3 years** for medium to large size homes toward the right of the chart.



The <u>net</u> 20-year cost savings, after deducting conversion costs, for a mid-range installation is **$76,000** by switching to oil from electric heat and hot water based on existing energy prices. This is an excellent opportunity for homeowners to cut their energy costs by tens of thousands of dollars.



The chart on the left shows payback periods in years for homes converted from **electric heat pumps** for space heat and electric hot water to oil powered equipment. Paybacks a shorter (better) for larger homes with higher fuel use toward the right hand side of the chart. The family of curves is for varying conversion costs ranging from $3,000 (bottom) to $8,000 (top). These costs are usually lower than for converting homes with electric resistance heat because the warm air heating ducts are already in place.

Some key observations regarding these calculations include the following:

- <u>Paybacks periods</u> ranging from only **0.9 to 6.5 years** are produced by converting to oil in New England and the Northeast.
- The lowest (best) **payback periods are one to two years** for low conversion costs of $3,000 to 4,000 and higher energy use.
- Mid-range values conversion costs and home fuel use produce **very good payback periods of only 2-1/2 to 3 years**.

The net 20-year cost savings (deducting conversion costs) for a mid-range installation is **$35,000** by switching to oil from an electric **heat pump** and electric water heater based on existing energy prices in New England and the Northeast. This is an important opportunity for homeowners who now use electric heat pumps to reduce emissions of nitrogen oxides, particulate matter, greenhouse gases, and other air pollutants, and to improve efficiency while also cutting their 20-year energy costs by tens of thousands of dollars.

Summary of Benefits - Switching From Electric to Oil Heating Equipment

Conversion of homes that now use electric energy for space heat and hot water to oil powered equipment produces many important advantages.

- Nitrogen Oxide emissions emitted for space and water heating with electricity are reduced by 90% by switching to oil equipment. Annual NOx reductions of 765 thousand tons per year are possible, if 10 million homes are switched from electric to oil heating equipment. **This reduction equals 3.5% of the total Nitrogen Oxide emissions in the US each year.**
- Particulate Matter emitted for space and water heating with electricity is reduced **by 94%** by switching to oil equipment. Annual PM reductions of 30 thousand tons per year are possible, if 10 million homes are switched from electric to oil heating equipment.
- Greenhouse Gas emissions (carbon dioxide) released by space and water heating with electricity is reduced **by 50%** by switching to oil equipment. Annual Carbon Dioxide **reductions of 120 million tons per year** are possible, if 10 million homes are switched from electric to oil heating equipment.
- Typical homeowners in the Northeast and New England who now use electricity for space heat and hot water can save more than $3,000 a year by switching to oil. Switching a home with an electric heat pump to oil heat can save about $2,000 a year.
- **Simply switching from an electric to oil powered water heater can save homeowners $485 a year** based on current oil and electricity prices in New England and the Northeast. In addition, carbon dioxide emissions are reduced by **2 tons a year** for every water heater that is converted to oil.
- Excellent payback periods are produced by converting electrically heated homes to oil powered equipment, with typical paybacks of only 2 years or a **50% return on investment** for homeowners based on current energy prices for the cases that were examined. This produces a **20-year cost savings of $76,000** for homeowners.
- Very good payback periods are often produced by converting homes with electric heat pumps to oil powered equipment, **with typical paybacks of only 2-1/2 to 3 years or a 33% to 40% return on investment** for homeowners based on current energy prices.
- Major reductions in other air pollutants including **carbon monoxide, hydrocarbons**, and **sulfur oxides** are also produced (ranging from 84% to 98% reductions) by replacing residential electric heaters with oil powered boilers, furnaces, and water heaters.

Policies that encourage homeowners to switch from electric to oil powered equipment can substantially reduce air emissions, and homeowners benefit through much lower energy costs.

NOTE: This summary report is excerpted from "Expanded Use of Oil Burners to reduce Ambient Ozone and Particulate Levels", prepared in October 1997 by John E. Batey for the Petroleum Marketers Association of America, the New England Fuel Institute, and the Oilheat Manufacturers' Association (OMA) . For a complete copy of this report please call OMA at 802-325-3509.

Paper No. 98-08

PMAA's Oil Heat Technician's Manual (Third Edition)

George V. Lanthier, President
Firedragon Enterprises Inc.
132 Lowell Street
Arlington, MA 02174-2756

and

Robert V. Boltz, Vincent R. Boltz Inc.
45 Guilford Street
Lebanon, PA 17046

PMAA Oil Heat Technician's Manual

George V. Lanthier, Firedragon Enterprises, Inc., and
Robert Boltz, PMAA Heating Fuels, Education Committee Chairman

Abstract of Presentation

This presentation will outline the history, the current status, and hopefully the future of the PMAA Oil Heat Technician's (Silver Level) Manual.

The presentation will follow the Manuals' history from its origins as an in-house training Manual for the Pure Oil Co., a division of the Union Oil Co. of California in the 1950's, to its evolution under the National Oil Fuel Institute (NOFI) as an industry wide Manual. The history goes on through the NOFI years to the years under the guidance of the Petroleum Marketers Education Foundation (PMEF), and finally to the ongoing custody of the Petroleum Marketers Association of America in the 1990's.

The presentation will discuss the efforts of many organizations and oil heating related firms to provide a Manual that the industry could use to create a 'same book, same page' philosophy. This philosophy allows for training under various State code jurisdictions and the teaching policies and styles of the training organizations. By maintaining the policies and personalities of the individual training organization, while using the Manual, the Manual and the associated effort is to create a cohesive policy on industry education while providing continuity, and using established oil heat terminology. The initial and continuing efforts and contributions of firms such as Union Oil of California (Union 76), Mobil Oil Corporation, Humble Oil and Refining Company (Exxon), and Shell Oil Company in the development of a text that is easy to understand, yet highly accurate in technical content will be discussed.

In addition, the paper will also focus on the continuing use and editorial input by industry associations such as the Oil heat Manufacturers Association (OMA), and many teaching and educational organizations. Some of these being schools and seminars that incorporate the Manual into programs conducted by such groups as the New England Fuel Institute (NEFI), the Independent Connecticut Petroleum Association (ICPA), the Pennsylvania Petroleum Association, and the National Association of Oil Heating Service Managers (NAOHSM) and several others.

The presentation will emphasize the major rewrites of the 1990 and 1992 revisions and the current Third Edition to be released in 1998 with the majority of the discussion centered on the Third Edition.

Under the First Edition of the current Manual the Principal Editor, Gene Mangini developed the concept of all editorial content being reviewed by him. By having final editing authority it presented a Manual that appears to have been written by one individual instead of a committee or group. The concept worked, and eliminated repetitive statements and comments and opposing points of view by Chapter Editors. Further, it reduced the total page count of the Manual, thereby reducing the cost of production, while ironically increasing the quality and quantity of the information enclosed.

One concept that did not work with the two previous Edition's was of having each Chapter Editor submit questions on his respective writings. In the First Edition there literally ended up being no questions developed by the text Committee or Editors and so NAOHSM and others developed their own. With the Third Edition, the plan is for one person to do all of the questions for the entire text.

Continuing on that basic premise, the Third Edition's goal is to maintain this high level of continuity, while bringing the Manual up to date with current state-of-the-art technologies and techniques. Further, another ongoing and continuing goal since the First edition is to continue to enhance the quality of the drawings and graphics within the Manual to reflect those emanating ideas and products in the marketplace. Although this was the primary emphasis placed on the Second Edition, the ever continuing emergence of new technology and ideas has proven that this effort will ironically continue to be the goal of any further editions.

Major contributing editors to the Third Edition include Bob Hedden of OMA, John Batey of Energy Research Center, Inc., Dan Holohan, Jim Todd of PETRO, and members of NAOHSM, most notably John Wilcox of Moyer Fuel, and Richard Levi of Oil Services Inc..

Although having gone through several rewrites, revisions and reprints under three major sponsors the Manual continues to be recognized as 'the bible' for the training of basic and intermediate levels of oil heat technicians and is the cornerstone of the PMAA Silver Certificate training program.

Material included in the presentation will be many new drawings and illustrations from major manufacturers of oil heating equipment and several new drawings in the Chapters on Electricity. These all new drawings are being produced by Firedragon Enterprises for the third Edition and will be shown in overhead format. The drawings concentrate on basic circuit design and construction and work their way up to the many common wiring diagrams for oil fired systems in use today.

Finally, a closing comment will be made by Robert Boltz, of Vincent R. Boltz, the current PMAA Heating Fuels, Education Sub-Committee Chairman and President of NAOHSM. Bob will outline the goals of the Manual's Editorial Committee to continue a periodic review of the Manual, and the mechanism to be put in place to receive input from users on the material to include in a review to occur in a two to five year period.

Paper No. 98-09

Direct Venting Concept Development

John M. Laisy, P.E.
R.W. Beckett Corporation
P.O. Box 1289
Elyria, Ohio 44036

DIRECT VENTING CONCEPT DEVELOPMENT

John M. Laisy, P.E.

OBJECTIVE:

The objective of this study was to develop basic concept guidelines for appliance manufacturers in the use of high static pressure flame retention oil burners in direct vent applications.

INTRODUCTION:

Sidewall venting, which removes the products of combustion from a building without the use of a chimney, can be accomplished in oil fired heating appliances in one of two ways. The first option is to use an induced draft fan ("power venter") to create a negative pressure (draft) condition in the appliance and flue pipe and to expel the flue products through the wall and out of the building. The second option is to utilize the oil burner as a forced draft fan which "pushes" the products of combustion with positive pressure through the appliance, flue pipe and exhaust vent wall fitting or hood.

Since at least 1984 there have been discussions, studies, and applications related to sidewall venting of oil heat appliances in the U.S. and Canada. In 1987, at the U.S. Department of Energy Oil Heat Technology Conference at Brookhaven National Laboratory, four of twelve papers that were presented and two of five workshops conducted addressed sidewall venting. By the early 1990's, numerous oil heat appliance OEM's were either interested or involved in developing sidewall vented equipment.

Most of the work with power vented oil heat appliance applications in North America has been undertaken by the primary manufacturers of induced draft fans, Field Controls and Tjernlund. For forced draft (or "direct vent") applications, however, the heating appliance manufacturer typically looks to the burner manufacturer for guidance and assistance. This report is a summary of the R.W. Beckett Corporation's findings, understandings, and concerns regarding direct venting of oil heat equipment.

TEST EXPERIENCE:

1. Boilers

In boiler design, U.S. manufacturers have led the way in the North American oil heat industry in the area of direct venting, because pressure tight design and positive overfire pressure firing are not uncommon with boilers. In the past several years, numerous boilers have been tested at Beckett in direct vent configurations. Several of these boilers are now being marketed as direct vented packaged systems.

Boilers tested at R.W. Beckett Corporation included:

- an American made low mass steel boiler tested in 1993 with the AFII 150 burner at firing rates ranging from 0.75 to 1.10 gph. Flue lengths of 2' and 20' were tested, in an outside combustion air ("balanced flue") arrangement. Flue diameter for all rates was 5", with a Field Controls wall terminal. Combustion air intake duct was 4" diameter. Pre- and post-purge of the boiler/system was recommended.

- an American made steel boiler tested in early 1995, with firing rates approved at 0.65 and 0.75 gph with the AFII 85 burner. Flues of 4" and 5" diameter with Field Controls wall terminals were tested at a 20' length. Outside combustion air was provided directly to the burner via a 4" diameter duct. Short term cycle testing results were acceptable. Pre- and post-purge of the system was specified.

- another American made steel boiler tested later in 1995 with the AFII 85 and AFII 150 burners at 0.67 to 1.21 gph firing rates. Pipe of 4" diameter was used for both the combustion air inlet and exhaust vent, with run lengths of 15 feet plus two 90° elbows (= 27 total equivalent feet). Pre- and post-purge of the system was specified.

- a pair of European cast iron boilers tested in early 1996, with rates approved at 0.75 gph for the smaller unit with the AFII 85, and 0.85 gph for the larger unit with the AFII 150. Tests were run with minimum (2') and maximum (15') vent pipe lengths. Ducted outside combustion air was provided. Pre- and post-purge controls were specified. Short term cycle testing results were acceptable.

2. Furnaces

A conventional, traditional chimney vented heating appliance has the inherent safety advantage of negative pressure in the system. If a leak occurs in the heat exchanger of a conventional chimney vented furnace, air will be drawn <u>in</u> from the ductwork system. In direct vent systems, the combustion chamber, heat exchanger, and at least part of the flue vent system are typically under positive pressure, so that a leak in the heat exchanger may force flue products into the duct system when the warm air circulating fan is off. Several Canadian manufacturers led the way in developing unique designs with features such as coaxial combustion air/exhaust vent pipes, low pressure drop heat exchangers, small diameter/high velocity exhaust vent pipes, and wind resistant wall terminal fittings.

Furnaces tested at R.W. Beckett Corporation included:

- a Canadian furnace designed for direct venting, tested in 1991 and 1992. The AFII 85 was recommended at 0.65 to 0.85 gph, with the AFII 150 required at 1.0 gph. A 4" inside diameter, 15' long insulated stainless steel flexible flue provided by the customer was used for testing. The customer also supplied a coaxial inlet/outlet wall terminal for combustion air intake and exhaust.

- three models designed by another Canadian furnace manufacturer for direct venting, tested in mid-1992. The AFII 85 and 150 were applied at rates from 0.51 gph to 0.95 gph. All units were tested with 3" flue, to promote high flue gas velocity to maintain flue gas temperatures above the condensation points for sulfur and water. Outside combustion air was not specified by the customer. Pre- and post-purge of the system was specified.

- an American made multi-position furnace tested in 1994 with 6" diameter, 15' and 30' long vent pipes. Testing was performed with the AFG burner at 1.10 gph, with various outside air intake configurations. Post-purge was recommended to reduce off cycle temperatures.

- a pair of Canadian furnaces, modified for direct venting, tested and approved in mid 1996 with the AFII 85 and 150 burners. A 4" diameter duct was used for outside combustion air, with 3" inside diameter, 20' long flexible stainless steel insulated flue pipe used for venting. Pre- and post-purge was specified. Firing rates were 0.60 to 0.84 gph for the smaller furnace and 0.72 to 1.08 gph for the larger furnace. Short term cycle testing results were acceptable.

- a Canadian "chamberless" furnace (i.e., steel combustion chamber with no refractory lining) also tested in 1996. This furnace performed successfully with the Beckett AFG burner. Outside air for combustion was provided by a Field Controls air boot with a 3" diameter, 25' long inlet pipe. Exhaust venting was via a 25' long, 3" diameter flue pipe. Final testing was with 0.40 and 0.50 nozzles at 180 psig.

- a series of American furnaces modified for direct venting which were tested in 1997 with AFII 85 and 150 burners. System design included 3" and 4" inside diameter flexible stainless steel insulated flue pipes, with 4" diameter outside combustion air duct. The furnace manufacturer designed a wall terminal with separate air intake and exhaust fittings, with special consideration for wind effects. Controls for optimal reliability were included in the system design.

3. Water heaters

Many homes in North America that use oil for space heating use an electric domestic hot water heater. In many cases, an oil fired water heater can be installed which will reduce the cost of water heating. Also, electric furnace and electric heat pump systems can be modified to include a water heated coil, which can be supplied by the oil fired hot water heater that supplies the domestic hot water.

To date, the only water heaters in sidewall vented service utilize power venters. Direct venting is a future possibility, but temperature and combustion gas leakage concerns must be considered.

SYSTEM DESIGN RECOMMENDATIONS:

Special design considerations are required for direct venting of oil fired appliances such as boilers, furnaces, and water heaters.

A. Appliance

-Appliances must be sealed to prevent leakage from positive pressure firing (including inspection doors) and factory tested in production for leaks.

-Combustion chambers should be designed so that burner head and air tube temperatures do not exceed allowable limits.

-Tight fit of the combustion chamber to the burner head/air tube is required, to minimize carbon blowback on startup.

-Extensive study and life testing of furnace heat exchangers are required due to leakage concerns.

-Heat exchanger design should incorporate minimum pressure drop to reduce restriction and resultant pressure pulse and smoke/soot on startup.

-Appliance sizing should be optimized/minimized to match heating load to reduce short cycling (i.e., maximize typical "on" time to minimize condensing mode in vent exhaust pipe).

B. Burner

-High static pressure burners like the Beckett AFG and AFII burner are required.

-Provision for outside air connection is required, either as a built-in feature of the burner or as an accessory (see Air Inlet below).

-Pre-purge to initiate flow in the system, and post-purge to cool the system and purge any flue gases, are required, either by a conventional primary control with a pre- and post-purge timer kit, or by an integrated advanced pre- and post-purge primary control.

-With pre- and post-purge, a solenoid operated oil valve with standard fuel unit, or a pump with integral solenoid valve, is required.

-Two-step firing, with high excess air on startup to minimize startup smoke, may provide benefits in keeping the system clean.

C. Air Inlet

-Ducted outside combustion air is required for balanced air flow and "tight" house construction, with a screened intake air hood and vacuum relief valve (to provide combustion air in case of intake air hood blockage).

-Air inlet can be solid or flexible, with required diameter and maximum allowable length determined by testing.

D. Vent Exhaust Pipe

-Stainless steel or other corrosion resistant material is required, with specific type and suitability to be determined by the appliance manufacturer.

-Vent exhaust pipe can be solid or flexible, with required diameter and maximum allowable length determined by testing.

-Insulation is recommended to maintain high flue gas temperatures to minimize condensation. Double wall flexible type pipe with insulation between the walls and minimal joints is highly recommended.

-Design must be leaktight with all joints sealed with high temperature silicone caulk or equal.

-No barometric damper is to be used.

-Slope horizontal sections down 1/4" per foot to drain any condensate to the outside, instead of toward the appliance.

E. Vent Hood

-One common option is Field Controls SWH or equivalent (stainless steel; material type and suitability to be determined by appliance manufacturer).

-Various appliance manufacturers have developed their own proprietary designs.

-Development of other designs is recommended, with wind effect resistance and "ejection" of combustion products away from the wall to minimize house staining.

F. Appliance Controls

-A pressure switch to detect a blocked heat exchanger or flue (or a blocked combustion air inlet), to shut down the appliance, is recommended.

G. Installation

-Extended field tests should be performed by the appliance manufacturer to confirm the design of the heat exchanger, vent exhaust pipe, and vent hood related to unit sooting, wall staining and corrosion.

-Combustion air inlet should be on the same outside wall as the flue gas outlet, with east or south wall preferred to minimize wind effects.

-Intake and outlet locations should be per National Fuel Gas Code, ANSI Z223.1 (see attached figure) and any applicable national or local codes.

-Appliance manufacturers must include explicit requirements, approved system components list, and system limitations in their installation manuals.

H. Miscellaneous

-Flue gas temperature at the inlet of the vent hood should typically be in the range of minimum 350°F - 400°F to reduce the possibility of sulfur condensation on the outlet terminal.

-Flue gas temperature at the outlet of the appliance should be maximum 600°F to reduce possibility of damage to high temperature silicone caulk.

-Vent pipe length and diameter should be minimized to maintain high flue gas temperature and high flue gas velocity (consider 3"- 4" diameter).

-Wind tests per ANSI Z21.13 and/or ANSI Z21.47 or equal should be performed to confirm suitable system operation.

CONCERNS:

The following items are of specific concern or caution as relates to direct venting system design:

Staining/sooting of house wall--Some concern has been expressed by experienced field personnel regarding oil/heat/combustion products-related staining and carbon sooting in power and direct vented systems. For this reason, extended field testing by appliance manufacturers in a variety of environments is strongly recommended. Special controls (such as the Flame Quality Indicator) may be warranted to shut down an appliance which is not operating optimally before it causes damage to the side of a house.

High flue gas temperatures--Flue gas temperatures that are too high at the appliance outlet may damage the silicone caulk needed for the gas-tight installation required due to positive pressure in the vent pipe. Proper burner/heat exchanger design can prevent this problem.

Low flue gas temperatures--Flue gas temperatures that are too low can lead to condensation of sulfur (at about 220°F - 240°F) and water (at about 120°F) in the flue pipe and/or wall exit terminal. Flue gases are cooled as they pass from the appliance through the vent pipe to the wall, then they are chilled by the cool or cold outside ambient air that surrounds the vent terminal.

Corrosion--Condensed sulfur, along with ambient moisture or condensed water vapor from the flue gases, will create sulfuric acid, which will attack carbon steel, galvanized steel, aluminum, and some stainless steels.

Vent terminals--Special wall terminals may be needed to project flue gases out and away from the house wall, while shielding the flow from high wind effects. Coaxial exhaust terminals/air inlets have the benefit of preheating combustion air and requiring only one hole in the house wall, but chilling of the flue gases will occur and may be detrimental. Recirculation of flue products to the inlet of a coaxial terminal must be avoided. Wall terminals and exhaust vent pipes must be constructed of corrosion resistant materials.

Appliance design--Because of the positive pressure firing of a typical direct vent system, special consideration must be given to appliance design. Leaks in a positive pressure heat exchanger in a furnace can result in flue gases in the house ductwork. Leaks in a positive pressure fired boiler can also result in combustion products in the home. Loose fitting inspection ports/doors and flue collectors will lead to damage from hot flue gases and soot leakage. Highly restrictive heat exchangers can result in high transient gas pressures and restricted airflow on startup with resultant sooting.

Exhaust vent lengths--Long exhaust vents result in highly restrictive systems and flue gas temperatures that are too low at the wall terminal. Some manufacturers have tested and approved systems with short exhaust vents (2' to 15' maximum), while others have tested exhaust vents of 20', 30' and 40'. Appliance manufacturers must limit exhaust vent lengths in their installation instructions to lengths approved by laboratory testing.

Standardized wind tests--Wind tests are required for sidewall vented gas-fired heating appliances. At this time, wind tests are not included in UL, CSA, or ANSI standards for oil-fired equipment, although the gas standard wind tests are required in Canada and often applied in the U.S. Uniform requirements need to be developed and applied for equipment for the North American market.

Building codes--Barriers related to local and national building codes need to be addressed. This issue includes updating of NFPA 31 for installation of oil fired heating equipment in sidewall vented applications.

System design--All components of the direct vent appliance application--boiler or furnace, burner, air supply, vent components, materials, controls, and codes--must be considered together in an engineered system approach.

CONCLUSIONS:

1. Direct venting, as part of an engineered oil heat system, is a viable option to a conventional chimney.

2. Further development of components and extended testing of systems need to be performed. Several issues need to be considered, including corrosion of vent systems, appliance sooting, house wall staining, and design of vent piping/wall fittings. Also, field experience information needs to be documented and communicated to the oil heat industry.

3. The best burner offerings for direct vent applications provide stable positive pressure firing capability and the feature of easy outside combustion air connection.

REFERENCE INFORMATION:

The following technical papers from past Brookhaven National Laboratory Oilheat Conferences may be referred to for more information regarding direct and power venting:

1987
"Potential Energy Savings by Direct Vent Oil Heating Systems", John E. Batey, pg. 13.
"Safe Venting for Fossil Fuel-Fired Residential Heating Equipment", Harry R. West (w/ A.C.S. Hayden), pg. 87.
"Mechanical Horizontal Venting Equipment", Steve Guzorek, pg. 131.
"Direct Venting Oil Systems -- Field Experience", John D. Marran, pg. 133.

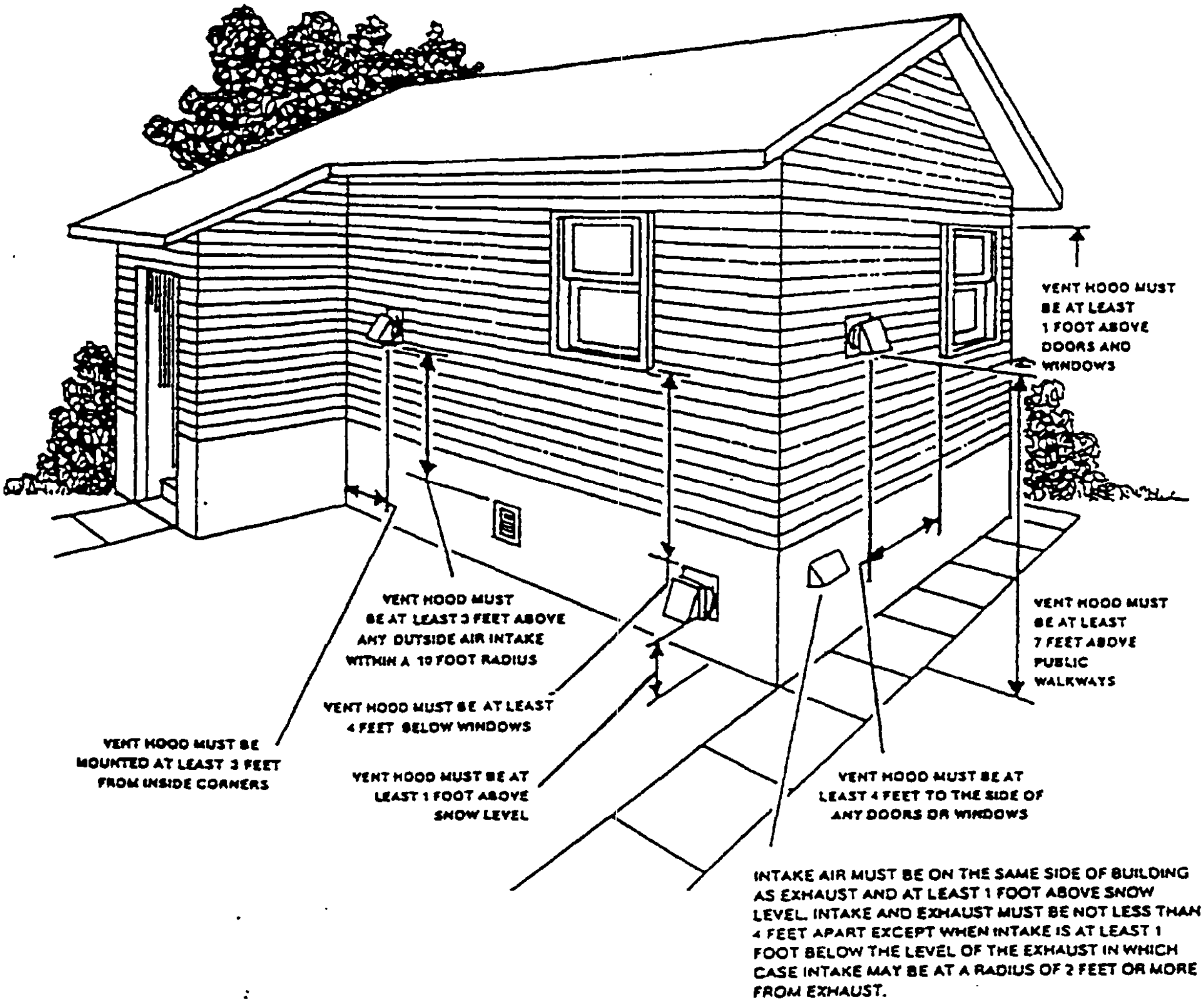
1990
"Oil Appliance Venting Technology", Richard F. Krajewski, pg. 43.

1991
"Guidelines for Venting Oil-Fired Heating Appliances", Krajewski, pg. 143.
"Side Wall Vent Systems: The Challenges, The Solutions, The Future", Jeff Trieb, pg. 155.

1993
"Oil Heat Venting Guidelines -- Vent Materials and Corrosion", Krajewski, pg. 85.

1994
"Canadian R&D on Oil-Fired Combustion Systems", Hayden, pg. 53.

THROUGH-THE-WALL VENT HOOD LOCATIONS



Location of the termination of the vent pipe shall be in accordance with the National Fuel Gas Code: A.N.S.I., Z223.1 (see requirements below) and any local codes which are applicable. Only one boiler may be exhausted through each vent hood.

a. The exit terminals of mechanical draft systems shall not be less than 7 feet above grade when located adjacent to public walkways.
b. A venting system shall terminate at least 3 feet above any forced air inlet located within 10 feet.
c. *The venting system of other than a direct vent appliance shall terminate at least 4 feet below. 4 feet* horizontally from or 1 foot above any door, window or gravity air inlet into any building.
d. An appliance with an input of over 50,000 BTU per hour shall require a 12 inch vent termination clearance from any opening. The bottom of the vent terminal and any air intake shall be located at least 12 inches above snow level.
e. Forced draft systems shall be designed and installed so as to prevent leakage of vent gasses into building.
f. The vent termination point shall not be installed closer than 3 feet from an inside corner of an L-shaped structure.

Paper No. 98-10

Evolution of the Chimney

Arthur A. Irwin

Kerr Controls Limited
3595 Strawberry Hill
Halifax, Nova Scotia Canada B3K 5A8

EVOLUTION OF THE CHIMNEY

Arthur A. Irwin

Background

What brought about the thought process for the subject of this paper? Ironically, an outspoken elderly gentleman who was frustrated with his new heating boiler connected to his eighty year old chimney stated "They can put a man on the moon, why can't they build something as simple as a chimney that works?"

An energy crisis in the seventies and high energy costs accelerated research and development in residential heating equipment. Today, the consumer has an excellent variety of options from which to choose. The main focus was on burners, furnaces and boilers and the lowly chimney was left behind as it was not realized there would be future problems in venting. The consumer and the industry pushed for higher efficiency and when this equipment was put in service, the problems began. In addition to the new housing installations, the heating equipment installed in the forties and fifties was reaching the end of its lifespan. During those years, thousands of conversion oil burners converted homes from wood and coal to oil actually giving many of todays oil dealers their start in business. The next step was the installation of new, more efficient equipment and it was assumed the large, outside brick chimneys would serve the purpose. Unfortunately this was not the case and at this point, the condensing chimney was born. This dealt a major blow to the manufacturing industry as it struggled to develop heating appliances that would perform with existing conditions. The oil heat industry was down but not out and struggled to its feet. Manufacturers, researchers, oil suppliers, and all players combined their efforts and gradually rallied forth. It was obvious alternative options was the solution and at this point, a new breed of venting devices gradually appeared.

Back To Basics

The term "Chimney" covers a vast spectrum of a basic principle. Websters Dictionary defines the chimney as: "A vertical structure incorporated into a building and encloses a flue or flues that carry off smoke". It also describes the chimney as: "A tube of glass placed on a lamp around a flame" Here we have the same basic principle applied to the 200 foot high industrial stack and the old fashioned kerosene lamp.

The Early Years

Let us go back to the turn of the century when considerable progress was made in the residential heating industry. Central heating systems became the norm with large furnaces and massive duct systems and similar progress was made with hot water and steam systems. Efficiency was not a major issue with oil at 18 cents per gallon, research and development (R & D) toddled along at its own leisurely pace.

As burners, boilers and furnaces became more efficient, the traditional brick chimney gradually became a troublesome burden. The situation has changed so drastically, many of the existing tile chimney liners will not meet today's codes. For example, manufacturers of 8" x 8" and 8" x 12" tile liners have been producing the same sizes for over 60 - 70 years and have made few changes.. They have lost a large portion of their chimney market share because they do not conform to the present requirements. More common in rural areas, the first brick chimneys served a kitchen stove and had no tile liner and the earlier furnaces were later connected as well. Today's heating equipment has reached a high level of operating efficiency and that simple device called the "Chimney" with its new problems has left many installers and service people in a quandary.

Interesting Designs
Those large,outside brick chimneys came in many shapes and sizes and were considered as an important part of the architecture of the home as they stood in a stately fashion, carefully crafted by the skilled tradesmen of the era. In fact, many bricklayers were hired because of their design skills and the internal size and shape were secondary. The large size was necessary because the homes were heated with solid fuel. Many of these chimneys have been well maintained and others have been patched, re faced and transformed into structures that hardly resemble a chimney. The original chimneys used for venting heating appliances were inefficient but did meet the needs at that time. Those massive fireplaces were also a main source of heat loss.

A Reversal Began
Running parallel with the introduction of improved burners, furnaces and boilers, manufacturers worked frantically at the drawing boards to improve their products. For many , it was a matter of survival. In fact, many did not. R & D barrelled along which resulted in better burners and better furnace and boiler heat exchangers. In just a few short years, efficiencies climbed from 65% to 80% plus. It has been said that the Flame Retention Burner with its 100 to 300 Deg.F hotter flame and lower emissions was the greatest breakthrough in the history of oil heating. This provided a much needed companion for those fast improving heating appliances that were being developed. These progressive improvements in efficiency also created a major problem.

Higher efficiency meant less waste heat going up the chimney and a drastic drop in stack temperature. Those previous 700 F. degree temperatures that kept the chimney warm dropped to the 350 degree F. level. As the exhaust gases travel up the chimney and drop in temperature, they reach the condensing or dew point and the moisture in the gases forms a corrosive liquid.. The older chimney is also drastically over sized and not compatable with today's heating appliances. Installing a high efficiency heating appliance in an over sized, outside chimney will often guarantee problems. Inside chimneys have far fewer problems because they sit in a warm environment and the draft is more consistent.

Why All The Problems?
After many years, that faithful device, the chimney suddenly became a costly burden. We now had an imbalance in heating technology. Equipment manufacturers had made excellent progress in the development of more efficient burners, boilers and furnaces but the chimney industry lagged far behind. This was understandable in the early stages because nobody suspected in advance there

would be a problem. There are several reasons why the conventional large chimney is not compatible with today's modern heating equipment:

1. Higher efficiency equipment:
    - Lower temperature emissions.
    - Less chimney warming.
2. New burners:
    - Less excess air
    - Less chimney warming.

3. More Efficient Buildings
    - Less running time.
    - Less chimney warming.

Burner - On - Time

What is an average "burner on" time during those cold winter nights ? Very large homes with marginal levels of insulation and an outside brick chimney and an oil burner operating at a steady state efficiency level of 86 - 88% are the typical problem homes. The ASHRAE 103 Standard [3] [4] assumes an average "burner on" time of 9.7 minutes and "off" period of 33.3 minutes. These numbers will vary with each home, heating system and locality.

As we can see, there is not one but several contributing factors that compound these problems. The end result is, the burner runs for shorter periods producing lower stack temperatures than the old, less efficient equipment. It is not the fault of the heating equipment manufacturers, it is a result of temperatures and chemistry. The higher the efficiency, the greater the problem. I call it "The High Cost of Efficiency". Heating equipment that operates in the 80 to 83% efficiency range will have fewer problems than equipment that operates in the 84 to 88% range.

Less Excess Air

The Flame Retention Burners use less excess air which is a definite plus in energy efficient homes. This means the burner is taking less air from the living area in the home. The down side of this statement tells us that less excess air means less warming effect in the chimney and this of course adds to the condensing problem. The following is a typical example:

OLDER EQUIPMENT	
Breech Temperature	600 deg. F.
9% CO2, Efficiency	76 %
Excess Air	69%

TODAY'S EQUIPMENT	
Breech Temperature	450 deg. F.
12% CO2, Efficiency	84%
Excess Air	28%

WE NOW HAVE A REDUCTION OF 41% LESS EXCESS AIR.

Not only are burners more efficient, heat exchangers in furnaces and boilers are much improved resulting in reduced exit temperatures. The new, more efficient heat exchangers actually "wring"' or squeeze more heat energy out of the fuel, leaving less heat energy travelling up the chimney.

More Energy Savings

The third major factor that contributes to the cold chimney problem is the energy efficient building envelope. Blowing in insulation and upgrading the energy efficiency of the home can reduce heating costs by 30 - 40%. Less heating load means faster temperature recovery and less 'on time' for the burner; again, less chimney warming.

The Barometric Damper

Is it necessary? Unfortunately it is unless the heating appliance is certified otherwise. The damper stabilizes the draft over the fire during those unsettled windy periods. This device does contribute to the problem by permitting dilution air to enter the chimney from the living space, adding to the cooling effect. We can easily see the drastic reduction in temperature and the reduced flow of flue gases in today's chimneys versus those installed thirty years ago.

First Symptoms

When modern, highly efficient heating appliances with low stack temperatures are installed in large, outside brick chimneys, the brick increases in temperature very slowly because of the large cold mass. Each five minutes of firing may increase the chimney temperature by only five degrees. If this large mass of brick sits "cold soaking" for several hours, it eventually gets colder rather than warmer. The condensing and formation of the corrosive fluid may take place for some time before it is visually detected. One of the first symptoms is that the corrosive fluid will be seen weeping out around the flue connector thimble and running down the basement wall. When the problem is more serious, the liquid will leech out through the mortar between the bricks and run down the exterior face of the chimney. This can create an unsightly mess. The question is. how much damage has taken place? Inspections with video cameras will not always reveal the severity of the problem.

At What Temperatures Do These Problems Occur?

The moisture in the combustion gases condenses (forms a liquid) as the temperature drops below the dew point. The dew point for sulfuric acid will vary depending on the sulfur content in the oil. Until we see a dramatic reduction in the sulfur levels in furnace oil, we will continue to have the problem. The acid dew point for # 2 furnace oil with 0.25 percent sulfur lies between 225 and 240 degrees F. (Krajewski, 1993). Surfaces below these temperatures will be subjected to a very corrosive environment which can destroy the chimney and the heating appliance heat exchanger. Factors that influence these conditions include chimney wall temperature and flue gas velocity, temperature and dew point each affects the condensate as well.

Suggested Codes and Standards

In this paper, I am using Canadian codes as examples. Any installer or persons selecting materials and equipment should own or have access to, and be familiar with the appropriate codes. I do refer to several examples in the codes but I stress , these sections referred to should not be used without referring to the codes in their entirety, otherwise costly errors could take place. Installers use codes as guidelines which cover most conditions. Codes also specify that it is the responsibility of the user of the standard to judge its suitability for that specific installation. Quite frequently, an installer when involved in an installation in abnormal circumstances, will seek an interpretation for a specific section of the code from the office of the provincial fire authority or a local building inspector. I must stress the fact there are codes and there is common sense! If we can somehow permit a bit of both to enter the picture and allow these to be our guide, we will have far fewer problems with all of our heating installations.

The Canadian Standards Association CAN/CSA - B139-M91 Installation Code for Oil Burning Equipment addresses all residential oil heating installations in Canada. This code was last revised in 1991 primarily to include power venters. This code has served the industry very well but there are sections that are due for upgrading. Another familiar code is CAN/CSA - B365 - M91 Installation Code for Solid - Fuel Burning Appliances and Equipment. Several Canadian insurance companies are now only recognizing solid fuel installations carried out by Wett certified installers. (Wood Energy Technology Transfer Inc). These courses and the certification programme are administered by both government and the wood heat industry primarily on a volunteer basis. Chimney masons are required to use CAN/CSA - A405-M87- Design and Construction of Masonry Chimneys and Fireplaces.

Applying The Codes

As previously indicated, today's heating specialist must be better informed and more versatile than in the past. They must also have a good understanding of codes dealing with related trades. They must be familiar with ventilation systems and heat recovery ventilators because balancing the ventilation rate can have a close relationship with combustion air and venting. To better illustrate an example of how one code can contradict or misinform the user, the CSA B139 - M91 code, section 4.2.2.6 states: " A new appliance or burner shall not be connected to an unlined masonry chimney. Such chimneys shall be relined in accordance with CSA Standard CAN/CSA - A405." This section gives one the impression any **"new"** installation must have a lined chimney and the unlined chimney is acceptable for old or existing equipment. The 1995 National Fire Code for Canada, Section 2.6.1.4 specifies that **"all"** installations must have a lined chimney. The National Fire Code supersedes all other codes and by - laws. By the term "Lined", they refer to a lining of either tile or metal or approved material.

There is a lack of enforcement in many areas which makes life very difficult for the heating contractor who attempts to follow the codes. The contractor quotes the homeowner on the cost of a liner installation and the homeowner often feels the contractor is attempting to make an unnecessary sale This is one of the greatest complaints I receive from the entire heating industry. Another example is: section 5.1 of the B139 - M91 code which specifies that an efficiency test must be performed on all burners after the installation of, or after alteration to or servicing of, or addition to, oil burning equipment. This is a minimum requirement and should be enforced in all jurisdictions.

Using The Flue Sizing Charts.

The CSA- B139-M91 code illustrates Permitted Flue Sizes for both insulated and uninsulated flues in both Imperial and Metric. See table (1) for Uninsulated Flue Sizes.. The problems generally only exist in the uninsulated flues. The table lists four chimney heights with minimum base temperatures based on the total input rating of all connected appliances for various firing rates in USGPH. For example, if the total input is 140,000 Btu/hr. and the firing rate 1.00 GPH, the minimum inside flue diameter is 4" and the maximum is 6", the minimum allowable base temperature is 300 Deg.F. The sizing chart covers firing rates from 0.50 to 5.00 USGPH.

The large, outside brick chimneys are the greatest offenders. Chimneys located inside the building envelope usually contain sufficient heat to prevent serious problems; thus, inside chimneys should be our first choice.

Partial Solutions

There are chimneys with marginal condensing problems that occur on an intermittent basis. If the problem can be properly diagnosed, insulating the vent connector with high temperature insulating blanket can increase the flue gas temperature entering the chimney by 65 to 85 Deg.F. I stress, in minor cases, this approach may or may not correct the problem. Increasing the firing rate of the burner is another corrective measure that may reduce the severity of the problem. Do not fire above the recommended range for the heating appliance.

Not Recommended

A procedure I have seen being used by frustrated oil burner service personnel and do not recommend; is that in an attempt to increase the stack temperature, they remove several tube baffles in steel boilers. Those tubes with the baffles removed will have an accelerated flow of flue gases which will increase the stack temperature. The remaining tubes with baffles will have a slower flow rate of combustion gases. The two flow rates can result in the upper tube sheet being subjected to two temperature differences. This leads to two rates of expansion and contraction which can result in weld fatigue and leaks and reduced boiler life.

Good Practice

When giving seminars on this subject, I continuously stress a very important point to the audience. When quoting on a boiler or furnace installation in an outside brick chimney and feel there is even a remote chance the chimney will condense, put a notation on your quote. Example: "Because of the high operating efficiency of this heating appliance, it may be necessary at a later date to install a metal liner at a cost of X dollars". If you do not take these precautionary measures, the homeowner could legally force you to install the liner free of charge. The homeowner in good faith paid for a new appliance installation and it is not performing. I have seen several examples of this happen and both parties ended up in court. A simple paragraph on the quote would have prevented much grief.

VENTING OPTIONS

Brick Chimneys

The majority of manufacturers of the tile liners are limited to outside dimensions of 8" x 8" or 8"x12" which are oversized. The 8" x 8" tile liner has inside dimensions 6¼" x 6¼". There are manufacturers who are now producing 7, 8 and 10" round liners of tile material but they are too large for the low firing rates encountered in todays energy efficient housing.

The Factory-Built Insulated Chimney - This is a popular option for new construction. The inside dimensions must conform to code requirements. These chimneys are available in all sizes for residential applications. The insulated chimney performs very well because the inside temperature is easily maintained. This is not always an option for renovations in existing buildings because of space limitations and the installation can be labour intensive. Many exterior installations are boxed in as the homeowner often objects to the shiny appearance of the pipe installed outside the building.

"L" Vent - DWS (Double Wall Steel)

The vent consists of an uninsulated metal liner with an inner liner of stainless steel and an outer galvanized type casing with a 1/4" to 1/2" air space between the two. These cannot be used outdoors and require an enclosed shaft with metal spacers to comply with the code and protect the assembly. These are more commonly used in new construction.

"Z" Flex- Flexible or Rigid Chimney Liners

The most logical solution for existing older buildings with large exterior or interior brick chimneys. The flex versions work well in those chimneys with a slight offset. Installation requires the cutting of an opening in the base of the chimney and the liner can be dropped from the top. In the past, installers often back filled with waterproof granular insulation. This procedure is no longer permitted in many jurisdictions. Should the metal liner fail, the insulation could run in and plug the vent and cause a fatality.

Power Venters

The Power Venter, also known as the sidewall vent system, is installed in the chimney connector. It has improved since first introduced, with better materials to withstand corrosion. The venter has an internal blower that boosts the flow of emissions from the appliance to the outdoors. New improved venters have a "0" clearance feature. Extreme care must be taken when installing and balancing these devices to ensure they are operating at maximum efficiency. The Power Venter must be certified by a recognized testing agency for use on each boiler or furnace. The appliance label must specify which venter may be used. The Power Venter should not be confused with the Draft Inducers. The Draft Inducer is simply a paddle wheel blower device that is installed in a slot cut in the side of the flue gas connector. These are sometimes used when poor draft conditions exist but they can have a negative effect on the efficiency of the burner. These can be a compromise when everything else fails.

Direct Vent System

The term " Direct Vent" refers to a non mechanical sealed combustion vent system and is dependent on the static pressure produced by the burner to exhaust the piped emissions through the side wall.

This system performs especially well in airtight houses that are normally sensitive to pressure changes within the structure. Combustion air is piped from the outdoors directly into the burner. The entire system is completely isolated from the home environment. This is of interest to those with environmental sensitivities. Both the intake and the exhaust vent terminal must be on the same exterior wall to ensure the air pressure is balanced through the system. High quality sealants must be used to ensure there are no emissions leaking into the home. The later versions consist of a high grade stainless flex pipe wrapped in a blanket of insulation and enclosed in an aluminum outer spiral flexible pipe. These are safe to touch and are approved for zero clearance through a wood structure. Other advantages includes the much lower sound level and they can be installed with the same simplicity and time frame required to install a clothes dryer. The same exit terminal installation clearances and specifications that apply to the Power Venter are used for the Direct Vent installations. The Direct Vent has become popular in electric to oil conversions because of cost and simplicity in installations.

Other Considerations

Research has been carried out on non corrosive, porcelain lined materials for chimney use which is another option. In Europe, porcelain lined cast iron pipe has been used successfully.The actual cost per foot will be much higher than the present products available but the life expectancy will make the investment practical.

Conclusion

This overview of the history of combustion venting has illustrated how the simple brick chimney has served our needs for several hundred years and how it is now almost obsolete. The energy crisis of the seventies was costly but we would not have the variety of high performance heating equipment available to the consumer today if the crisis had not taken place. The heating industry has come a long way in recent years, but not without problems. Much is expected of today's equipment. It must be as reliable as the household refrigerator. One malfunction causes annoyances, two malfunctions and we have an irate consumer. The credibility of the product, the installer and the heating company are at stake. There is much to be done in the area of information transfer from the manufacturer, the code source legislators and the installation industry. There must be more code enforcement to ensure the heating equipment is properly installed, serviced and maintained. In many jurisdictions, this issue is not presently being properly addressed. Unfortunately, the Oil Heat Industry must pay the price. The end result is always equipment failure, shoddy workmanship and a scar on the image of the industry.

References

Irwin, Arthur. (1997). Kerr Direct Vent System. 1997 Enerhouse Conference. Halifax, Nova Scotia.

Irwin, Arthur. (1994). Sidewall Vent Hood Installation Locations, National Oil Heat Conference. Halifax, Nova Scotia.

Krajewski, Richard. (1993). Paper #93-7. Oil Heat Technology Conference. Brookhaven National Laboratory, Long Island, New York.

Canadian Standards Association. Rexdale, Ontario. - CSA - B139 - M91 Installation Code for Oil Burning Equipment.

ASHRAE - American Society of Heating, Refrigerating and Air Conditioning Engineers Inc. (Standard 103 -Burner On Time)

NOTE: Table 1 (Imperial) Permitted Flue Sizing is from CAN/CSA - B139-M91 Installation Code for Oil Burning Equipment - Fire Safety and Fuel Burning Equipment- A National Standard of Canada. (Do not use this table without referring to the code in its entirety.)

Table 1 (Imperial)
Permitted Flue Sizes and Minimum Base Temperatures for Circular Flues* in Chimneys with Thermal Resistance Less than R6 (6 ft^{2}·h·°F/Btu)

Total input rating of all connected appliances			Flue inside diameter, in		Minimum base temperature, °F, for chimney height, ft, of			
kW	kBtu/h	USGPH	Minimum	Maximum	11	20	28	36
21	70	0.50	3	5	300	400	535	725
27	91	0.65	3	5	275	340	430	535
31	105	0.75	4	5	260	320	380	475
36	119	0.85	4	5	250	300	355	430
41	140	1.00	4	6	225	300	365	430
51	175	1.25	4	6	240	275	320	365
62	210	1.50	5	7	240	275	320	365
72	245	1.75	5	7	230	265	295	330
82	280	2.00	6	8	230	265	295	330
123	420	3.00	7	10	230	250	275	300
164	560	4.00	8	11	220	240	255	285
205	700	5.00	9	12	220	240	250	265

**See Table 3 for equivalent rectangular flue sizes.*

Notes:

(1) *Thermal resistance values for typical chimneys are as follows:*

R2 (2 ft^{2}·h·°F/Btu): clay-lined masonry
A-vent
R3 (3 ft^{2}·h·°F/Btu): metal liner in clay-lined masonry
R6 (6 ft^{2}·h·°F/Btu): metal- or clay-lined masonry with R4.5 (4.5 ft^{2}·h·°F/Btu) insulation between liner and masonry (eg, 2 in of expanded mica or 1-3/8 in of high density glass fibreboard).

(2) *Table is based on 40% excess air. For higher excess air ratios, minimum flue size shall be increased. See commentary.*

(3) *Example:*

- *A furnace with 0.75 USGPH nozzle is to be connected to a 20 ft tall clay-lined, masonry chimney.*
- *The thermal resistance of this type of chimney is R2, which is less than R6. Therefore this table shall apply.*
- *The minimum size permitted shall be 4 in inside diameter.*
- *The maximum size permitted shall be 5 in inside diameter.*
- *The minimum base temperature shall be 320°F.*

Note: Table (1) applies to uninsulated chimneys in Imperial Measure (CAN/CSA - B139 - M91, page 31). Refer to the following pages in the code: page 30, Table # 1 (Metric) = Uninsulated Chimneys; Page 32, Table # 2 (Metric) Insulated Chimneys; Page 33, table # 2 (Imperial) Insulated Chimneys.

Paper No. 98-11

Combating Fuel Related Problems

Wai Lin Litzke, BNL

COMBATING FUEL-RELATED PROBLEMS

Wai Lin Litzke, BNL Project Engineer

INTRODUCTION

Fuel quality affects the performance of a heating system and is an important parameter in the proper and efficient operation of an oil-burning system. The physical and chemical characteristics of the fuel can affect the flow, atomization, and combustion processes.

During 1990-93, a study was conducted within BNL's Combustion Equipment Technology (CET) program under the Fuels, Fuel Quality, and Storage project. The goal of this project was to provide a background of information for future actions by the industry to deal with problems related to fuel. This project was completed in three phases, and the findings summarized in reports [1,2,3]. The 1990 (Phase 1) report presented a broad view of factors that have brought about changes in the quality of distillate fuel, identified the range of problems and concerns with No. 2 fuel oil in the oil-heat industry, and examined trends in variations in fuel oil properties. A broad survey and testing of fuel samples obtained from residential tanks and bulk suppliers was included. The 1992 and 1993 reports (Phases 2 and 3, respectively) looked at the effects of low temperature on fuel cloud- and pour-points, and the effectiveness of some marketed chemical additives in modifying these characteristics. A major study examined the effects of varying fuel properties on combustion performance and emissions, including the effects of aromatics, viscosity, and fuel sulfur content. Guidelines also were developed to inform fuel suppliers about fuel quality, and to provide practical means for minimizing or resolving some of the most common problems related to fuel quality. These guidelines were revised in 1997 with updated information, new sections, and appendices. They will be reprinted by the Petroleum Marketers Association of America as a manual and will be available in 1998. This paper summarizes the contents of this manual.

The scope of the topic of fuel quality is extensive and the manual compiles information with references to technical documents, standard procedures and other resources available to the petroleum industry. Research work at the Department of Energy's Brookhaven National Laboratory (BNL) under the Combustion Equipment Technology program is reviewed; some background information is taken directly from existing BNL reports and BNL conference papers, updating it where applicable. The manual emphasizes the functional and practical aspects of maintaining fuel quality, and consequently, some subjects are discussed more briefly than they deserve, with references noted for further details. The manual includes both technical discussions and hands-on procedures.

FUEL QUALITY ISSUES

The quality of middle distillates, including No. 2 fuel oil, is of growing interest amongst the residential heating fuel industry. Fuel problems related to poor handling characteristics in cold weather, the buildup of sludge in storage tanks, microbial growth, and increased service needs of fuel delivery components are cited as too frequent occurrences each heating season. In addition, with the advent of environmental regulations in 1993 to reduce the sulfur content in diesel fuel, concerns were raised about the current and future quality of home-heating oil. The effects of a red dye that has been required since 1994 by Federal tax regulations in some diesel and home-heating oil has engendered many questions on its impacts on the operations and emissions of burner equipment.

Fuel quality may be determined by standard testing and evaluation methods. The American Society for Testing and Materials (ASTM), particularly its Committee D-2 on Petroleum Products and Lubricants, and the Institute of Petroleum (IP) are long-established sources of such methods for petroleum and petroleum products. Many of these standard methods are accepted internationally as yardsticks for determining product quality. These standards, their significance, and effects on heating-system performance are discussed in this report.

The second group of factors that strongly determines the overall quality of the fuel after it leaves the refinery are conditions of the storage facility. A storage facility, such as a tank, or tanker truck that is not well maintained and allows contaminants to enter the fuel contributes to many of the apparent fuel problems that the typical fuel marketer or homeowner encounters; the contaminants are a combination of fuel-degradation products, water, microbiological growth, and other foreign matter (such as rust, dirt, and corrosion debris). These contaminants form sludge and, therefore, increase the chances of plugging the fuel lines and filters. In turn, this raises service needs and reduces efficient operation of heating equipment.

Fuel quality also is affected by the conditions during handling and storage. Problems related to poor handling characteristics in cold weather, buildup of sludge in storage tanks, microbiological growth, and increased service needs of fuel delivery components are noted often each heating season. In a BNL survey of oil marketers selling No. 2 fuel, service managers, and manufacturers of heating equipment, the most common problems observed in the field are caused by the buildup of sludge and sediment in homeowners' tanks. Plugged nozzles, clogged filters, and pump screens contribute to the highest service needs. Many of these problems relate to the fuel itself or its contamination during storage. The main objective of this manual is to discuss essential aspects of fuel monitoring to maintain its quality.

The use of chemical additives by fuel-oil marketers has become more common as a method of improving the quality of the fuel. Numerous types of additives are available on the market, but reliable information on their proper use and effectiveness in the field is limited; thus, selecting an additive is difficult in many situations. Different types of additives are described in this report to help users understand the functions and limitations of chemical treatment; tips on how to select and effectively use additives are included.

EFFECTS OF FUEL SULFUR ON FOULING OF BOILERS

BNL has studied the role that fuel sulfur plays in the corrosion and fouling of the heat transfer surfaces of home heating boilers. The metal convective heat transfer surfaces of heating boilers are normally above the water vapor dew point (assuming no sulfuric acid - about

120° F) but below the dew point of sulfuric acid (calculated from published correlations and based on actual sulfuric acid and water vapor content - about 220° F). Here, corrosion occurs almost entirely by the condensation of sulfuric acid on the surface, and its reaction with the surface to form iron-sulfate scale.

BNL conducted a series of studies on the effects of fuel sulfur on the rate of fouling of oil-fired boilers. There was a strong correlation between the fuel's sulfur content and the rate of accumulation of deposits on the convective section surfaces . Side-by-side boiler tests with sulfur levels of 0.35% and 0.04% showed that after four months of operation the higher sulfur content fuel produced fouling deposits at a rate 11 times greater. [7,8]

FUELS IN STORAGE AND FUEL CONTAMINATION

Low fuel quality is often reflected in poor handling properties (highly viscous, high cloud- and pour-points), poor combustion, or inherent unstableness increasing the tendency to form gums and sediments. Fuel quality also can be degraded by contamination with water, gum, biological growth, and other debris which can cause sludge to accumulate at the bottom of a tank. Gum is formed when fuels degrade over time in a complex process, which is not fully understood. This process involves different types of chemical changes and is affected by many constituents found in the fuel. Table 1 lists the types of components found in contaminated distillate fuels. They can plug filters, nozzles, and fuel lines, clog screens, and cause wear in pumps and other parts with close tolerances. In addition, dissolved metals can catalyze the degradation of fuel and contribute to its spoilage. Water can promote microbial growth and the buildup of sludge.

The initial step to minimizing quality-related problems is to monitor the fuel. BNL's survey of oil companies who sold No. 2 oil, service managers, and heating equipment manufacturers showed that more than 41% of the respondents indicated that sludge was a frequent problem, and that plugged nozzles occurred most often. However, 41% of the respondents did not monitor fuel oil quality; the remainder did monitor quality somewhat, with only 12% sending samples out for laboratory analyses [1]. Through an effective quality control program a baseline of information can be established to identify the extent of the problem, its specific causes, potential solutions, and the degree of success with treatment options.

Type or Category	Examples
1. Inorganic compounds	1. Dirt, dust, sand
2. Fuel filter particles	2. Paper, cotton
3. Metals	3. Fuel pump wear particles, fuel tank corrosion debris, corrosion debris from filler pipe screens, walls, and caps
4. Biological growth	4. Fungus, yeast, bacteria
5. Organic compounds	5. Fuel-derived sediment and/or gum, wax

Source: U.S. Army Belvoir Research, Development & Engineering Center [10]

Table 1. Particulates (or debris) in Fuels

FUEL OIL SPECIFICATIONS AND TESTS

Numerous fuel specifications exist which may be established through the refinery, transporting pipeline company, or harbor requirements. General specification guidelines provided by international standards writing organizations can be used to distinguish the various grades of fuel. For example, ASTM D396 details the requirements for burner-fuel oils. Table 2 lists the properties and ranges that currently define No. 2 distillate oil used for heating and for engines. Both are included here for comparison since these are commonly used as fungible products. These properties and their significance are defined in the glossary of terms in Appendix A. Specific ASTM reference methods used to determine each fuel property are also cited. These and other applicable test methods can be found in the Annual Book of ASTM Standards [11]; the significance of these test procedures is described in reference [12].

The National Institute for Petroleum and Energy Research (NIPER), formerly the Bartlesville Research Center, conducts an annual survey of petroleum products; one of them is for heating oils [13]. In 1996, analytical data on the properties of 52 heating oils marketed in the United States were submitted to NIPER for processing and reporting. The fuels analyzed came from 26 domestic refineries located in five different geographic regions in which they are marketed. The reported values reflect the average quality of heating oils produced in each geographical area by U.S. refineries. However, the data may not represent the spread of values experienced at the point of end-use and do not reflect weighting based on volume produced or consumed.

The dramatic reduction in sulfur content for heating oil in 1993 is of notable interest. During that year, regulations under the Clean Air Act significantly cut back and limited the sulfur content in diesel fuel used for on-highway transportation to reduce environmental pollution. Sulfur levels appear to have been lowered overall in a large proportion of the distillate pool rather than just in the transportation fuels.

ANALYSES OF FUEL SAMPLES FROM BULK SUPPLIERS/ RESIDENTIAL TANKS

Fuel quality varies more extensively at the point of end-use, such as at the marketers' distribution level or at the customers' tanks. This reflects the continuous mixing of existing fuels in the tanks with new fuels as the supply is replenished. Existing "off-spec" or contaminated fuel may contaminate another fresh batch delivered to a tank or along the distribution chain.

In 1990, BNL obtained 68 fuel samples from suppliers and homeowners' tanks and analyzed them to establish a database of fuel property information [1]. Fuel samples from suppliers were intended to determine the range of property variations in fuels supplied to the domestic heating market. Twenty residential tank samples were obtained from homes with recurrent service needs based on their heating equipment service history. These samples were intended to identify what type of fuel-related problems contribute to such service needs.

The results showed that the cloud point ranged from 16°F to 44°F, with an average of 31°F. The cloud-point temperature, which is currently not specified by ASTM for heating oil, is the point at which wax or precipitation first appears. The average value of 31 °F seems rather high, especially since the majority of the fuel samples were obtained from the Northeast. For comparison, the Colonial Pipeline Company has a specification for fungible fuel oil with a cloud point of 15 F for the winter months and 20 F for the summer months.

In addition to the chemical analyses, other information was recorded for the residential tank samples which includes the tank's location, age, heating equipment service needs, and approximate height of sludge and water from tank-bottom samples. The bottom samples showed that 65% of the tanks contained appreciable amounts of water, and more than 50% of these tanks contained detectable levels of sludge, showing a strong relationship between presence of water and microbial growth. The most common complaints about heating equipment include clogged fuel lines, filters and nozzles, which required the greatest service needs, such as cleaning and replacement. These fuel delivery components are the most vulnerable to contamination and correlate with the results of the survey.

PROPOSED CHANGES TO IMPROVE FUEL QUALITY SPECIFICATIONS

Members of a technical committee within the ASTM Committee D02 on Petroleum Products and Lubricants, Subcommittee E (Burner Fuels) are proposing to revise the Standard Specification for Fuel Oils (ASTM D396) to improve the quality of burner fuels. The proposed changes include reducing the sulfur content in No.1 and No. 2 grade distillate, and to add information regarding low temperature properties. Industry discussions on this proposal are on-going.

MONITORING PROGRAM

Monitoring the fuel is an essential part of maintaining good quality. Guidelines have been established for maintaining fuels used by the military, utilities, and the automotive industry. Although most fuels used for home heating have a relatively rapid turnover rate, usually a certain amount of fuel remains in the tank and becomes mixed with new fuel. Contaminants in the old fuel, such as sludge and water at the bottom of the tank, can degrade the quality of the new fuel. Additionally, fuel can typically be stored for several months over the summer with little or no use, setting up conditions for microbial growth. Therefore, it is important to monitor the condition of the fuel within the tank, the transfer system, and the incoming fuel.

The requirements specified in the American Society for Testing and Materials (ASTM) for distillate fuels used for home heating (ASTM D 396) provides the ranges for various fuel properties. A fuel surveillance program should contain components of quality control. Fuel specifications should become an integral part of the contractual agreements between the fuel supplier and the purchaser. In other words, a bulk sample of fresh fuel oil for heating should at least meet all of the limits in specification ASTM D 396. The buyer is then responsible for periodically sampling and checking the quality of the fuel as it is received. Many of these tests can be performed by private testing laboratories that analyze petroleum samples.

Not all of the ASTM tests need to be done for every batch of fuel. With the rapid turnover of fuel supply between the time of purchase by an oil marketer and delivery to the homeowner, a quick diagnosis of the quality of fuel is needed for some basic minimum requirements. Table 2 gives guidelines that the fuel marketer can use when accepting a batch of fresh fuel from a supplier which might indicate an off-spec fuel or contamination. A visual inspection for haze and floating particles is the easiest and one of the most important tests to do; these tests are simple with the appropriate equipment and training. Most of these tests overlap the requirements under ASTM D 396.

ASSESSING FUEL QUALITY IN STORAGE

Sampling fuel from a storage facility, such as a tank, will help to assess its specific condition. These samples will differ from those obtained for fresh fuels or from any other tank. Contaminated fuel in a tank will degrade the quality of a fresh fuel supply after fill-up.
A visual inspection of a bulk sample will generally show if the fuel is clear or contains free water. Color is not a measure of a fuel's quality. If the color appears to have changed during long-term storage, the fuel may have deteriorated or changed. Look for floating particles or haziness. Haziness usually indicates water, or in cold weather, wax. The fuel can then be analyzed and compared to the specifications of ASTM D 396 or D 975 (No. 2 diesel). Additional tests can be run on the bulk samples, such as particulate contamination (ASTM D 2276), accelerated stability (ASTM D 2274. Dupont/Octel F-21), and biological growth (not an established ASTM test). Although these tests are not listed as requirements under ASTM D 396 or D 975, they are used to establish diesel fuel quality for military purposes (military specification VV-F-800D).

Test	Property Going Off-Spec or Contaminant	Type of Sample
1. Visual[1] (clarity and color)	Water (haze), dirt and other solids	Bulk
2. Visual, appearance	Water[4], sediment, sludge	Bottom
3. Field test kits for fuel microbes[2]	Fuel microbes	Bottom
4. Flash point[3]	Other petroleum products (gasoline, jet fuel)	Bulk
5. Cloud or pour point[3]	Cloud or pour point (critical during cold weather operation)	Bulk

[1] The fuel should be bright and clear. Methods ASTM D 4176, D 1500.

[2] No ASTM methods are available. Manufacturers of biocides often market these test kits for field use. Some kits can approximately measure the degree of contamination (i.e. no contamination, moderate, or severe).

[3] ASTM D 93, D 2500, D 97 respectively; results should conform to ASTM D 396, D 975 fuel specifications, see Table 2.

[4] Commercial water-indicating paste on a stick ("sticking the tank") may be used to determine water contamination.

Table 2. Quick and Easy Tests to Determine Off-spec Fuel.

The particulate contamination test accurately measures the cleanliness of the fuel. However, the accelerated stability test, in general, is not very accurate. It is a predictive test carried out at elevated temperatures to accelerate aging of the fuel. While this test may give a good indication of the performance of a stabilizer additive in the fuel and its resistance to oxidation, it is not necessarily a good test for predicting how a fuel will respond to the tank's environment under normal field conditions.

Bottom samples may either be tested by a laboratory or the fuel marketer for biological activity. Several field test kits reveal whether or not a fuel is contaminated with biological growth. These kits usually contain sample bottles, the nutrient, and an indicator (dye or chart); results can be obtained in several days. These kits are much less expensive than laboratory analyses. While laboratory testing for biological growth can give results expressing contamination in organisms/ml, they may be misleading because of the time lag between taking the sample and getting it to the laboratory.

There is no need to test bottom samples of the tank for stability or cleanliness because the tank will have water and sediment on the bottom. This does not mean that all of the fuel is bad, but that there are contaminants that should be removed.

The following is a recommended time schedule for sampling and analysis:

- In a static tank commonly used for bulk storage, both bottom and bulk sampling should be conducted at least twice a year. Water accumulation in the tank should be checked every 90 days.
- In a tank that has a relatively consistent turnover, such as in a homeowner's tank, a bottom sample should be taken annually, and water accumulation checked monthly. Because the fuel is constantly changing during turnover, a bulk sample will be of little value.
- Samples of the incoming fuel supply should be taken randomly to ensure that the supplier complies with your specifications.

MONITORING SERVICE REQUIREMENTS

Maintaining a strong quality program allows the fuel marketer to deliver to the customer a product that meets specifications, and minimizes fuel-related service calls. One practical way of assessing fuel quality and the efficacy of a fuel treatment program is to establish a record of the customers' service histories. Recording such information as the total number of service calls during a heating season, the number of calls per gallon of fuel throughput, the type of service needed, the type of fuel storage system, and costs, allows the best options for fuel treatment to be selected.

CORRECTING THE PROBLEM

There are several ways to deal with off-specification fuel. If the problem is discovered in time with a fresh batch of fuel, then the fuel should not be accepted from the supplier. The alternatives are to bring the fuel back into specifications by methods such as dilution/blending, fuel additive treatment, tank cleaning, fuel filtration, or a combination of these options.

PREVENTATIVE MAINTENANCE

A preventative maintenance program should be based on need, resources, and common sense. A successful fuel quality surveillance program must include the following items: (1) specifications when purchasing fuels; (2) monitoring/sampling and record-keeping; and (3) good housekeeping.

A set of procedures and guidelines should be established for the sampling and testing program and adhered to. This program should become a routine part of maintenance. Documentation should be set up so that sampling, testing and remediation efforts can be reviewed at any time. This information is valuable, and in the long run, will save money and quickly solve problems.

Good housekeeping requires minimizing dirt and water entering a tank. Water promotes the growth of microbes, which use the fuel as a food source, and accelerates internal corrosion of the tank. Water can enter a tank through cracked or leaking fill pipes and vents, and therefore, these should be checked when water contamination is suspected. The change in air temperatures can cause condensation within the tank. Dirt and debris are generally introduced into the fuel through careless handling.

Personnel who carry out the maintenance program should be trained and motivated on why they are doing the work. Sloppy procedures can be costly and ineffective. The system should be checked from the receipt of fuel, through delivery and storage.

REFERENCES

[1] Coughlan, R.T., Gang, W., Sanchez, J. and Strasser, J., "An Overview of Residential Heating Fuel Quality", Interim Report, Brookhaven National Laboratory, BNL Report No. 45996, December 1990.

[2] Litzke, W., Fuel Quality Issues in the Oil Heat Industry, BNL Report No. BNL-48524, December 1992.

[3] Litzke, W., Small Oil-fired Heating Equipment: The Effects of Fuel Quality, BNL Report No. BNL-49630, August 1993.

[4] Lee, S.W., "The Effects of Changes in Fuel Quality and Burner Technology on Oil Furnace Performance," ASHRAE Transactions, 1990, Paper SL-90-15-2.

[5] Lee, S.W. and Hayden, A.S., "Effects of Middle Distillate Fuel Properties on Residential Oil Combustion Characteristics," ASHRAE Transactions, 92, part 1B and 2B, 1986.

[6] Energy Information Administration (EIA), Petroleum Supply Annual, 19871-1990, Department of Energy, DOE/EIA-0340(90)/1.

[7] Butcher, T. A. and Celebi, Y., "Fouling of Oil-Fired Boilers and Furnaces," Proceedings of the 1993 Oil Heat Technology Conference and Workshop, Brookhaven National Laboratory, Upton, NY, March 25-26, 1993, BNL Report No. BNL-52392.

[8] Litzke, W., Celebi, Y, and Butcher, T., "Fuel Sulfur and Boiler Fouling," Proceedings of the 1995 Oil Heat Technology Conference and Workshop, Brookhaven National Laboratory, Upton, NY, March 22-23, 1995, BNL Report No. BNL-52475.

[9] Laisy, J. and Turk, V., "Fuel Oil Quality Task Force," Proceedings of the 1997 Oil Heat Technology Conference and Workshop, Brookhaven National Laboratory, Upton, NY, April 3-4, 1997.

[10] Diesel Fuel Stability and Cleanliness Problems in the Field, Special Bulletin, U.S. Army Belvoir Research, Development & Engineering Center, June 1987.

[11] American Society for Testing and Materials, Annual Book of ASTM Standards, Section 5, Vols. 5.01, 5.02, and 5.03, on Petroleum Products, Lubricants, and Fossil Fuels, ASTM, 1916 Race St., Philadelphia, PA. 19103, 1988.

[12] Manual on Significance of Tests for Petroleum Products, American Society for Testing and Materials, ASTM Publication Code Number (PCN) 28-001093-12, November 1993.

[13] Heating Oils, 1996, National Institute for Petroleum and Energy Research, Report No. NIPER-196 PPS, June, 1996.

[14] "Storage and Handling of Fuel Oil for Standby Diesel Generator Systems, A Guide for Nuclear Power Plant Maintenance Personnel", Electric Power Research Institute, August 1988.

Paper No. 98-12

The Effects of Red Dye and Metal Contamination on Fuel Stability

Robert E. Tatnall, P.E.

Fairville Products Inc.
302 Robinson Lane
Wilmington, DE 19805-4674

The Effects of Red Dye and Metal Contamination on Fuel Oil Stability

Robert E. Tatnall, P.E.

ABSTRACT

Distillate fuels can degrade and, in doing so, produce suspended particles which foul and plug filters, strainers and nozzles. Various things can catalyze this degradation, including certain dissolved metals. Many in the business believe that these problems have become worse in recent years, and may coincide with the introduction of red dye into fuels. This study looks at the effects of copper contamination, red dye, and fuel stabilizer on No. 2 heating oil and low-sulfur diesel fuel. In addition, light absorbance is evaluated as a better alternative to filtration methods for determining the quality of a fuel.

INTRODUCTION

Among fuel oil dealers there is widespread concern about fuel quality, and a widespread belief that operating problems in heating systems are on the increase in recent years - perhaps due to some sort of drop in fuel quality. This term "quality" is not well understood, even among fuel chemists. The required use of red dye in non-taxed distillate number 2 has introduced another unknown into the fuel issue, and some people suspect that the dye may be partly or fully responsible for a decrease in fuel quality.

Refiners and fuel chemists contend that overall fuel quality has, if anything, improved in the past decade as a result of better refinery control. They also say that red dye should not affect fuel performance in any way, and that perceived recent increases in operating problems are due either to increasing awareness of problems on the part of the industry, or to the fact that newer burners are more sensitive to normal variations in fuels than were the older-design burners.

While many fuel oil dealers profess concern about the quality of fuel, few of them even bother to test the fuel they buy and resell. They have no way, therefore, to know whether fuel quality is really varying with time - let alone whether such variations in fuel properties actually correspond with periods of high service demand. It is only when extreme problems develop in customers' heating systems that oil dealers tend to have their supplies analyzed.

As one example of fuel quality issues, several reports have been received in the past two years of unusually high numbers of plugged nozzles but without fouled filters and other classic signs of fuel sludge fouling. Several dealers have also complained about receiving "black oil", which invariably leads to plugging problems. In some cases the fuel oil in question had been analyzed by the refinery or the fuel distributor and appeared to meet common criteria for acceptability, except perhaps for color.

To a fuel chemist or consultant, "black" fuel oil usually means the fuel has degraded and is loaded with suspended particles. How about those cases where there is no obvious discoloration of the fuel? It is possible that such cases are due to fuel which is good while in the tank, but becomes destabilized in the heating system.

Fuel stability, then, is an important quality factor which should be monitored. There are several industry standard tests of a fuel's stability, but all are voluntary unless specified by the customer or by the transporter of the fuel (including pipeline companies). The most widely applied specifications for U.S. distillate fuels, in fact, are those drawn up by the Colonial Pipeline Company, and which include a specification for both thermal stability (PAD rating) and oxidation stability (ASTM D4176).

There are several factors which can affect the stability of a distillate fuel, including heat, light, and contamination by any of several types of metal ions. Metals which are thought to catalyze fuel degradation include copper, iron, nickel, cobalt and manganese. The basic hydrocarbon chemistry of fuels may also be an important factor in its stability, although the chemical parameters which lead to instability are not well understood.

These degradation accelerating factors, or "catalysts", are additive. In other words, fuel that is unstable may not degrade rapidly until it is heated. This might explain, for example, why some apparently "good" fuel forms large quantities of particles just behind the nozzle - and why some dealers report that their plugging problems seem to occur mostly in newer systems where the nozzle runs hotter.

The fact that metal ion contamination is an important factor in fuel instability has become apparent through analysis of the particles that have caused plugging. Figure 1 shows an energy dispersive spectroscopy (EDS) scan of a deposit removed from a plugged pump strainer submitted by one fuel oil dealer. These particles contained high levels of iron, copper, manganese and sulfur. Figure 2 shows a similar analysis of particles which formed in a jar of fuel oil from a dealer's bulk storage tank and then was exposed to light for several months in a closed polypropylene bottle. These particles also showed significant levels of iron and copper, though much less than did the first sample. Obviously these metals were present in the fuel oil when it was drawn out of the bulk tank, as they could not have come from the polypropylene jar. The dealer who sent this latter sample said that the fuel looked good in his tanks, but that he was having a lot of problems with plugging of nozzles and strainers. In neither of these cases had the dealers actually tested the fuel for stability or contamination.

While metal contamination was probably a factor, the exact causes for these deposit plugging problems was never determined. The problems eventually went away as those lots of fuel were consumed and replaced with new (presumably better quality) fuel oil.

Metal ion contamination may occur for a variety of reasons. It may come from the crude oil itself, although refining should normally send such contaminants out with the residual fuels and the distillate bottoms (asphalt), rather than passing them through to the lighter distillates.

Corrosion of fuel-handling systems is another possible source. Most often, however, corrosion of tanks and pipelines leads to iron oxide corrosion products which are insoluble and therefore not nearly as catalytic as are dissolved ions.

As for copper contamination, fuels generally do not contact copper or copper alloys in their storage and handling - until they arrive at a residential or small business heating plant where copper tubing is the most common conduit from storage tank to burner. Even then, fuels are generally not corrosive to copper unless there is either 1) significant biological activity (i.e. active sludge deposits) or 2) free sulfide in the fuel. Hydrogen sulfide carryover from the refining operation has historically been a concern, and ASTM Standard Test Method D 130[1], was developed primarily to address this possibility. Major refineries generally check their production by this method and add copper corrosion inhibitors as required to meet the Colonial Pipeline specifications, which are the most commonly applied standards for U.S. petroleum products.

Sulfides may also be formed after the fuel leaves the refinery by the action of sulfate reducing bacteria (SRB). While these particular types of organisms have not been widely reported in liquid fuel systems, neither have tests for their presence been widely applied in these areas. Because active sludge in fuel oils is now known to contain a rich biological ecology, it is quite likely that SRB are present in at least some such contaminated systems.

In addition to concerns about fuel contamination and fuel stability, the government-mandated use of red dye in non-taxed No. 2 fuel oil has been suggested as another possible cause of heating system problems. While dye is added at only trace levels, its use roughly coincides in time with the increased incidence (or awareness) of fouling and plugging problems in oil heat systems. The fact that burner-side deposits frequently show a distinct reddish tint tends to help convince some that the dye is at least partly to blame. At least one study has concluded that the red tint seen in these deposits is simply a manifestation of the presence of red dye, and not because the dye caused the depositing.[2]

Because of these concerns, we decided to run tests to measure the effect of copper contamination, red dye on the stability of fuel oil - as well as the ability of chemical stabilizers to prevent fuel degradation in the presence of copper contamination.

In the course of these experiments, it became obvious to us that the accepted "filtration" method of measuring fuel degradation was difficult to apply and prone to operator error. That method involves passing a measured amount of the fuel through a filter paper, then comparing the appearance of that filter paper to a set of standards to estimate the number of particles removed from the fuel. A secondary purpose for this work, then, was to evaluate light absorbance measurement as an alternative to filtration methods for estimating particle loading of a fuel.

TESTS USING HIGH SULFUR FUEL OIL

Standard number 2 fuel oil was obtained from a Philadelphia area refinery, both with and without red dye. Only the dye feed was momentarily shut off for the latter sample, so that the two fuel samples were identical except for the presence or absence of dye. We were told that it is normal practice at this refinery to produce to Colonial Pipeline specifications, with only pour point depressant and corrosion inhibitor added as required to meet the pertinent specifications.

These fuel oil samples were divided among several plastic jugs, each receiving about three and a half liters. One ml of water, condensed from the atmosphere, was added to each jug to simulate naturally condensed moisture expected in most stored fuel oil. Some of these jugs were then contaminated with ionic copper in the form of cupric naphthenate, 6% solution in mineral spirits, purchased from Pfaltz & Bauer, Inc., of Waterbury, Connecticut. This was added at a level to equal 25 ppm copper by weight. Some were treated with an additive containing a fuel oxidation stabilizer, "N-5302", made by Nalco/Exxon Energy Chemicals, L.P. of Sugarland, Texas. The stabilizer component of this product, which is identified only as an "amine substituted resin", is typical of the general class of oxidation stabilizers found in many multi-purpose fuel additives. Those treated with this additive received 114 ppm dose by weight, roughly in the middle of the manufacturer's recommended dosing range of 20-200 ppm. The various treatments are shown in Table I.

Addition of the copper naphthenate produced an immediately visible greenish tint in the undyed fuel. The stabilizer additive treatment itself produced no immediate visible effect - nor did it affect the initial greenish tint in those samples also treated with copper.

Samples from the various jugs were placed in 13mm glass test tubes and the absorbance at 650 nanometers (nm) was measured with a Baush & Lomb (Now Spectronic Instruments) Spectronic 21D spectrophotometer, using distilled water as a zero reference. This particular light wavelength was chosen because 650 nm is considered the standard red wavelength, so red color should not be absorbed by a 650 nm beam. (Colors of light seen by the eye are determined by which portions of the spectrum are not absorbed, so a distinct red color, as imparted by a red dye, would normally mean that all colors other than red are absorbed by that dyed substance and our eye receives only the non-absorbed red.)

These initial absorbance measurements showed a significant increase in absorbance as a result of copper naphthenate addition, which apparently was the result of direct absorbance by this compound and not the result of particles in suspension, as none were visible nor detectable by filtration of these initial samples.

The jugs were placed inside corrugated cartons to shield them from light and stored indoors at ambient temperatures ranging from a high of about 32° C (90° F) to a low of 15° C (60° F).

After two weeks all of the jugs treated with copper had turned a dark blackish color. The jugs which were not contaminated with copper appeared unchanged to the naked eye since the start of the test. Once again, and at monthly intervals thereafter, absorbance values were determined, and are shown in Figure 3. Some of the most degraded fuel was filtered through a 0.45 micron nylon membrane filter to collect the suspended particles, and these were then analyzed by EDS as described earlier. The results are shown in Figure 4. This deposit had many similarities to the two samples discussed earlier from field plugging problems, including high levels of copper and sulfur - as well as cobalt, which is not explained.

OPTIMIZATION/VALIDATION OF ABSORBANCE METHOD

The above work raised several questions about the use of light absorbance as an analytical replacement for the filter method. For example, can the initial shift in readings caused by copper naphthenate addition be eliminated, so that only particles which subsequently form are measured? Is there a better light wavelength to use than 650 nm? Is the change with time only a result of suspended particles, or is it also affected by fuel color changes as well?

A sample of the undyed, untreated fuel as used for the above experiment was treated with dye at ten times the normally recommended dose. The dye that was used was Unisol Liquid Red B-50 obtained from United Color Manufacturing, Newtown, PA. This is the same red dye used by the refinery that supplied the fuel for the previous experiment. The absorbance of this dyed sample was determined at various wavelengths, as was a sample of the same fuel undyed. The differential between these two sets of readings is plotted in Figures 5a and 5b. It was found that the two samples gave the same exact reading only at 900 nm, which is beyond the visible light spectrum in what is called the "near infra-red" region. Based on this observation it was decided to read all future samples at 900 nm.

To address the question of whether measuring absorbance is really a measure of suspended particles, we mixed the most degraded (undyed) fuel from the experiment described earlier with clean diesel fuel in varying ratios, and then measured the absorbance of these mixtures at 900 nm. The results are shown in Figure 6. It was seen that there is a good arithmetic correlation between relative numbers of particles and light absorbance. It may be argued, however, that the color of the mixed samples also varied with the mix ratio, so this experiment did not rule out the possibility that the light absorbance was as much an indication of sample color as of suspended particles.

To resolve this issue, some of the badly degraded fuel oil was filtered through a 0.45 micron membrane to remove the particles, placed in a test tube, and compared with unfiltered fuel from the same jug as well as with undyed fuel oil from the same test but which had not been contaminated with copper. The unfiltered, contaminated fuel oil had a deep amber color as seen in a 13 mm test tube - but looked black when viewed through the greater cross-section of a quart jar. The fuel oil which had not been contaminated still had the same pale straw color it had at the start of the test five months earlier. The filtered sample had the same deep amber color as did the unfiltered sample. In fact, it was difficult to distinguish between the two copper-contaminated samples with the naked eye, as the black particles suspended in the unfiltered sample were mostly too small to be seen by eye. The 900 nm light absorbance readings, however, were as follows:

Uncontaminated sample (pale straw color)	.006
Contaminated, filtered (dark amber color)	.015
Contaminated, unfiltered (dark amber color)	.127

Whether the slight difference between the filtered and the uncontaminated samples was the result of remaining particles which were not filtered out, or whether it was due to color or changes in the fuel chemistry was not clear. The important thing is that filtering the sample, though apparently not affecting the visible color of the sample, did lowered the absorbance to near that of an uncontaminated sample. From this it is apparent that the absorbance measurement detects mostly suspended particles and is relatively insensitive to changes in fuel color.

To compare readings of absorbance with the classical filtration method, the various mixtures used to generate Figure 6 were also filtered using prescribed procedures and the filters compared with the standard chart. As seen in Figure 7, there was good correlation as read by "Person A". When two other people were asked to interpret the same filters, however, they assigned very different values, as also shown in Figure 7. The fact that different people see this comparison differently indicates that the filter comparison method is subjective in nature.

EFFECTS OF COPPER AND DYE ON LOW-SULFUR FUEL

Several questions and issues remained. All of the deposit analyses contained sulfur. Does this mean that sulfur chemistry plays a role in the degradation process? If so, would a low-sulfur diesel fuel behave as this fuel did? These samples received a very high level of copper contamination. Would lower levels such as 1 or 2 ppm cause similar degradation? An oxidation stabilizer was tried in the first experiment. There are other types of stabilizer on the market, however, which are specifically intended to deactivate metal contaminants such as copper. How effective are they in the presence of known copper contamination? Red dye at normal levels did not seem to have a significant effect, as indicated in Figure 3. This curve showed what night be a slight effect, however. Was this simply normal test variability, or does dye really have some effect on fuel stability. If so, perhaps adding much higher levels of red dye would show this effect more clearly.

To address these issues, low-sulfur diesel fuel was purchased at a local service station. According to the station manager, this diesel fuel was not considered to be "additized", so it should contain only whatever minor additives were used at the refinery to meet commercial specifications.

This fuel was placed into one-liter PET plastic bottles, each bottle receiving 800 ml. Half of these were then dyed with the B-50 red dye at the rate of 24 ounces per 1000 barrels of fuel, approximately ten times the normally refinery dose. Each bottle also received 1 ml of air-condensed water as in the first experiment. Some of the bottles were treated with copper naphthenate at a dose equivalent to either 1 or 5 ppm copper.

Some of the bottles with copper added were also treated with the same oxidation stabilizer used in the first experiment, but this time we used the pure oxidation stabilizer component rather than the multi-purpose product used in the previous tests. Other bottles were treated with a different type of stabilizer. This latter product, "EC5305-A", and also sold by Nalco/Exxon Energy Chemicals, is a blend of oxidation stabilizer with a copper deactivator intended to tie up the dissolved copper and make it less catalytic in nature. Both of the stabilizer products used here were initially added at a dose of 25 ppm by weight. All of the bottles were then placed in a dark container and held at a temperature of 15° to 22°C (60° to 72° F).

After 17 days, only minor changes were observed in the contaminated bottles, so the copper levels were increased from 1 and 5 ppm to 5 and 15 ppm respectively. At the same time the two stabilizers were increased from 25 to 125 ppm in the bottles which had originally received stabilizer treatment.

At day 38, only minor changes were still apparent, so copper levels were further increased to 20 and 40 ppm respectively. No additional stabilizer was added at this time. Fourteen days after this last increase, significant absorbance changes were measured in the bottles containing added copper, so the bottles previously treated with the two stabilizers had their treatments increased from 125 to 625 ppm.

Figure 8 shows the overall absorbance curves for dyed and undyed bottles, with and without the higher doses of copper added. It is seen that the dye made no difference, either in the uncontaminated control or in the contaminated cases. Figure 9 shows the absorbance curves for undyed bottles with and without copper at the higher doses.

It should be pointed out in this experiment that the initial dose of mixed stabilizer/copper deactivator, 25 ppm, was the dose recommended by the manufacturer for treating fuel containing 1 ppm copper. The bottles containing the higher levels of copper contamination were, therefore, undertreated with respect to the copper deactivator.

Figure 10 shows the absorbance curves for the undyed bottles which received the lower doses of copper. During the first part of the test period (up to day 38) these bottles, unlike those represented in Figure 9, received the full recommended dose of the copper deactivator product (25 times the copper level). From day 38 to day 52, they were somewhat undertreated, and then, starting on day 52 they were again "properly" treated.

This only applies to the mixed stabilizer, however, and not the straight oxidation stabilizer. As mentioned earlier, the manufacturer does not normally specify just an oxidation stabilizer in the presence of copper contamination - so its recommended dose rate is independent of copper level. The initial dose of 25 ppm would be considered, according to product data sheets to be a "middle range" dose; the 125 ppm dose from day 16 to day 52 would be considered a "high" dose; the final dose rate of 625 ppm starting day 52 would be considered "unusually high". Nonetheless, we chose to use the same dose rates for both of the two stabilizers for these tests.

In this test using low-sulfur diesel fuel, the degraded fuel did not darken as much as did the high-sulfur fuel for a given amount of absorbance increase. Similarly, when degraded low-sulfur fuel was filtered, the particles remaining on the filters were seen to be a pale greenish color rather than the dark brown/black typical for degraded high-sulfur fuel. While these greenish particles were not analyzed, it is believed that this color difference reflects the fact that it is a sulfur product (perhaps iron or copper sulfide) which gives particles and fuels their very dark color, and not the degraded hydrocarbon itself.

DISCUSSION AND CONCLUSIONS

It was confirmed that distillate fuel, whether high-sulfur heating oil or low-sulfur diesel fuel, degrades rapidly in the presence of dissolved copper. It appears, however, that the copper level must be high - perhaps on the order of 25 ppm - for severe degradation to occur at room temperature in a matter of a few weeks. This is surprising, as we were previously told that even one or two ppm copper should trigger rapid degradation.

It is clear from these experiments that red dye, even if added at excessively high levels, does not cause fuel oil to degrade faster in the presence of copper contamination - nor does dye by itself seem to trigger degradation on fuel not otherwise contaminated.

While stabilizer additives do seem to have some benefit in the presence of copper contamination, it was seen that very high levels of stabilizer are required to completely protect against degradation in such cases - levels which may not be cost effective. The low levels provided in most multi-purpose additives when used at recommended dose rate would seem unlikely to protect against metal ion problems. When extremely high levels of stabilizers are added, it appears that a straight oxidation stabilizer is probably as effective as is a mixed oxidation stabilizer/metal deactivator additive - and is probably the more cost-effective choice.

For monitoring fuel quality and interpreting the results of fuel stability tests, it appears that light absorbance at 900 nm is a simpler, more reproducible and more dependable method than are the current filtration methods. While we did not look at factors other than fuel degradation, it seem likely that light absorbance should be capable of detecting not only degradation, but other quality parameters as well - such as the haze produced by entrained water. It will also apparently spot fuel which has been contaminated with metals but which has not yet started to degrade.

One might envision an inexpensive, hand-held instrument to be used by fuel oil dealers to routinely check fuels for signs of degradation and other problems detectable by this method.

An important advantage of measuring light absorbance to monitor fuel quality is that it ignores the red dye which makes visual inspection so difficult. If a dealer accepts all fuel unless it is black, he will risk accepting fuels that are degraded but not enough to show past the red dye. Visual inspection offers yet another challenge for users of low-sulfur fuels, as these apparently do not necessarily blacken as do the high-sulfur fuels, even while they are degrading badly. Here, again, the use of light absorbance at 900 nm is uniquely useful, as it sees suspended particles regardless of their color.

Should new fuel show no signs of degradation or metal pickup during storage and transit, the next most likely source for metal contamination is by corrosion of tanks, copper lines, pumps or filters. Fuel itself is not normally corrosive, even when it contains some water. When microbiological contamination is added to this mix, however, then the deposits and sludge formed by those microorganisms can be corrosive.

As for fuel stabilizers, this work raises questions about their effectiveness, and especially their cost-effectiveness, in the presence of metal ion contamination. Because stabilizer ingredients tend to be expensive, dealers should be especially skeptical of multi-purpose additives that promise to stabilize fuels as well as doing several other good things - all at a very low price. For example, the cost of treating at the very high level necessary to protect against 20 ppm copper contamination using the oxidation stabilizer tested in this program would cost on the order of two to four cents per gallon of fuel oil - and that is without adding any other functional benefit! It would appear more cost effective for the dealer to 1) check incoming fuel and reject any that fails the 900 nm light absorbance test, and 2) take steps to prevent contamination within his systems.

RECOMMENDATIONS

This work presents interesting and potentially useful results, but it is far from complete. Some organization - perhaps Brookhaven National Laboratory - should build on this work to develop meaningful specifications and methods for use by fuel oil distributors and dealers. If further work supports the use of light absorbance at 900 nm, equipment manufacturers should be urged to make a suitable hand-held instrument available.

In addition, new specifications for fuel oils should be developed which include acceptable levels of light absorbance, as well as metal ion contamination.

Finally, fuel oil dealers should be educated in the need to purchase fuel to a meaningful specification - and to check those fuels to be sure they meet that specification. Only then will fuel quality cease to be a major factor on oil heat reliability.

ACKNOWLEDGEMENTS

Mr. Brian Hills provided many of the samples of fuel and additives used in this study, as well as much-needed information about refinery practice and fuel chemistry. Corrosion Testing Laboratories, Inc. did the EDS analyses.

REFERENCES

1. ASTM D 130-94, "Standard Test Method for Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test", American Society for Testing and Materials, Philadelphia; 1994.

2. Laisy, J. and Turk, V. "Fuel Oil Quality Task Force", Proceedings of the 1997 Oil Heat Technology Conference and Workshop, Brookhaven National Laboratory, Upton, NY; 1997.

Jug No.	Dye?	Cu?	Stabilizer?
1	No	No	No
2	"	Yes	"
3	"	No	Yes
4	"	Yes	"
5	Yes	No	No
6	"	Yes	"
7	"	No	Yes
8	"	Yes	"

TABLE I - Makeup of test containers in first experiments.

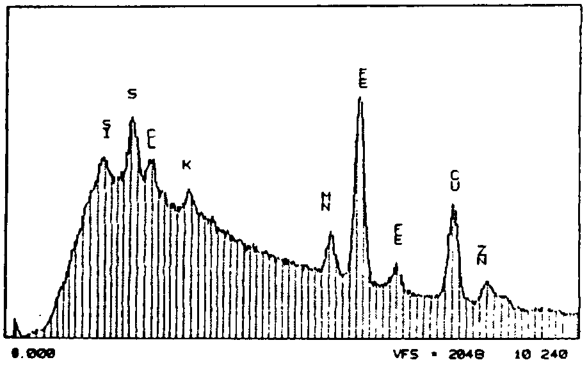


Figure 1 - EDS scan of dark particles removed from plugged screen. Iron, copper, sulfur and manganese are the major (inorganic) components.

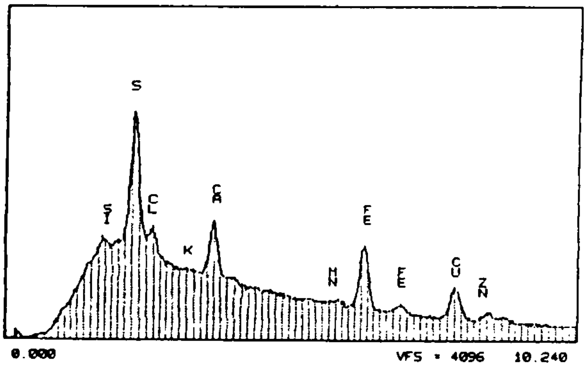


Figure 2 - EDS scan of dark particles filtered from stored fuel that had sat in the light for several months. Again, iron, sulfur and copper are major elements.

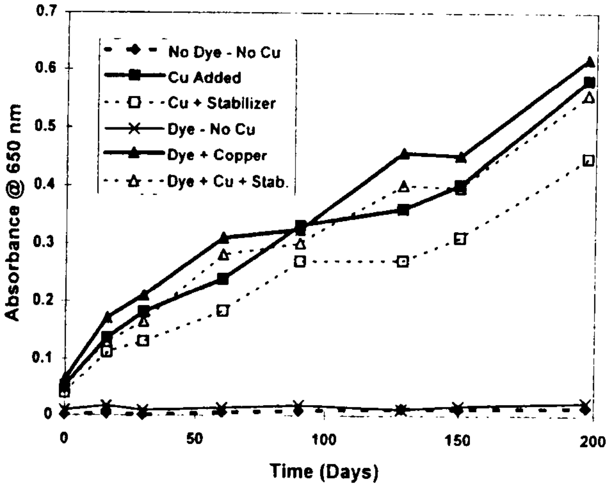


Figure 3 - Curves showing light absorbance at 650 nm vs. time in the first experiment. Samples without copper but with stabilizer are not shown, but their values were virtually the same as the other samples without copper (the two lines at the bottom here.).

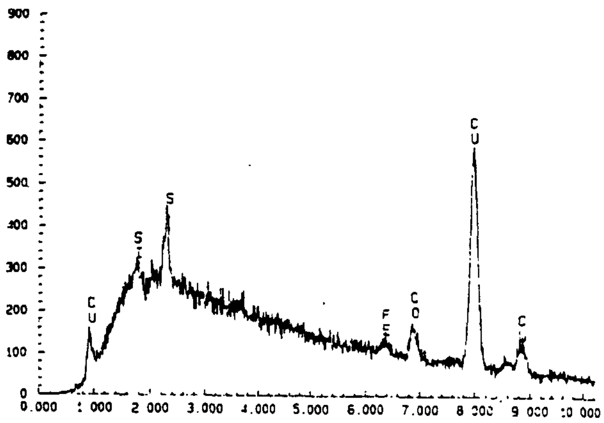


Figure 4 - EDS scan of particles filtered from the first experiment. Copper is the dominant element, followed by sulfur and cobalt.

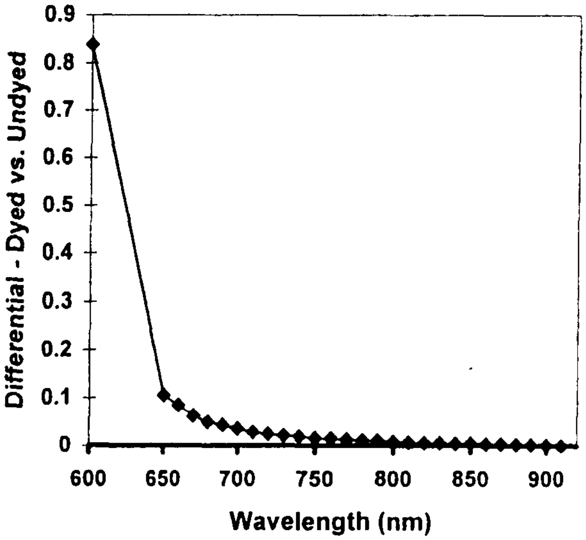


Figure 5a - Curve of difference in light absorbance at various wavelengths for clean, non-degraded fuel, dyed vs. undyed.

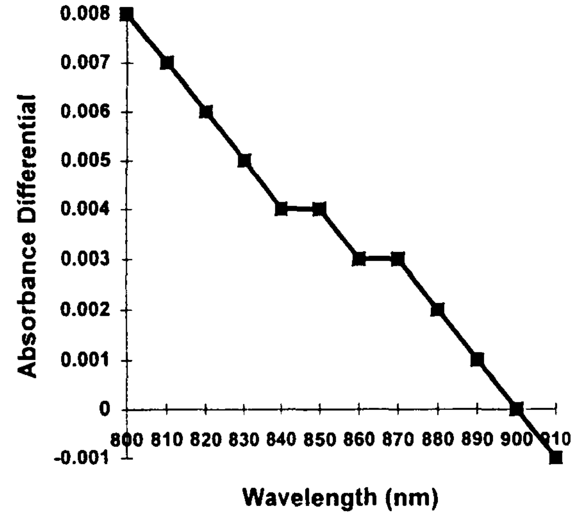


Figure 5b - Portion of Figure 5a over the range of 800-910 nm, expanded to show how the response is the same (i.e. differential is zero) with and without dye at 900 nm.

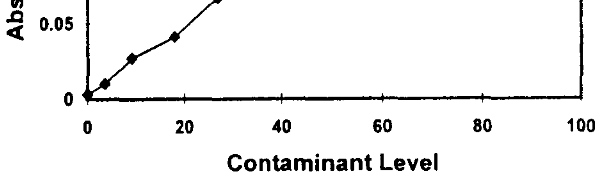


Figure 6 - Absorbance at 900 nm of samples representing various ratios of degraded fuel containing suspended particles and clean fuel. "Contaminant level" means percent of mix that is degraded fuel.

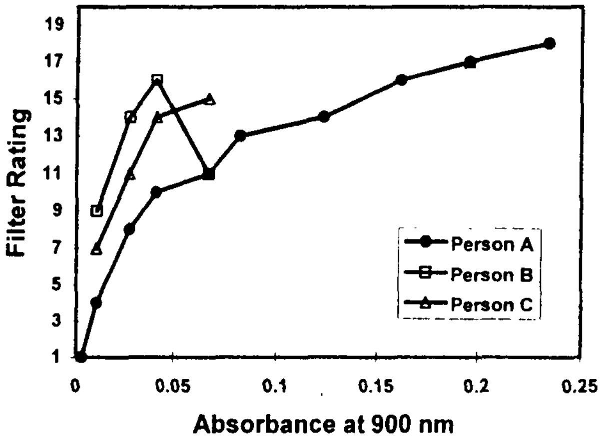


Figure 7 - Correlation between light absorbance at 900 nm and filter "rating" as used for present tests of fuel stability and cleanliness. Note that while Person A found reasonably good correlation, Person B and Person C interpreted the same filters quite differently.

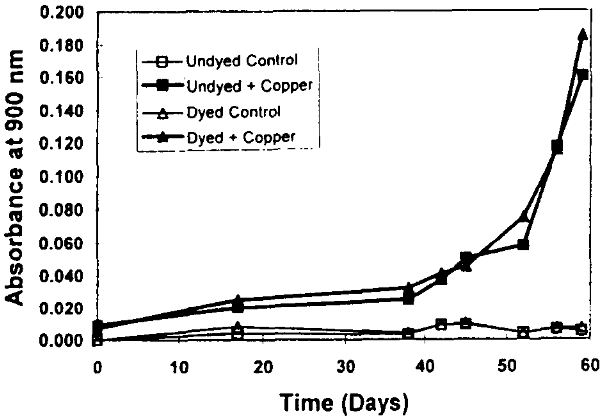


Figure 8 - Light absorbance at 900 nm vs. time for samples in the experiment with low-sulfur fuel, showing that dye makes no difference in stability of this fuel, with or without copper contamination.

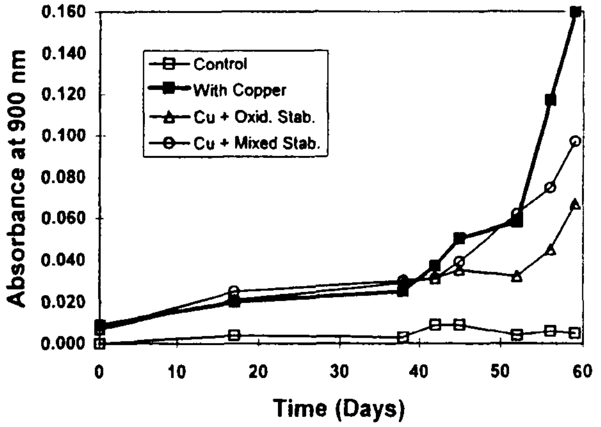


Figure 9 - Absorbance values with low-sulfur fuel, showing degradation caused by copper contamination at doses of 5 ppm (days 0-17), 15 ppm (days 17-38), and 40 ppm (days 38-59) - as well as the marginal benefit gained by adding either of two types of stabilizers.

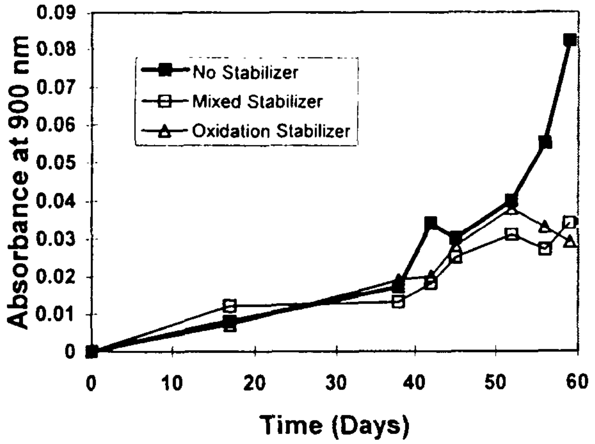


Figure 10 - Same as Figure 9 except these samples received lower doses of copper (1, 5 and 20 ppm respectively). These samples, however, received the same levels of stabilizers as did the high-copper samples represented in Figure 9.

Paper No. 98-13

New Standard for Above ground and Basement Residential Fuel Oil Storage: Plastic and Steel Composite Secondary Contained Tanks

Mark C. Annis, President

ANCO Environmental Services, Inc.
654 Springfield Avenue
Berkeley Heights, NJ 07922

and

Jürgen Dreier

Roth Industries
Germany

THE NEW STANDARD FOR ABOVE GROUND AND BASEMENT RESIDENTIAL FUEL OIL STORAGE: PLASTIC AND STEEL COMPOSITE SECONDARILY CONTAINED TANKS

by Mark Annis and Jürgen Dreier

ABSTRACT

Leaking storage tanks negatively affect public perception of fuel oil as a safe energy source. A proactive, industry-led tank replacement program is a long-term goal; however, this goal may never be achieved without philosophic change in our attitude toward tank replacement. This change becomes more urgent with each passing year, considering the cost of environmental remediation and fire restoration. An economic need exists today and provides the incentive to upgrade tanks to that of a corrosion-proof design. A sound twenty-eight year track record underscores the success of double walled plastic and steel composite tanks in Europe. Seamless and corrosion-proof blow-molded internal polyethylene tanks are jacketed inside an outer galvanized steel tank. Each double walled tank system includes an interstitial leak detector, level gauge, fill and vent unions, stand and suction piping/valve assembly. As many as five tanks can be interconnected into a battery using pre-fabricated parallel fill and vent piping systems. These 275 gallon tanks are nearly half the weight of 12-gauge lapwelded UL 80 tanks, yet can withstand more than twice the burst pressure of standard endwelded 14-gauge tanks. Several European manufacturers produce similar products and all include 15-year warrantees against leakage. Some include $1,000,000 of product liability insurance. Corrosion-proof plastic inner tanks eliminate the environmental (corrosion based) leaking tank risk and reduce oil fire risks. Steel-catalyzed sludge and gum formation is eliminated, as is nozzle-clogging iron oxide formation. Polyethylene is compatible with fuel oil additives. Double walled tank systems of this design are priced lower than comparably insured single walled lapwelded UL 80 tanks. NFPA and UL code amendments are in progress.

INTRODUCTION

The fuel oil industry has reached a critical juncture in its history. Attacks by the gas industry and some environmentalists are creating the public perception that oil heat is risky and archaic. At the center of this controversy is the very heart of the oil heat system: the storage tank. The tank is feared by many. What can we do? The best response currently is a variety of tank insurance programs; however, programs such as these are entirely reactionary. They minimize effects of the risk, but do nothing to prevent the risk. They encourage us to ignore the real problem: tank deterioration by corrosion. Many companies are offering graduated tank replacement programs, but the new tanks are primarily of all-steel construction with the same vulnerability to corrosion as the original tank. This paper presents an alternative, permanent fuel storage solution, built around a well-established and proven technology.

As an industry, we must develop new technologies to provide our customers with a tank that does not leak. There are two major stumbling blocks. The first is outdated tank construction codes which result in tanks that are strong but not long-lasting. UL 80, the construction code for interior steel tanks, or basement tanks, was first introduced in November of 1927. The effect is a well-established standard for tanks that are vulnerable to inevitable long-term deterioration. This vulnerability leads to the very environmental liabilities fueling the negative public opinion about oil heat. The second stumbling block is the absence of a lightweight, durable, fire-safe, and environmentally safe product. To secure the role of oil heat as a viable domestic fuel through the next century, fuel dealers must champion a new philosophy of fuel storage. No longer should we try to control and manage corrosion; instead, we must eliminate it. This philosophy, supported by new technologies and a tank design that provides total environmental and fire safety, will fortify our industry against gas utility attacks - "Safe, Reliable Oil Heat" will apply to all system components.

In the sections that follow, the economic need for improved fuel storage is presented. New tank system design parameters are presented that provide a solution to fire safety and environmental safety fuel storage challenges. The plastic and steel composite aboveground storage tank system is thoroughly discussed from both a technical and a philosophical perspective.

THE NEED FOR A NEW STANDARD FOR RESIDENTIAL FUEL STORAGE

For as long as there have been building and design codes, steel has been the choice construction material for fuel storage tanks. Structural strength, availability of raw materials, and a well-understood and affordable manufacturing technology have secured the role of steel. Yet it is the simple malleability of steel that is also its Achilles Heel. Steel cooperates with physical processes. It is easily shaped, cut, bent, and welded. It readily responds to heating; however, uneven heating and cooling, imperfect welds, and some installation environments seriously compromise the durability of steel tanks. Corrosion due to oxidation occurs spontaneously in moist environments. Out of sight and out of mind, millions of buried steel tanks are silently deteriorating. Above ground steel tanks (ASTs) face a similar fate, with the added detriment of impacting human health and posing a fire hazard where a basement tank leaks. Both ASTs and their underground counterparts are prone to internal corrosion along the bottom centerline of the tank, where trace amounts of water accumulate. Additionally, there are fuel quality concerns that are worsened by storing oil directly in all-steel tanks. Rust and metal-catalyzed gum formation detract from fuel efficiency and oil heat reliability. Corrosion contaminants, sludges, and gum have a significant negative impact; they clog nozzles, soot up heat exchangers and chimneys, and create a fire risk. This problem is identified and quantified by several reports incorporated into this paper as follows:

1992 Brookhaven Nation Labs (BNL) report BNL 48406 titled <u>Maintenance & Storage of Fuel Oil for Residential Heating Systems.</u> On page 2, Wai-Lin Litzke states:

> "Other contaminants, such as water, rust, dirt, and microbiological growth, contribute to the spoilage of heating fuels. These types of contaminants can plug filters, nozzles, and fuel lines, clog screens, and cause wear in pumps and other parts with close tolerances. In addition, dissolved metals can catalyze fuel degradation."

The fuel quality subject was furthered by paper No. 97-11 at the 1997 BNL Oil Heat Technology Conference. Residential Fuel Quality by Thomas Santa states:

> ". . . the leading cause of oil burner malfunction is the clogged fuel system"

While Mr. Santa reports an improvement in oil heating equipment reliability with use of a broad additive program, most revealing is his control group data:

> "For the past several years in the sample population used in this study, the equipment failure rate has been consistent at roughly 18 fuel system failures per 100,000 gallons. Stated another way, given the average customer has an annual consumption of 1,000 gallons, 18% of customers are affected each year."

The fire risk problem is succinctly presented in the 1/98 National Fire Protection Association (NFPA) US Home Products Report, 1991-1995 Forms and Types of First Ignition in Combustible Liquid Fires. Researched and written by Kimberly D. Rohr, findings include:

> ". . . central heating units were the leading type of equipment associated with Class II combustible liquid fires."
>
> ". . . annual average of 4800 fires, 57 civilian deaths, 213 civilian injuries and $37.4 million in direct property damage per year starting with these liquids."
>
> ". . . most of the fires, 88 percent, involved equipment (failure)"

While many of the fires (and most of the deaths) involved portable kerosene heaters, most fires involved central heating units. Roughly half (2200) of all equipment failures in the NFPA report can be linked either to tank or piping system corrosion, or to corrosion assisted fuel clogging/maintenance sources. Relevant ignition factors in this 1/98 NFPA report are as follows:

Ignition Factor	Fires	Deaths	Injuries	Property Damage
Part failure, leak, or break	700(15.4%)	9	20	$5.8M
Lack of maintenance/worn out	500(9.8%)	0	7	$1.0M
Backfire	400(8.7%)	9	6	$0.4M
Fuel accidentally released	300(5.8%)	6	25	$4.6M
Unknown mechanical failure	300(5.8%)	4	10	$2.3M
Totals*	**2200(45.8%)****	**19**	**68**	**$14.1M**

*Totals represent average annual US fire losses (1991-1995) sustained by oil heat customers due in part to secondary effects of storing fuel oil in corrosion vulnerable steel tanks.

**Remaining, first ignition sources include automatic control failures (1100/23.7%), incendiary or suspicious (400/9.3%), and other (1000/21.8%).

The environmental risk is also serious, with the exception that there are no known deaths by direct exposure to fuel oil leaked from a storage tank. There is, however, ample evidence that environmental losses have been staggering. The best example of this has been the loss experience of the H.E.L.P. tank insurance program that operated for three years in Connecticut, New Jersey, New York, and Pennsylvania. While many factors contributed to the collapse of the program, the common denominator was the leaking fuel storage tank. The leaking tank risk is best quantified by residential losses tracked by the Fuel Merchants Association of NJ. Figures presented at the December 10, 1997 tank insurance meeting identified a "historic track record of about 700 (leaking tank) claims per year" with the "average claim just under $6,000". Extrapolating the estimated 1% per year loss rate experience by the program over the entire US tank population (11,218,000 tanks*) and applying a $5,000 average** site cleanup cost yields total estimated US annual environmental costs of $560,900,000. Add in the fire restoration costs and the total becomes 575 million dollars.

*US DOE report based on 1990 census information.
**Adjusted due to Metropolitan NJ business costs being higher than the national average

ECONOMIC INCENTIVE FOR A NEW FUEL OIL STORAGE PHILOSOPHY

The estimated current rate of $575 million spent annually on environmental and fire restoration is equivalent to 287,500 tank replacement projects, with an average project cost of $2,000.00. Our industry should encourage the reallocation of site restoration funds to a tank replacement fund by encouraging tank replacements before they fail. Aged and underground tanks should be addressed first. Replacement tanks should be above ground and of the most durable design available, so they will never have to be replaced again.

What are the ideal design criteria for a durable above ground or basement 275 gallon oil storage tank?

Environmental impact minimization: This means a double walled or secondarily contained tank. Environmental risk ranks first in the minds of today's homeowners.

Long term durability: Construct the tank of corrosion proof materials that are compatible with fuel oil.

Handling ease: Light weight and compact design facilitates easy installation.

Fire proof design: This meets NFPA requirements.

Inclusion of all components: This eliminates the need to separately stock and supply leak detector, gauge, stand, suction piping, fittings and fire safety valve, etc.

Product liability insurance: Include a ten-year minimum program with limits that amply cover replacement of the oil customer's entire house should disaster strike.

Tank system cost: The cost must be comparable to a conventional UL 80 tank system including cost of components and insurance. Wholesale costs of a 275 gallon conventional single walled tank system, (not including installation labor) including tank insurance are typically as follows:

UL 80, 12 gauge lapwelded tank	$191
Level gauge	11
Legs	4
10 years of tank insurance @ $40/yr.	400
Fully insured conventional tank system cost	$605

THE IDEAL PRODUCT ALREADY EXISTS

The plastic and steel composite secondary containment "Safety Tank" exists today in Europe. Developed nearly 30 years ago in Germany, this off-the-shelf product has proven itself at over two-million installation sites. The product was developed in response to an economic need brought on by a fire code requirement.

In the 1960s fuel was stored outside or in small cellar tanks, and tanks were of a horizontal design made from welded steel. Most heating systems were portable oil heaters. Fuel was manually pumped from the tank into a can then carried one gallon at a time to the portable heater. With the prosperity of the 1960s, came an increased preference for central heating systems. Fire codes governing the construction of boiler rooms evolved from centuries of often-disastrous fire fighting experiences. European combustible liquid storage codes changed to require the single walled storage of Class II liquids within sealed masonry secondary containment areas. This was extremely expensive and cost saving strategies were needed. In 1969 the plastic industry saw an opportunity to market a light weight blow-molded tank to be installed inside the sealed masonry tank containment area. In 1971 two steel tank competitors jointly developed and gained approval for an economic, secondarily contained "household tank" utilizing a welded and painted steel basin fit beneath the plastic blow-molded tank. This basin was economically superior to the sealed masonry containment area. By 1973 the basin design was improved, replacing the welded steel with crimped and sealed galvanized steel. In 1978 the tank configuration was modified to cover less floor area, yielding the current upright closed-top design. In 1992 a piping system was devised and approved allowing the interconnection of up to five tanks into a fuel storage battery.

Today's plastic and steel composite tank system has all the design parameters discussed in the New Philosophy for Fuel Storage section at a price of less than that of a comparably insured conventional tank system. The secondarily contained tank system is made of thick-walled seamlessly blow-molded high-density polyethylene which is absolutely corrosion-proof. The outer tank is manufactured of 18-gauge nominal galvanized steel designed to shield the inner tank and hold contents of the inner tank in the unlikely event of a leak. The tank weighs 45% less than a 12-gauge lapwelded UL 80 tank, and comes with handles, leak detector, level gauge, stand, fill and vent unions, and a suction/supply line/fire safety valve assembly. Finally, the tank comes with 10 years of product liability insurance against leaks and environmental loss with $1,000,000 limits (at the time of this writing a longer coverage term of 25 years is being developed). This tank package is less expensive than a comparably insured conventional UL 80 corrosion vulnerable single walled tank system.

THE TECHNOLOGY

Plastic and steel composite secondarily contained tanks systems are the standard in Europe. They are available in 165 and 275 gallon sizes. Each tank sits on a metal stand that elevates it off the floor and maintain an upright configuration. Each tank has four 2" NPT tappings set inside unions that screw onto HDPE tank nipples. There are no bottom connections. The tank system is built from seven subassemblies (Fig. 1). These include the internal polyethylene tank, the secondary galvanized steel outer tank, the leak detector, the suction/supply line assembly, the fill and vent piping system, the level gauge, and the stand. Details of each subassembly are as follows:

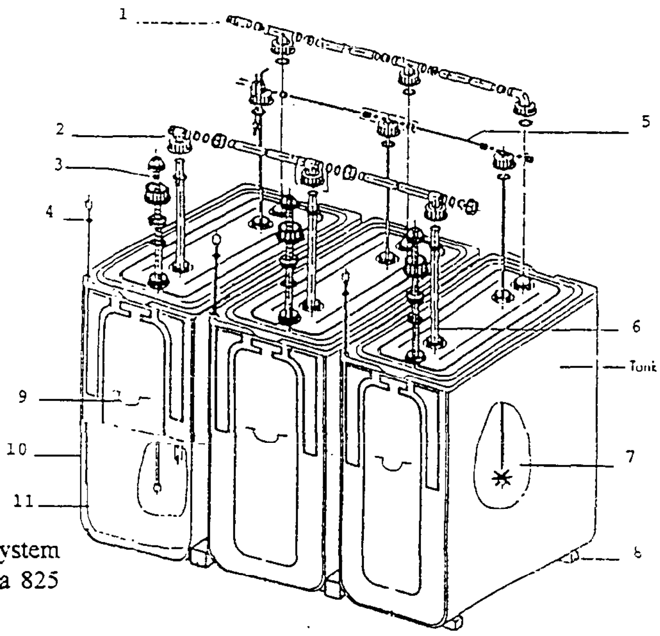


Figure 1 - Plastic and steel composite tank system showing 3 interconnected tanks in a 825 gallon tank battery

Internal Tank is seamlessly blow-molded from high density polyethylene (HDPE). Pelletized feed stock is melted in extruders at 200°C, homogenized, then continuously conveyed to a heated accumulation chamber inside the blow-molder. In cyclic sequences, molten HDPE is extruded downward through a ring nozzle die. Wall thickness is metered from 3 mm to 6 mm, via computer control of the die orifice. The fluidized 'tube' of plastic roughly resembles a lady's nightgown. Once the tube reaches the required length it is gripped by two water cooled mold halves, squeezed on the top and bottom, and inflated inside the mold through blow mandrels which simultaneously form the threaded nipples of the tank. After sufficient cooling time, the cast tank is removed from the mold and excess material is trimmed. Nipple threads are manually re-threaded, and tanks are immediately subject to quality control inspection. The tank is weighed, ultrasonic thickness tested at critical locations, then grasped by a tank jig where it is tested to 7 psi in a protective cage. After passing the quality control tests, each tank is serialized.

Galvanized Steel Secondary Tank is manufactured of 18-gauge nominal thickness material, .040" thick galvanized sheet steel is ordered with G-90 galvanization. Sheets are sheared to appropriate dimensions, stamped, and subjected to a three-stage breaking process that molds the rounded corners. Tank shells are fastened together using a three-step crimping process together with an oil and fire resistant bonding agent. Tanks are then air pressure tested to 7.5 psi by lowering an expandable square test jig into the top of the tank. This verifies that the crimped seams are liquid tight. The tank is now ready for assembly.

The polyethylene tank is placed inside the galvanized steel secondary containment shell. Finally handles are attached and a galvanized steel lid is placed and riveted to the secondary containment shell.

Leak Detector - This mechanical device is set between the inner and outer tank walls. It is a product differentiating sensor that will only react to the presence of #2 fuel. It will not respond to water. Product soaks into a sponge that is bound on two axis. Expansion is limited to the vertical axis which is connected to a visual indicator.

Suction/Supply Line Assembly (Fig. 2) - This subassembly includes a lift tube, a fire-safety valve, and an expandable tapping to enable the connection of multiple tanks through top-of-tank tappings. The suction/supply line assembly will accommodate one or two pipe oil line systems. When connecting multiple tanks to a maximum of five, one expansion kit per additional tank is required. Each expansion kit includes a T-joint and a siphon/suction pipe that ensures drawing off fuel at an equal rate from all tanks.

Fill and Vent Piping System - For single tank installations, the installer supplies 2" NPT fittings and connect them as he would to any tank. For multiple tank installations, the expansion kit bag includes precisely engineered fill and vent piping that greatly simplifies the pipe installation process, and assures that all tanks fill at an equal rate (see figure 2). The filling system of each tank includes an anti-foaming fill tube that outlets fuel at the bottom of the tank during filling.

Level Gauge - A retracting line mechanized gauge comes with each tank. It has a vertical axis movement and a 4" x 4" full face scale that indicates percent of capacity.

Tank Stand - Made of welded steel, the stand is molded to fit the U-shaped tank bottom. It stabilizes and maintains the upright configuration of the tank, and elevates the tank about 4" off the floor.

SUCTION/SUPPLY LINE SUBASSEMBLY

This subassembly differs greatly from standard US industry practice. (Fig. 2) When multiple tanks are interconnected, the standard European filling system ensures all tanks (up to 5) are filled uniformly. It is the suction system, however, that equalizes fuel levels after every burner shut-down (Fig. 3). The principal is a simple siphon. Even when a two pipe system is connected to the first tank, subsequent tanks in the battery are only interconnected with a single siphon line. Differing hydrostatic pressure causes fuel to slowly flow from the tank with the higher level into the tank with the lower level (Fig. 3). All components necessary to interconnect additional tanks are supplied in an "expansion kit" bag, which also includes 2" fill and vent pipe interconnections.

1 - Suction and return valve with manual lever and fire safety valve
2 - Female 3/8" suction port
3 - Female 3/8" return port
4 - Return port blind plug*
5 - Male siphon connection thread (capped parts #9 & 10 with single tank installations)
6 - Cap plug
7 - Cap
8 - Plastic union nuts
9 - Sealing circlip gasket
10 - Suction pipe with tank spider to bottom of tank
11 - 10 mm metal ferrel
12 - Metal ferrel nut
13 - 10 mm metal siphon pipe
14 - Metal ferrel nut
15 - 10 mm metal ferrel
16 - T joint, threaded to accept ferrel nut

Note: - Subassembly parts #11-18 to be used only with second and other tanks
*- Item 4 is used only when there's no return line from burner

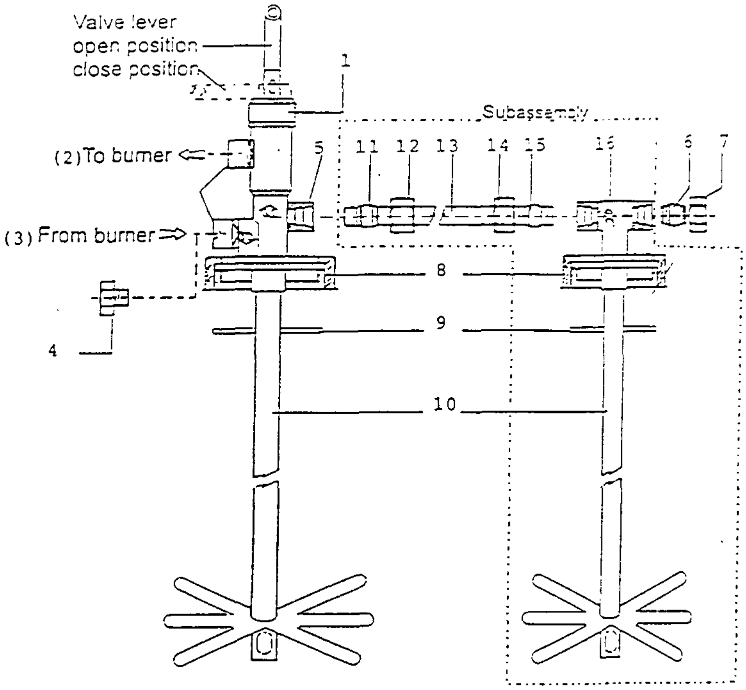
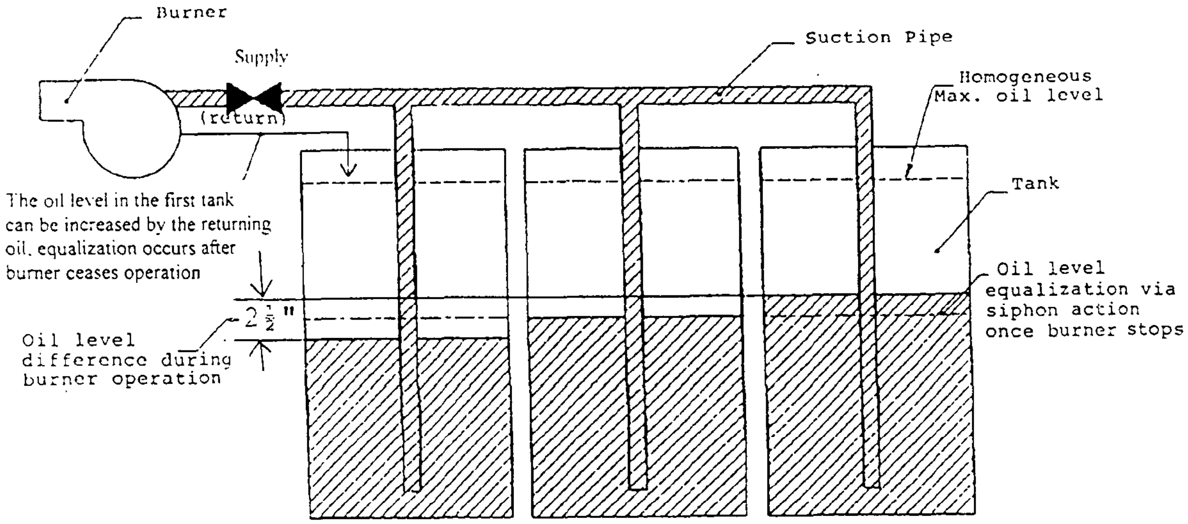


Figure 2 - Siphon tapping system components for a tank battery



The oil level in the first tank can be increased by the returning oil, equalization occurs after burner ceases operation

Figure 3 - Siphon tapping system principal of operation

INSTALLATION EASE

Tank installation technicians are the first to appreciate the light weight and vertical configuration of the plastic and steel composite tanks. Back injuries are minimized with this 150 lb., double-handled tank. Twelve-gauge UL 80 tanks, on the other hand, weigh 275 lbs and sometimes have no attached handles. Placing the tank is also simplified due in part to the tank stand as well as the lighter weight. The stand slips beneath the tank, slides easily from side to side to optimize vertical alignment (i.e., if the floor is uneven), and distributes the load over an area 100-times greater than that of conventional UL 80 tank legs.

Each tank includes a "fundamental" attachment and fitting kit, which contains all the necessary attachments: level gauge, suction/supply line assembly, fill and vent union nuts, installation instructions, etc. When additional tanks are joined to the first, an expansion kit is substituted for the fundamental kit with each extra tank.

Piping in the tank system is greatly simplified, especially in multiple tank installations, which ultimately cuts installation time in half. Pre-engineered pipe fittings and suction supply line components, tank nut unions, and fill and vent manifolds, are the key. Even with single tank installations, the tank nut unions allow starting fill and vent piping construction from any point along the pipe run. The longest section is strapped to the ceiling. Shorter sections and swing joints can then be easily fitted to the first section, with the final tank connection made via the union nut. Where sites are close together a two-man crew can install two double tank systems (4 tanks total) in a single day.

OIL HEAT INTO THE 21st CENTURY

Oil heat has been and should continue to be a major energy source for years to come. Our industry is strong, and has traditionally embraced new technologies to keep pace with any improvements which could ultimately benefit our customers. Oil burner technology has improved remarkably over the last 25 years leading to a new generation of burners. Furnaces, boilers and hot water heaters have all undergone significant redesign, greatly improving efficiency, reliability and ease of maintenance. Reduced sulfur fuel oil formulations and additives packages have been developed to control contaminants.

Now we must turn our attention to improving basic storage tank technolgy. Beyond a weld design change, the vast majority of new tank installations utilize UL 80 technology that was first developed 71 years ago and leaves tanks open to the ravages of corrosion, the greatest physical threat to the fuel oil system. There is a tremendous economic incentive to upgrade steel tanks to corrosion-proof plastic and steel secondarily contained tanks. Hundreds of millions of dollars, currently spent annually on fire and environmental restoration are at stake.

It is time for the American fuel oil industry to recognize and embrace a decades old European solution to the problem of corrosion. The 100% corrosion-proof tank design has completely eliminated Europe's corrosion-based leaking storage tank problem. It is time for us to adopt this technology and consider it as a solution to our own dilemma.

Paper No. 98-14

Money Left on the Table: An Economic Analysis of Tank Cleaning

Karl Thomas, Vice-President
and
Peter Gruman, Vice-President Marketing

Clarus Technologies Corporation
2015 Alpine Way, Suite A
Bellingham, WA 98226

Money Left on the Table: An Economic Analysis of Tank Cleaning

by

Peter Gruman & Karl Thomas

INTRODUCTION

In our conversations with heating oil distributors, we always ask if they believe there is a problem with the condition of their customers' fuel tanks. Virtually every response we hear is that there isn't a problem. Our follow-up question asks whether the distributor has to make any service calls because of plugged fuel filters. To this the answer is generally, "Sure, about 3-7% of our calls are due to plugged filters."

That answer usually helps the distributor see the relationship between the first question and the second.

Given the revenue generated by annual service contracts, many distributors are not actively seeking alternatives to solving problems caused by plugged fuel lines and contaminated fuel tanks. For these distributors, the status quo is just fine.

We believe that the status quo leaves money on the table, and will demonstrate in this paper how a distributor can increase profits by establishing a fuel tank cleaning service program.

BACKGROUND

Ever since civilized man began putting fluids in closed containers, there have been problems caused by condensation. When the fluid is water, condensation doesn't create too much trouble. But when water is introduced to heating oil, it triggers a sequence of events which often causes heating systems to fail and customers to become upset.

This is essentially the story of oil heat tanks. Whether the tanks are above ground or below ground, fuel oil levels are eventually low enough to allow significant quantities of moist air to enter the tank. As the tank cools, water condenses from the air and settles on the tank bottom. And this happens in every tank, from the refinery to the 250 gallon tank outside my house.

The problems caused by water are not insignificant. In fact, water is the source of most equipment problems experienced throughout the oil heat industry. The water that is present in virtually every tank corrodes steel and provides the environment needed for the growth of micro-organic matter. Both of these outcomes compromise the delivery of heat. The real problems caused by water contamination arise, however, when your service department gets a call at 8 p.m. on a Saturday night from a customer with a plugged fuel line.

Actually, that is just the beginning of the problem, because the customer experiences a defect in the uninterrupted delivery of heat that he believes he paid for when he purchased the fuel. At this point, one of two culprits are likely to jump into the mind of the customer, neither of which is the water in his tank. First, not knowing that the presence of water is endemic to the fuel distribution system, the customer thinks the culprit is the distributor who delivered bad fuel to him. Or, if the customer is more charitable, he can start believing that the real problem is with fuel oil as a heat source.

This latter view is most likely to be raised when the delivery of heat to the home is compromised more than once. Buying into one of the conversion programs offered by the natural gas or electric utilities may become appealing for a customer. His friends tell him they've never had a plugged filter in their gas or electric heating systems, and he starts thinking about converting. And we don't mean to suggest converting to another oil heat distributor.

The two issues this paper will addresses are how to (1) eliminate service calls required by tank contamination, and (2) accomplish the first goal in a cost-effective manner. By achieving these two fundamental and related goals, a distributor will greatly enhance customer satisfaction with his level of service and improve the bottom line financial success of his company.

I. THE PROBLEM OF FUEL TANK CONTAMINATION: SOURCES AND COSTS

A. Sources of Contamination

> ***"Keeping a fuel system entirely dry is impossible."***
>
> Cummins Bulletin 3379001-05

The unavoidable presence of water in fuel tanks is the catalyst for the contamination problems addressed by this paper. Water enters a tank in three ways. First, in some instances, faulty and improperly installed lids and vents permit water to enter the tank directly. Second, moist air collects in the tank and condenses as the air cools. And third, water can enter the tank through the distribution chain, at any point from the refinery to the distributor. No matter how the water enters the tank, once in the tank it falls to the tank bottom and begins its damaging work.

Water in the tank creates the proper environment for the growth of a variety of micro-organic matter, commonly but mistakenly called algae or "bugs." It is somewhat counter-intuitive that these micro-organisms can bloom in fuel tanks, given that there is no light and only heating oil and water for them to grow. Nonetheless, this micro-organic matter feeds off the fuel and water, and blooms on the interface between the water and fuel and in the fuel itself. When this matter dies, it settles to the bottom of the tank, congeals, and turns into what high science refers to as sludge.

Exhibit A shows a cross-section of tank contamination.

Examining a tank which has been in place for ten years or more reveals several types of contamination that are problems for your customers and, by extension, your service business.

B. Types of Contamination

1. Water. In addition to being the primary building block for all other types of contamination, water present in the fuel can damage the burner and lower the heat generating capacity of the heating system.

2. Micro-organic Matter. This matter, which lives on the interface between the fuel and the water and in the fuel, finds its way to the fuel tank discharge line and plugs the fuel line, the filter, and can damage the burner.

3. Oxidation. In steel tanks, which are by far the majority of tanks currently in use, water leads to the creation of rust dust and flakes. The water, which typically remains in the bottom of the tank, becomes fully dispersed throughout the tank every time the tank is filled with new fuel. As the fuel level lowers, water is left on the side of the tank and can then begin the oxidation process. The effects of oxidation contribute to the sludge on the bottom of the tank.

4. Sludge. Once the micro-organic matter has finished its growth cycle, it begins decomposing and settles on the bottom of the tank. This matter, along with the rust dust and flakes, take the form of a viscous sludge. When the tank is filled with new fuel, this sludge becomes dispersed and suspended in floating globs in the tank for several days before it settles on the bottom again. When the fuel is used during this period, the debris can easily plug filters and reduce the efficiency of the burner - or even damage the burner.

Taken alone, each of these types of contamination can be problematic. Most tanks, however, are subject to the development of all of these types of contamination. And this is when the service/repair component of your business is called into play.

II. COSTS OF CONTAMINATION

From our perspective as manufacturers of tank cleaning equipment, there are two primary economic dangers caused to distributors by contamination and the resulting interruption of oil heat service. First, there are the tangible and intangible costs associated with servicing customers whose heating systems have failed. These are the labor, equipment and overhead costs, as well as the loss to the credibility of the distributor and/or to oil as a heat source. Second is the long term economic impact of losing customers to alternate heat sources: electric and natural gas utilities are very anxious to win conversion to their products, and often find a receptive audience in fuel oil customers who have experienced failed or compromised heat delivery from fuel oil. The important point, however, is that conversion away from fuel oil as a heat source represents a cost to distributors that simply cannot be recaptured.

Focusing on the direct costs of contamination will provide a baseline to evaluate alternatives to servicing tanks with contamination problems.

A. Direct Cost Assumptions

To illustrate the direct economic costs experienced by distributors because of contamination, we need to make a few assumptions.

1. The ABC Fuel Co. has 2,500 customers.
2. Each customer pays a $120 contract annual fee to cover potentially required service.
3. 100% of customers require a fall tune-up.
4. For 90% of the customers, the heating system performs perfectly all year.
5. 7% of the heating systems have minor fuel tank problems and require a fall tune-up plus two additional calls.
6. 3% have fuel/tank problems and require a fall tune-up, plus 4 additional calls throughout the year to change out nozzles, filters and to re-start the furnace. Many of these calls are during off hours.
7. Service call cost the distributor an average of $50.00 for time and materials.

Exhibit B shows these the cost structure of callbacks based on the above assumptions.

B. Discussion of Costs from Exhibit B

For 90% of customer base, the distributor makes $70 profit on each customer ($120 contract fee less $50 fall visit). For 7% of the customers, the distributor loses $30 on each customer ($120 contract fee less 3 visits at $50 per visit). For 3% of the customers, the distributor loses $130 on each customer ($120 contract fee less 5 visits at $50 per visit).

For customers requiring a total of two visit per year, the revenue provided by the service contract ($120) is adequate to cover the assumed expenses (up to $100). For those customers requiring more than two service calls per year, however, the contract revenue is exceeded by the cost.

This paper examines whether there is an alternative service strategy which can reduce the direct costs of servicing contaminated fuel tanks, thus increasing profits and enhancing customer loyalty.

III. FUEL TANK CLEANING OPTIONS

We believe that the goal in every case of tank contamination is to address the problem and prevent it from re-occurring. Many times, however, distributors treat the symptoms of the problem (clogged filters and damaged nozzles) and not the problem itself. The ideal solution to tank contamination is to retain the inventory of fuel but eliminate all the water and particulate contamination from the tank. The following are the steps needed for an effective tank cleaning solution.

- First, agitate the fuel in the tank at a rate sufficient to place all the accumulated sludge, debris and water into suspension;

- Second, use filtration capable of removing the fine particulate matter;
- Third, eliminate all free and emulsified water from the tank, leaving the original inventory of fuel dry and free of water contamination.

The following are solutions distributors rely on to address tank contamination problems, however, each does not do so with the same degree of success.

A. Tank Cleaning Solutions

1. Change Filters Only. This option, is to look beyond the contamination in the tank and to focus on the clogged fuel filter. This is similar to asking your doctor to look beyond your disease and treat your symptom only; you may feel better right away, but you will have the same problem over and over. Replacing filters may eventually capture the debris residing in a tank, but it has the unfortunate requirement of a customer call to notify the distributor that there has been an interruption in heat. Changing filters does not adequately accomplish any of the criteria outlined above, creates unhappy customers, and thus should not be considered an appropriate long term solution.

2. Vacuum Truck. The second technique, used less frequently, involves pumping out all the fuel in the tank and putting in replacement fuel. While this technique has some appeal because it should eliminate the water in the tank, it does not provide adequate assurance that all the contamination will be removed, this means the clean fuel put back in the tank will have almost as much sludge mixed in with the new fuel as was present in the old fuel.

3. Tank Cleaning. The final option is to use filter/pump equipment to clean the tank. In general terms, the equipment removes fuel from the contaminated tank, runs the fuel, water and sludge through a series of filters, and returns the cleaned fuel to the tank. This process will remove virtually all of the water and particulate debris from the tank, assuming proper equipment and techniques are used.

B. Criteria for Tank Cleaning Equipment

If tank cleaning is understood to present the ideal solution, and assuming it can be accomplished economically, as the next section will demonstrate, there is some criteria that must be met by the equipment.

1. Water Removal. The tank cleaning equipment must remove virtually all free and emulsified water from the tank. Earlier we described how water is the source of all tank contamination problems. If the equipment cannot remove the water in the tank, the tank cleaning service cannot be effective, and the remaining water will continue to promote oxidation and the ongoing growth of micro-organic matter.

2. Adequate Filtration. The equipment must have filters which can capture fine debris. If the filtration media is not fine enough, fine rust particles, micro-organisms and sludge will get returned to the tank and will eventually end up in the clogging the customer's filter.

3. High Flow-Rate and Agitation. As fuel is processed through the filtration and the particulate and water are removed, the fuel will be absolutely clean when it returns to the tank. The return flow rate must be high enough to create agitation in the tank and, thereby, dislodge the sludge and rust and allow the suction hose to remove these contaminates from the quiet corners of the tank. If the sludge is not agitated, it will remain in the tank waiting to plug the filter.

C. Effect of Tank Cleaning

Tank cleaning has immediate and long-term results. The immediate benefit is that the customer's tank will not require a service call for fuel line problems that heating season. The longer term effect of tank cleaning is that it virtually eliminate contamination-based service calls for a 7-10 year period, which is typically the amount of time required for the initial tank contamination problems to appear.

Customers who must request several service calls in any one year not only cost the distributor money, but the customer may also begin thinking about what a pain in the neck it is to have his heat interrupted periodically.

IV. INCREASED PROFITS THROUGH TANK CLEANING: "TAKING MONEY OFF THE TABLE" (AND PUTTING IT IN YOUR POCKET)

Many distributors do not believe fuel tank contamination is a problem. These distributors are taking an "if it ain't broke, don't fix it" approach. Others recognize that tank contamination is a problem, but don't recognize that there is an economically viable solution that will increase the company's profits.

The goal of this section is to describe how tank cleaning enables distributors to avoid leaving money on the table.

A. Economic Model Assumptions

The assumptions for this model are the same as the costs described in Section II, and are summarized below:

1. 2,500 customer base.
2. $120 contract fee.
3. 100% of all customers require a fall tune-up.
4. 90% of customers don't need any more service.
5. 7% require a fall tune-up plus two additional service calls.
6. 3% require a fall tune-up, plus four additional service calls.

In this scenario, however, the ABC Fuel Co. is using tank cleaning as its repair technique for all tank contamination service calls. We will add the following cost structure for tank cleaning:

7. Tank cleaning labor for two hours, for a total of $100 per tank clean.
8. Variable costs of $25 for filters used on the job.

This latter assumption has two important consequences. First, after a tank clean, no customers call back a second, third, or more times to have filters replaced. Second, where 7% of the customer base can be assumed to have contamination problems, a tank cleaning service slowly reduces this percentage, so that in five years the original problem is virtually gone.

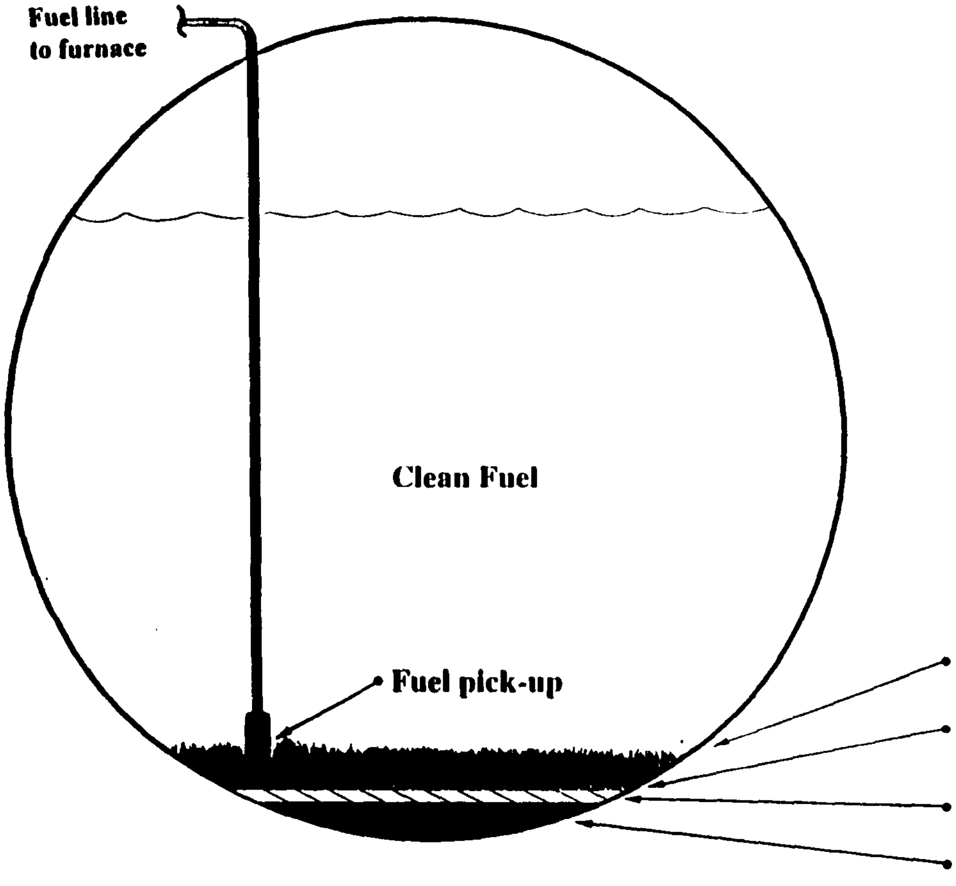
Exhibit C provides an economic analysis of the advantage of a tank cleaning program. This data clearly shows how a tank maintenance program can reduce costs by reducing the number of callbacks. Based on 3% of its customer base that has four additional callbacks per year or more, ABC Fuel Company can improve the profitability of its contract program by $65,625 over a five year period. On the 7% of its customer base that generates two additional callbacks per year over five years, ABC Fuel Company can save an additional $65,625 over the same five years on this customer segment. This adds up to a savings of over $130,000 over a five year period.

The facts speak for themselves, a tank maintenance program can improve the bottom line even in modest distribution systems; the larger the customer base, the more money can be returned to the business. Equally important, is that a distributor who develops a tank cleaning service will win the loyalty of the customer not only to oil as a heat source, but also to the distributor's business. It is possible that the intangible benefits of increased customer loyalty resulting from interruption free heat service will outweigh the tangible economic benefits of reduced costs through fewer service calls.

V. CONCLUSION

Fuel tanks become contaminated on their own, not through the fault of the supply chain or the customer. What is important to realize is that this contamination is costing the distributor time and money on service calls, and causing frustration for the customer. A growing number of distributors view tank maintenance as a way to enhance both revenues and customer loyalty and satisfaction. When appropriate equipment is used, tank cleaning accomplishes water and particulate removal goals, which in turn help ensure a reduction in heating system service calls.

By understanding the financial dynamics of this problem, distributors can create a win-win situation through tank cleaning by helping their customer and improving their own bottom line. Tank cleaning represents a progressive technique for reducing costs **AND** increasing profits, which is another way of saying that you have taken the money off of the table and put it in your pocket.



WHY CLEAN FUEL DEPENDS ON A CLEAN TANK

These must be removed from the tank, or the clean fuel will develop a contaminated interface layer.

EXHIBIT A

- **Because the tank is contaminated, clean fuel will become contaminated by the bacteria, fungus, water, and sediment which remain at the bottom if the tank is not thoroughly cleaned.**
- **Simply polishing the fuel will not remove the source of the fuel contamination problem.**

Exhibit B

Cost of Callbacks Over Five Years

Scenario 1 - Cost of Callbacks over Five Years on 7% of Customer Base (175 customers)

Contract Revenue over 5 years

	Year 1	Year 2	Year 3	Year 4	Year 5	totals
Contract Revenue	$ 21,000	$ 21,000	$ 21,000	$ 21,000	$ 21,000	$ 105,000
1 service call/year @ $50	$ 8,750	$ 8,750	$ 8,750	$ 8,750	$ 8,750	$ (43,750)

Five year contract income on 7% of customer base $ 61,250

Cost of Two Additional Callbacks to Distributor over Five Years
(7% of customer base, 175 customers)

	Year 1	Year 2	Year 3	Year 4	Year 5	totals
1st callback @ 50$	$ 8,750	$ 8,750	$ 8,750	$ 8,750	$ 8,750	$ 43,750
2nd callback @ 50$	$ 8,750	$ 8,750	$ 8,750	$ 8,750	$ 8,750	$ 43,750

Five year cost of callbacks on 7% of customer base $ (87,500)

Net loss to Distributor of Two Additional Callbacks on 7% of customer base ⟶ $ (26,250)

Scenario 2 - Cost of Callbacks over Five Years on 3% of Customer Base (75 customers)

Contract Revenue over 5 years

	Year 1	Year 2	Year 3	Year 4	Year 5	totals
Contract Revenue	$ 9,000	$ 9,000	$ 9,000	$ 9,000	$ 9,000	$ 45,000
1 service call/year @ $50	$ 3,750	$ 3,750	$ 3,750	$ 3,750	$ 3,750	$ (18,750)

Five year contract income on 3% of customer base $ 26,250

Cost of Four Additional Callbacks to Distributor over Five Years
(3% of customer base, 75 customers)

	Year 1	Year 2	Year 3	Year 4	Year 5	totals
1st callback @ 50$	$ 3,750	$ 3,750	$ 3,750	$ 3,750	$ 3,750	$ 18,750
2nd callback @ 50$	$ 3,750	$ 3,750	$ 3,750	$ 3,750	$ 3,750	$ 18,750
3rd callback @ 50$	$ 3,750	$ 3,750	$ 3,750	$ 3,750	$ 3,750	$ 18,750
4th callback @ 50$	$ 3,750	$ 3,750	$ 3,750	$ 3,750	$ 3,750	$ 18,750

Five year cost of callbacks on 3% of customer base $ (75,000)

Net loss to Distributor of Four Additional Callbacks on 3 % of customer base ⟶ $ (48,750)

Exhibit C

Increased Profits from a Tank Cleaning Program

Profit Analysis of Tank Cleaning on 7% of Customer Base (175 Customers)

Contract Revenues over 5 years

	Year 1	Year 2	Year 3	Year 4	Year 5	totals
Contract Revenue	$ 21,000	$ 21,000	$ 21,000	$ 21,000	$ 21,000	$ 105,000
1st callback @ 50$	$ 8,750	$ 8,750	$ 8,750	$ 8,750	$ 8,750	$ (43,750)

Five year contract income on 7% of customer base $ 61,250

Cost to Tank Clean All 175 Customers @ $125 Per Customer (no callbacks)

	Year 1	Year 2	Year 3	Year 4	Year 5	totals
Tank cleaning cost	$ 17,500	$ -	$ -	$ -	$ -	$ 17,500
Filters/supplies	$ 4,375	$ -	$ -	$ -	$ -	$ 4,375

Five year cost of tank cleaning $ 21,875

Contract program profitability with tank cleaning → **$ 39,375**

Net loss to Distributor from Scenario 1 on Exhibit B → **$ (26,250)**

Economic Benefit of Tank Cleaning Program on 7% of Customer Base → ***$ 65,625***

Profit Analysis of Tank Cleaning on 3% of Customer Base (75 Customers)

Contract Revenues over 5 years

	Year 1	Year 2	Year 3	Year 4	Year 5	totals
Contract Revenue	$ 9,000	$ 9,000	$ 9,000	$ 9,000	$ 9,000	$ 45,000
1st callback @ 50$	$ 3,750	$ 3,750	$ 3,750	$ 3,750	$ 3,750	$ (18,750)

Five year contract income on 3% of customer base $ 26,250

Cost to Tank Clean All 75 Customers @ $125 Per Customer

	Year 1	Year 2	Year 3	Year 4	Year 5	totals
Tank cleaning cost	$ 7,500	$ -	$ -	$ -	$ -	$ 7,500
Filters/supplies	$ 1,875	$ -	$ -	$ -	$ -	$ 1,875

Five year cost of tank cleaning $ 9,375

Contract program profitability with tank cleaning → **$ 16,875**

Net loss to Distributor from Scenario 2 on Exhibit B → **$ (48,750)**

Economic Benefit of Tank Cleaning Program on 3% of Customer Base → ***$ 65,625***