Advantages of Low Sulfur Home Heating Oil

Interim Report of Compiled Research, Studies and Data Resources

National Oilheat Research Alliance and the
United States Department of Energy

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The authors also express sincere gratitude to the **New York State Energy Research and Development Authority** for funding a multi-year field study of the benefits of low sulfur oil in actual oil-heated homes, and allowing the use of many of the results of this own ongoing project. The NYSERDA study, *"Premium Low-Sulfur Heating Fuel Marketplace Demonstration"*, has served a critically important role, because it demonstrates for the first time, the many real benefits of using low sulfur heating oil, as well as identifying some key obstacles to its widespread use. The NYSERDA work to date has substantiated the results of lab testing in the US and Canada of low sulfur oil, and validated these results in real-world conditions, which is vital for encouraging the widespread use of low sulfur oil in the residential marketplace.

In addition, the authors thank Buhrmaster Energy Group in Scotia, New York, for their valuable assistance in conducting the NYSERDA field study, including comprehensive cleaning services in test homes that are critical in quantifying the benefits of the lower sulfur fuel oil.

The authors also thank the dedicated staff of the **CANMET Energy Technology Center – Ottawa, Natural Resources Canada** for their continuing contribution to the research and scientific knowledge with regard to the combustion of heating oils with various sulfur contents and the measurement and documentation of data contained in this report.

Lastly, the authors want thank the **National Association of Oil Heat Service Managers** and **Victor Turk of the R.W. Beckett Corporation** for allowing us to use the results of a recent field survey to help establish service interval and cost data required to perform a cost-benefits analysis.

Executive Summary

The advantages of marketing low sulfur fuel, the subject of this interim report, are so significant that it will become clear that the marketing of this product can be both profitable and environmentally beneficial. Low sulfur fuel can play an important role in the Clearburn Science of Oilheat. The objective of this report is to present a summary of key research that is either ongoing or that has been completed to date, and offer preliminary findings and recommendations regarding the marketing of low sulfur fuel oil. A more detailed report with full documentation will follow.

Using low sulfur home heating oil, with a sulfur content of 0.05 percent by weight, offers many important operational and economic advantages for homeowners and fuel oil marketers. These benefits include: reduced service costs through less frequent vacuum cleaning of heating equipment; lower air pollutant emissions including sulfur oxides, nitrogen oxides, and particulate matter; improved fuel stability; lower environmental impacts that are equal to or better than natural gas; the potential to generate emission reduction credits; and potential cost savings of approximately $200 million a year in reduced equipment cleaning costs.

Sulfur oxides emissions by oil heating equipment is reduced by a factor of four or five by using the low sulfur oil, and Particulate Matter emissions are reduced by a similar amount. In fact, Particulate emissions with low sulfur oil may be lower than from natural gas powered equipment. Nitrogen oxide emissions are also reduced, as the nitrogen content of the oil drops as the sulfur is removed. The trend in US and Europe is toward even lower sulfur highway fuels approaching 0.0015 percent or 15 parts per million. (See Section 2.)

Laboratory and field studies comparing normal and 0.05 percent sulfur home heating oil clearly demonstrate that deposition rates in boilers are much lower for the low sulfur fuel oil. The measured reduction in fouling rates ranges from 2 – to – 1 to more than 6 – to – 1 for different studies. A value of 2.4 – to – 1 was used in this interim study to evaluate the savings in vacuum cleaning costs. NYSERDA research shows a 2 – to – 1 reduction with low sulfur oil. This produces service cost savings in the range of $200 million a year if low sulfur fuel oil is used in all homes. (See Section 3)

Initial research indicates that fuel stability is also improved by using the lower sulfur fuel oil. This is on-going work that will be discussed in more detail in the final report to follow. (See Section 4.)

An evaluation of environmental costs for home heating oil, natural gas, and other fuels was completed using externality values that were cited in an Oilheat Manufacturers Association (OMA) Report. This clearly demonstrates that the lower sulfur oil and natural gas have comparable environmental impact, and both are much better for the environment than all other fuels. OMA has passed a resolution that supports the use of low sulfur fuels as the preferred heating fuel for the industry. This analysis will be updated for the final report. (See Section 5.)

Emission Reduction Credits may be available by using lower sulfur oil, which can be used to help fund oil heat R&D activities. (See Section 6.)

Preliminary cost-benefit analyses indicate that 0.05% sulfur oil can lower vacuum cleaning costs in oil heated homes by from $2 to $10 a year for every added dollar of fuel cost. (See Section 7.)

Introduction

The vision of the oilheat industry is to be a customer-driven supplier of premium indoor comfort and for oilheat to be the fuel of choice. Part of that vision is the concept of Clearburn Science and the need to offer an affordable and environmentally friendly fuel. One major step toward Clearburn Science is already available to oilheat marketers. This option has many advantages for the marketplace, advantages for the customer, advantages for the dealer and advantages for the environment. This option is low sulfur fuel oil.

The voluntary shift to marketing low sulfur fuel is the first step towards the future. The advantages of marketing low sulfur fuel, the subject of this interim report, are so significant that it will become clear that the marketing of this product is advantageous. A more fully researched and documented version of the report will follow at a later date with final conclusions. This will contain more in-depth and updated analyses, and a complete listing of all reference materials and sources for obtaining the other materials .

Figure 1-1 No.2 Heating Oil % Sulfur Trend

Low sulfur fuel oil produces a huge benefit with regard to the reduction of environmental emissions. It substantially lowers both sulfur oxide and particulate matter emissions. This is of particular interest in the smaller size ranges (2.5 micron and below) which are of major concern to environmental air quality currently under review by the US EPA.

Low sulfur fuel also lowers the need for heating system maintenance related to furnace and boiler heat exchanger cleaning. The lower sulfur fuel oil is available at a small marginal cost increase, and it is completely compatible with current fuels, equipment, storage and delivery operations. While the average sulfur content of residential heating oil has been decreasing over the last fifteen years (**Ref 1**), over the last two years this number has risen, Figure 1-1. The ASTM specification for this fuel only requires that the sulfur content be below 0.5 percent sulfur. If the oilheat industry is to realize the many potential benefits of using low sulfur oil (0.05% sulfur), it must begin to market this product aggressively to its customers. This report will delineate the benefits and begin to provide some cost benefit analysis illustrating why this will be beneficial to the marketer and how it will translate to better profitability and enhanced customer relations. It will also detail the potential for an improved environmental position for oilheat industry. The discussions presented in this interim report will be developed and documented in more detail in the final report.

2. Air Emissions Reductions with low Sulfur Fuel
-Enhanced Environmental Acceptance

a. Sulfur Dioxide (SO_2) Emissions:

The sulfur in any fuel results in sulfur dioxide being released into the atmosphere when it is burned. During combustion in residential heating systems, roughly 99% of the sulfur in the fuel is oxidized to form sulfur dioxide (SO_2) and emitted from the stack. The remaining 1 percent of the fuel sulfur is converted to sulfur trioxide (SO_3) in the flame. Changing to low sulfur content fuel (0.05 %) could eliminate roughly 75-80 percent of the sulfur dioxide generated by residential oil heating systems. In volunteering to market a lower sulfur fuel, heating oil dealers can make a substantial contribution to helping preserve the clean air that we all breathe. Although this result requires knowledge of combustion science, there are numerous studies that can be cited to provide evidence. This was again reinforced in a recent paper (**Ref 2**) reported by S. Win Lee, Ph.D., of the CANMET Energy Technology Center-Ottawa, Natural Resources Canada as reported at the 2002 NORA Technology Symposium. Figure 2-1 is a plot of SO_2 emission rates for fuel oils of various sulfur contents from 0.05 percent (500 ppm) up to 0.6 percent (6000 ppm). This illustrates the linear relationship between sulfur content in the fuel and SO_2 emission rate resulting from combustion of the fuel.

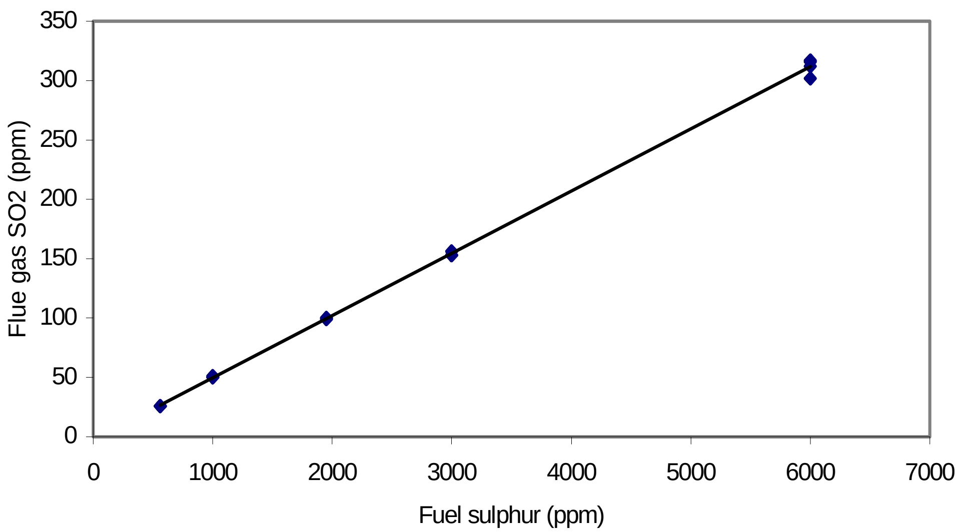


Figure 2-1 Effect of fuel sulfur on flue gas SO_2 emissions

Currently in the U.S., heating oil for residential use has an average sulfur content of about 0.20-0.25 percent (%). The ASTM limit for No. 2 heating oil is 0.5 % sulfur by weight. Considerably higher levels have been allowed, however, and regulations vary by state and area. Low sulfur fuel, 0.05 % by weight, is now mandated for use in highway diesel engines as an emissions control measure. Recently ASTM approved an additional Low Sulfur No.2 Heating Oil specification. The Oilheat Manufactures Association has already recommended its use as a fuel of choice when possible to improve air quality and reduce equipment maintenance requirements.

b. Particulate Emissions: Particulates in the ambient air are an important pollutant concern. These tiny particles can cause lung disease, cancer, and premature death. Sources of fine particulates in the atmosphere include power plants, vehicles, road dust, and industrial processes. Particulates from oil-fired heating systems can be considered as two major parts, solid particulates and condensable particulates. The solid particulates include soot emitted directly from the boiler and this is composed of unburned carbon particles and any ash residue in the fuel. The condensable particulates are not actually particles when the combustion products leave the boiler or furnace but vapors which condense into particulates when the exhaust gas cools after leaving the vent and mixing with cool ambient air. These condensable particulates include some hydrocarbons but the major part is sulfuric acid formed from a tiny fraction of the sulfur in the fuel.

For large stationary pollutant sources, such at power plants, the traditional method of measuring particulate emissions involves drawing an undiluted sample of the flue gas through a hot filter. This basically measures the solid particulates but not the condensable particulates. EPA Method 5 defines this in detail and this is the basis for particulate emission regulation. It is also the basis for particulate emission factors assigned to stationary sources in AP 42. There is growing recognition, however, that the condensable particulates are very important for health and there is now great interest in measuring these using sampling systems which simulate what happens after the exhaust leaves the vent. These sampling systems have a controlled cooling / dilution section prior to sampling on a cooler filter. For engine applications dilution sampling has long been used as the measurement standard.

Combustion sources emit particulates with a range of sizes. Health effects are most strongly associated with the smallest particles – those under 2.5 microns, roughly $1/30^{th}$ the diameter of a human hair. For many power plants some fraction of the total particulates are in this "fine particulates" category. Condensable particulates are all fine particulates. For oil-fired residential boilers and furnaces all particulate, both solid and condensable, are under 2.5 microns.

For diesel engines, a large fraction of the particulate emissions (solid + condensable) are sulfates, derived from the sulfur in the fuel. This situation has been a key driver in the recent reductions in allowable diesel fuel sulfur content. The situation is similar in oil-fired heating appliances where, for a typical fuel sulfur content, the composition of emitted particulate matter is roughly: 23 % filterable and 77 % condensable (**Ref 3**). The condensable particulate matter is largely sulfates. Based on this it would be expected that the particulate emissions from oil burners are a strong function of the fuel sulfur content. Figure 2-2 shows the results of recent measurements made at the CANMET Energy Technology Center with fuels with a range of sulfur content. This clearly shows the impact which fuel sulfur has on total particulates (**Ref 2**). A shift from ASTM No. 2 fuel with 0.2 percent sulfur to a fuel with 0.05 percent sulfur translates to a reduction of about 80 percent in particulate matter.

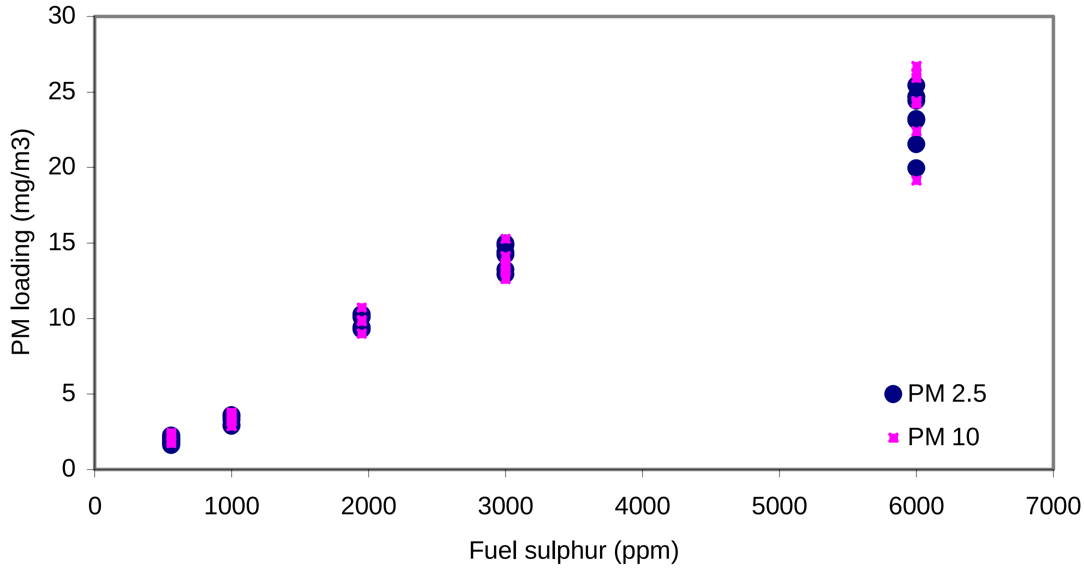


Figure 2-2 Effect of fuel sulfur on $PM_{2.5}$ and PM_{10} emissions

c. Nitrogen Oxides (NOx) Emissions:
All petroleum crude stocks contain varying small amounts of non-hydrocarbon materials or impurities, and the more important of these (at least from the emissions standpoint) are nitrogen- and sulfur-bearing compounds. The hydro-treating processes that are used to reduce sulfur during refining also reduce nitrogen by a similar mechanism. Although the two reactions have different rates and the effects are independent because nitrogen and sulfur are present independent of each other in different refinery stocks, the general rule is that by reducing sulfur content the nitrogen content of the fuel is reduced as well. Typical sulfur and nitrogen contents in common petroleum-based fuels are shown in Table 1.

Table 2-1 Typical Sulfur and Nitrogen contents in Petroleum Fuels

(all values, ppm)	S-Nom	N-Nom	S-Range	N-Range
Hi-Way Diesel (Gr. 2-D low sulfur)	360	150	< 500	100-200
Off Road Diesel (Gr. 2-D diesel)	3260	350	2000-5000	200-500
Heating Oil (Gr. 2 fuel oil)	1700	650	1000-3000	< 900

Work reported by Victor Turk of the R.W. Beckett Corporation (**Reference 4**) evaluated the effect of reduced sulfur / nitrogen fuels in three burner designs, and showed important reductions in NO_X formation. The reductions shown in Figure 3 show the cumulative effects of both fuel and burner effects. These fuel-related reductions were similar from burner to burner, with the low sulfur fuel reducing NO_X 5-10% compared to the standard fuel, and the ultra low sulfur fuel reducing NO_X by 20-30% compared to the standard fuel.

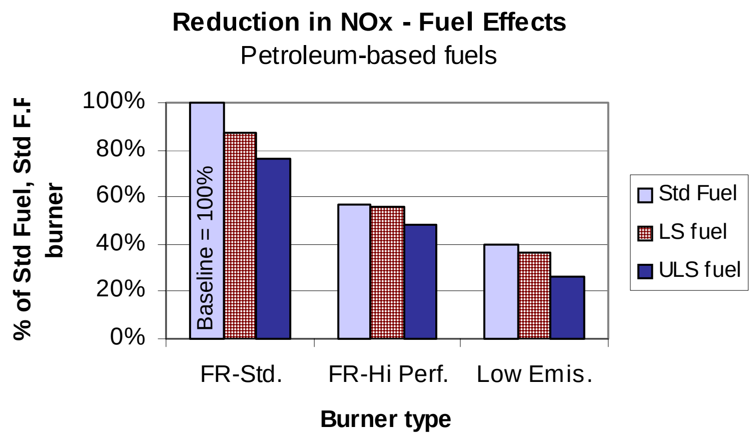


Figure 2-3 Fuel sulfur effects on NO_X formation

d. EPA Standards: Dr. Lee in her recent paper reported that “The U.S. Environmental Protection Agency (USEPA) promulgated revised National Ambient Air Quality Standards (NAAQS) for ozone and particulate matter in 1997 to address ambient concentrations of very fine PM. The particles with an aerodynamic diameter less than 2.5 µm, commonly known as $PM_{2.5}$, are introduced to the standards based on the reported concerns over human health effects associated with these respirable substances. Several studies have shown associations between fine PM concentrations and adverse health effects including increased mortality and cardiopulmonary and cardiovascular illnesses in most susceptible people although only a few key reports are referenced here. The effect of ambient fine PM on the visibility degradation has also been widely reported in industrialized countries. Similar regulatory considerations are given in Europe with the World Health Organization’s acknowledgment of the evidence of associations between PM concentrations and adverse effects on human health at low levels of exposure commonly encountered in developed countries. The Office of Air and Radiation of the EPA reported the U.S. implementation timeline for PM standards in 2000, as shown in Table 2-2.”

Table 2-2. The US implementation timeline for PM standards

1997	EPA issues Final $PM_{2.5}$ NAAQS
1998-2000	Ambient PM monitors put in place nationwide
1999-2003	Collect monitoring data
2002	EPA completes 5-year scientific review of standards
2003-2005	EPA designates non-attainment areas
2005-2008	States submit implementation plans for meeting the standard
2012-2017	States have up to 10 years to meet the standards plus one year extensions

Even thought the EPA has not finished its studies, it is very likely if not guaranteed that New England and East Coast States, which is the heart of oilheat marketplace, will be designated as non-attainment areas. This has been the case in most prior EPA designations of this nature. The oilheat community can get ahead of the curve by voluntarily shifting to low sulfur fuel and dramatically reducing the potential for negative publicity in this area. In fact, the oilheat industry has a unique opportunity to become a leader in this environmental area.

e. Low Sulfur Heating Fuel in Europe in Response to Emission Regulations:
In Europe the current range for the sulfur content of residential heating oil varies by country and is based on individual national standards which range from 0.2 to 0.1 maximum percent by weight. Several countries have two standards which define two different maximum sulfur levels. The second, more restrictive standards with the lower maximum sulfur content range between 0.005 and 0.05 sulfur percent by weight. In Switzerland the market share for the 0.05 percent sulfur fuel is about 20 percent and increasing. The price premium for such fuel has averaged about 2.5 cents per gallon in Europe. The EC-Limit for sulfur currently set at 0.2 percent will be 0.1 percent starting in 2008 as based on the European sulfur directive.

In Germany the basic standard is 0.2 percent sulfur by weight but the standard committee decided in 2001 to create a second standard for low sulfur heating oil with a maximum level of 0.005 percent sulfur. This is intended to improve the opportunities for compact, wall hung, oil-fired condensing boiler systems that have entered the German marketplace during the last two years. These products are needed to remain competitive with the gas industry. This fuel will be available for highway transportation in Germany in 2005 and it is presumed will also be available as heating fuel. In Switzerland there are two standards with two sulfur limits. The maximum legal limit for sulfur content is also 0.2 percent by weight. The second standard for heating fuel with has a maximum sulfur level of 0.05 percent. However, there is also a tax in place in Switzerland for all fuel oil which is higher than 0.1 percent and this tax is equal to roughly 2.5 cents per gallon. According to Dr. Rolf Hartl of the Swiss Oil Heat Association, there is very little fuel sold with a sulfur content higher than 0.1 and some dealers have even started marketing 0.03 percent sulfur fuel.

3. Reduced Equipment Cleaning and Cost Savings Potential

Research by the US Department of Energy at Brookhaven National Laboratory, the Canadian CETC, and others has shown a direct relationship between the sulfur content of home heating oil and the fouling deposit build-up on heat transfer surfaces. As the *percentage of sulfur in fuel is reduced*, the *rate of heat exchanger fouling drops*, and the *need for vacuum cleaning decreases*. This will allow extended intervals between vacuum cleaning, substantially lower service costs, improve customer satisfaction with oil, and improve oilheat's image as a "clean fuel". This interim report section reviews and summarizes both laboratory and field tests completed to date, and quantifies the potential impacts and benefits of using fuel oil with lower sulfur contents. A more detailed analysis, evaluations, and documentation will be included in the final report to follow.

The past and on-going laboratory and field-based research projects that are included in the present analysis include the following.

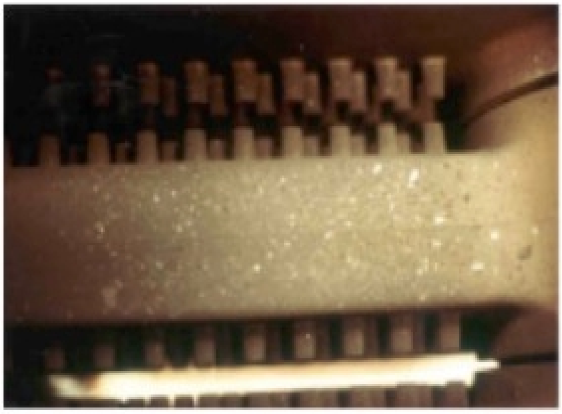
a. Laboratory tests by Brookhaven National Laboratory (BNL) on fouling rates for varying fuel sulfur contents
b. Laboratory tests by the Canadian CETC on fouling rates for varying fuel sulfur contents
c. Field test by BNL of fouling rates versus fuel oil sulfur content
d. On-going field test by the New York State Energy Research & Development Authority (NYSERDA), and

A brief summary of the key observations and conclusions for each study follows and additional details and analyses will be included in the final report.

a. Laboratory Tests at Brookhaven National Laboratory

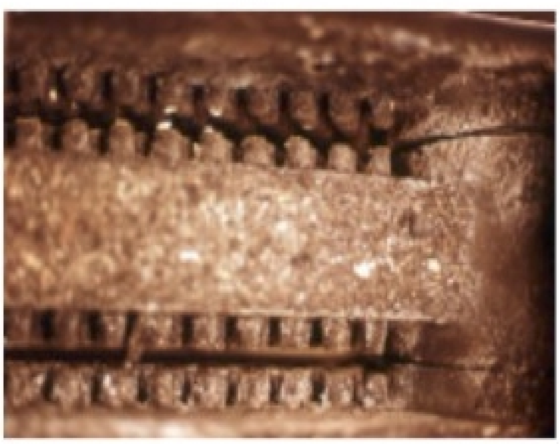
Brookhaven National laboratory (BNL) has been conducting research on oil heating equipment for more than 25 years under contract to the US Department of Energy. This program has helped to increase in oil heating equipment efficiency and reduce air emissions. For the past several years BNL has been evaluating the reduction in heat exchange deposition rates as the sulfur content of the fuel is lowered. The data indicate that the rate of heat exchanger fouling is directly proportional to the fuel's sulfur content. The deposits are combination of carbon-containing components (soot), and metal oxide and metal sulfates. Over the past 20 years, with the widespread use of flame retention oil burners, the carbon sooting of boilers and furnaces has dropped significantly - *WHEN THE BURNER IS PROPERLY ADJUSTED.* The majority of deposits in oil-powered equipment are from sulfates that are directly proportional to the sulfur content of the fuel.

Figure 3-1 is based on BNL testing and clearly shows how boiler deposits decrease as the fuel sulfur content is reduced from 1.08% to 0.04%. The deposition rates drops substantially as the fuel sulfur content decreases from 1% to 0.04 percent, which is the nominal amount now available with low sulfur diesel fuel required for on-highway use.



No 2 heating fuel, 0.04% Sulfur by weight

No . 2 heating fuel, 0.18% Sulfur by weight



No 2 heating fuel, 0.34% Sulfur by weight

No . 2 heating fuel, 1.08% Sulfur by weight

Figure 3-1. Boiler Deposition for Varying Fuel Sulfur Contents

A Brookhaven study in 1997 **(Ref 5)** developed a new laboratory method for evaluating boiler deposition rates by constructing a test section made from a conventional cast iron boiler. This test section was subjected to flue gases from a conventional oil boiler and the rate of deposition was accurately measured for a range of fuels with varying sulfur content. These tests showed that as the sulfur content increased, the rate of fouling deposition also increased. Therefore, cutting fuel sulfur content by 50% reduces the fouling rate by 50%. A plot of these results follows, Figure 3-2.

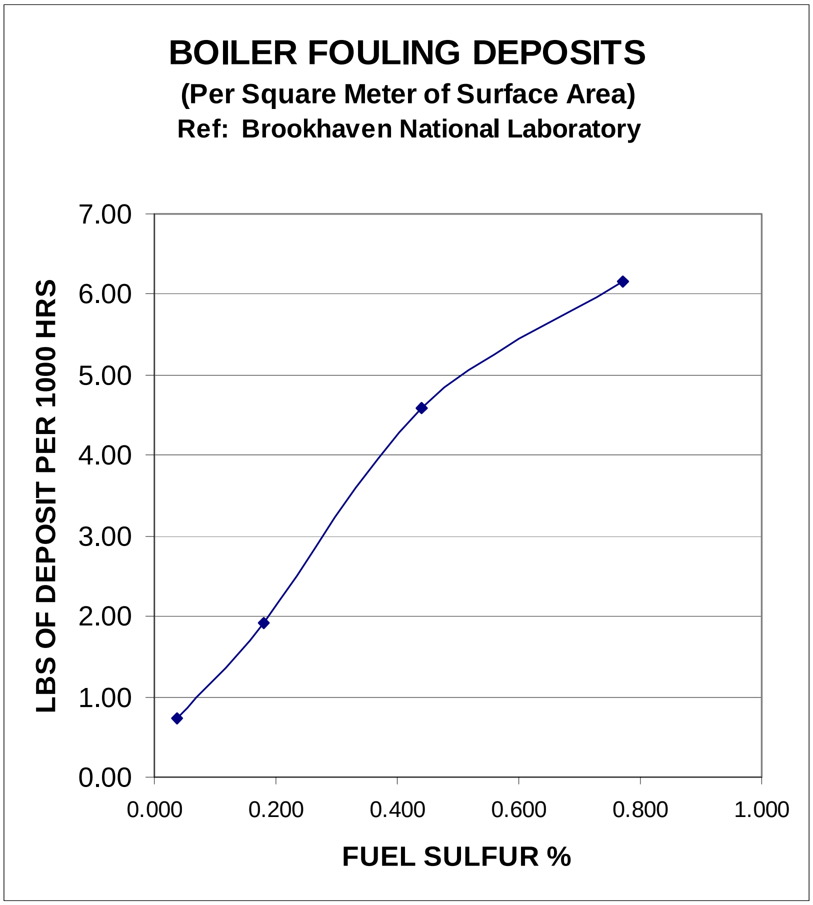


Figure 3-2

A fouling rate of **4.6 pounds** of deposits per square meter for 1000 hours of operation was measured for a fuel sulfur content of **0.44**%. This drops to only **0.73 pounds** of deposits when the fuel sulfur content is **0.04%**. This represents an 85% reduction in deposition rates. The fouling rate is for a fuel sulfur content of 0.22 percent, which is a typical value over the past 15 years **(Ref 1)**, the deposition rate is **2.3** pounds per 1000 hours. The 0.04% sulfur fuel lowers heat exchanger fouling rates by a **factor of 3.2** compared to this average sulfur fuel.

These tests indicate that using lower sulfur fuel oil can reduce deposition rates by about a factor of 3, and can lower the frequency of costly vacuum cleaning by a similar factor.

b. Laboratory Tests at Canadian Energy Technology Center

Deposition rate tests for various fuel sulfur contents were also completed in Canada using a test method similar the one used at BNL. The test results are also similar and corroborate the BNL tests, as seen in Figure 3-3. While the actual deposits are slightly higher, the overall trend is the same. See the plot that follows.

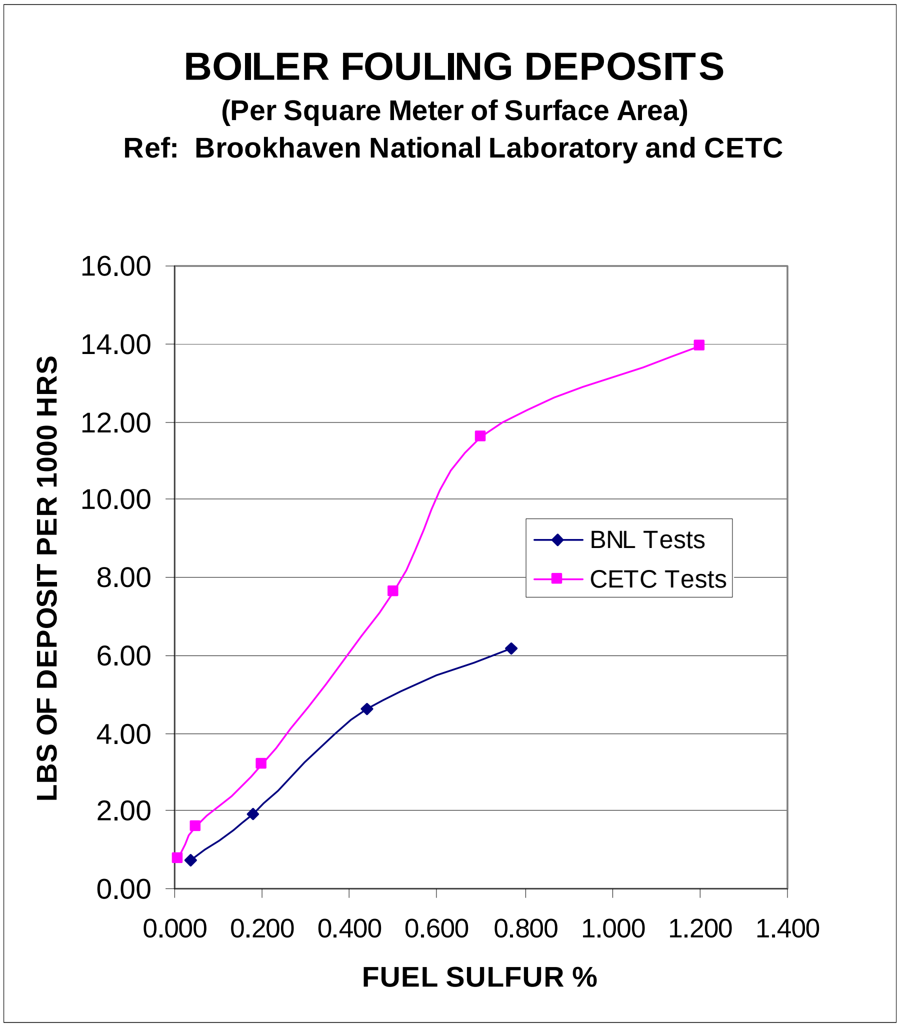


Figure 3-3

The Canadian test results show a change in deposition rate that is very close to the BNL tests. The average deposition rate for the two studies at **0.05 %** sulfur is **1.3 pounds of deposit** per 1000 hours of operation. The average deposition rate at **0.22%** sulfur is **3.1 pounds of deposit.** Therefore, if the fuel sulfur is reduced from 0.22% to 0.05%, the rate of fouling depositions is expected to decrease by a **factor of 2.4**. The frequency of vacuum cleaning and cleaning costs are expected to decrease by a similar factor.

c. Field tests by BNL of fouling rates versus fuel oil sulfur content

Brookhaven National Laboratory also conducted lab and field tests on conventional oil powered boilers to evaluate actual deposition rates and to validate the lab tests.

The in-lab long-term test was a four month side-by-side evaluation of two boilers operating with 0.04% sulfur fuel oil and 0.35% sulfur. These boilers were allowed to operate on a conventional chimney and the total deposits were examined at the end of the test period. The higher sulfur oil produced deposits of 386 gram compared to only 35 grams for the boiler fired with the low sulfur oil – a factor of **11 to 1**. If the higher sulfur oil contained **0.22 % sulfur**, the low sulfur oil would have produced about **six times fewer deposits**. These data suggest that the low sulfur fuel oil may actually lower boiler deposition rates even more than is predicted by the BNL and CETC tests reported above. The rate of temperature rise (due to boiler fouling) is **3 times higher** for the 0.35% S oil compared to the 0.04% S oil, suggesting a 3 –to – 1 reduction in deposition rates. See Figure 3-4.

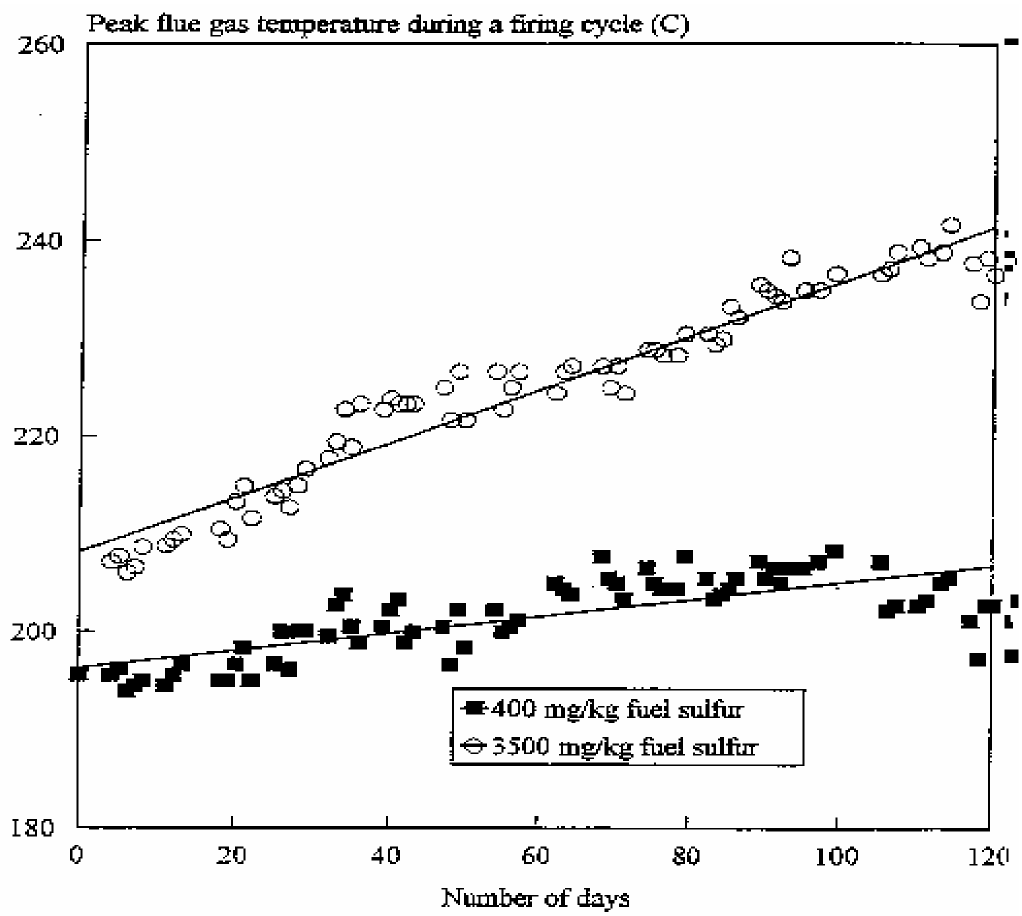


Figure 6. Trends in peak flue gas temperarure during full size boiler tests.

Figure 3-4

d. On-going Field Tests by the New York State Energy Research & Development Authority (NYSERDA)

NYSERDA has been conducting a multi-year evaluation of the benefits of low sulfur heating oil in homes over the past two heating seasons with the assistance of the Energy Research Center, Inc and Brookhaven National Laboratory, the Empire State Petroleum Association, and Buhrmaster Energy Group. NORA is co-funding Phase II of this work. The objective of this project is to demonstrate the advantage of low sulfur fuel oil in actual homes, measure the performance improvement, evaluate potential reductions in cleaning costs, and identify problems with its widespread use. Initial estimates indicate potential reductions in service (vacuum cleaning) costs of $65 million a year in New York State.

Work included collection and analysis of actual boiler deposits for low sulfur and normal sulfur homes, detailed analysis of changes in k-factors, and use of a visual rating scale for boiler fouling. The report on the first two years of field data has not been completed yet, but a summary of key data and conclusions follows.

Deposition data and analysis

The boilers in the test program were cleaned by specially trained oilheat service technicians using a method developed at BNL for collecting all the boiler deposits and placing them in a sample bottle for analysis. Figure 3-5 summarizes the data analyzed to date.

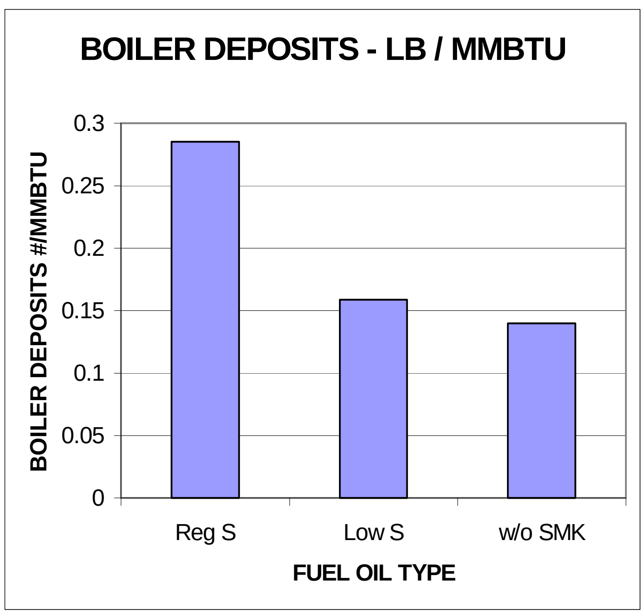


Figure 3-5

The normal sulfur fuel oil produced **0.28 pounds of deposits** per million BTU of fuel consumed. This is significantly higher than the deposits from the low Sulfur boilers. When the “heating only boilers” and with “high smoke number boilers” are removed, the average deposits in the low sulfur group equals **0.14 pounds** per million BTU of fuel. This is a **2 – to – 1** reduction in deposits for the low sulfur oil. This is consistent with the results shown in Figure 3-3.

Visual inspection data and analysis

As part of the evaluation program for the NYSERDA field study, Brookhaven engineers developed a **Visual Fouling Scale** that was used by service technicians to evaluate the level of deposition on the heat exchangers prior to cleaning. This scale is based on the fouling levels shown in Figure 3-1. This fouling scale was applied to the detailed study homes, and also in about 100 other homes to see how the visually observed scaling compares for the normal sulfur and low sulfur homes. Excellent correlation was observed between this fouling scale and the mass of deposits collected for the normal and low sulfur homes. The Figure that follows shows the Visual Fouling Scale averages for normal and low sulfur homes. It is very similar to the measured differences in deposition mass shown in Figure 3-5, with about a 2- to -1 difference.

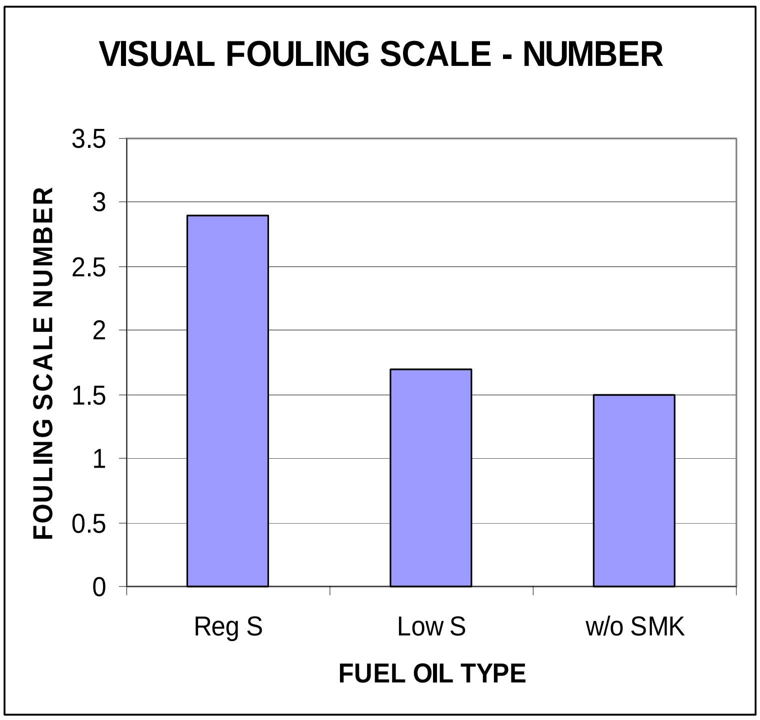


Figure 3-6

A similar difference in fouling factors was obtained for approximately 100 normal and low sulfur homes that did not have their deposition rates measured (Figure 3-6). The average Visual Fouling Scales for the Normal sulfur homes in this group was 2.6, and for the low sulfur homes was 1.7. The visual fouling scale appears to accurately predict the measured deposition rates, and gives similar difference when comparing the normal and low sulfur fuels.

This field study is very important because it is the first long-term evaluation of the performance of low sulfur fuels in actual homes. It validates many years of laboratory testing and demonstrates the important advantages of low sulfur fuel oil in homes served by oil marketers.

e. Comparison of Results – Expected Reductions in Deposition Rates

The studies cited above predict reductions in deposition rates for the low sulfur fuel oil. The BNL and CETC laboratory tests indicate a reduction of **2.4 –to – 1** when the fuel sulfur is reduced from 0.22% t o 0.05%. Long-term boiler tests at the BNL lab indicate a reduction of about **6 – to -1**, while the change in flue gas temperature suggests a variation of **3 – to -1** with the low sulfur fuel oil. Preliminary analysis of data from the NYSERDA field study of low sulfur oil shows a reduction in deposition rates of about **2 - to -1** for the low sulfur oil. For this interim report, the average of the BNL and CETC lab test of **2.4 - to -1** for a sulfur reduction from 0.22% to 0.05% will be used to evaluate potential cost savings by extending the interval between vacuum cleanings.

f. Preliminary Cost Saving Potential Evaluation and Discussion

A preliminary evaluation of service cost savings was completed using the BNL/CETC data on reduced boiler deposition rates. This was combined with information from a survey conducted by the National Association of Oilheat Service Managers (NAOSHM) and RW Beckett Corporation two years ago **(Ref 6)**, which shows average values for: existing service intervals, labor costs for service, and the time required for vacuum cleanings. This evaluation is summarized in the figure that follows.

COST SAVINGS POTENTIAL WITH LOW SULFUR FUEL OIL
REDUCED VACUUM CLEANING FREQUENCY AND COSTS
REF: RW BECKETT / NAOHSM SURVEY – September 1999

UNIT	**Service Interval (months)**	**Average Vac Time (Hours)**	**Average Vac Cost ($)**
Boilers	19	1.24	62.73
Furnaces	25	1.17	59.43
Water Htr	20	0.90	45.25
Average	**21**	**1.10**	**55.80**

Figure 3-7

COST SAVINGS POTENTIAL FOR LOW S OIL ($)

FOR:		
	11,150,000	Oil Heated Homes
	21 Month	Vacuum cleaning interval (for 0.25% S)
	1.10 hours	Per Vacuum Cleaning
	$55.80	Per Vacuum Cleaning
	0.05%	Sulfur Content of Low S Fuel Oil

		INITIAL SULFUR CONTENT OF FUEL OIL %				
		0.15	**0.20**	**0.25**	**0.30**	**0.35**
Existing Fouling Rate	Lb/1000 hr	2.4	2.9	3.5	4.0	4.6
New Fouling Rate	Lb/1000 hr	1.2	1.2	1.2	1.2	1.2
Ratio of Fouling Rates		1.9	2.3	2.8	3.2	3.7
Existing Vac Interval	months	31	25	21	18	16
Proposed Vac Interval	months	58	58	58	58	58
Existing Vac Clean	Million / year	4.3	5.4	6.4	7.4	8.4
New Vac Clean	Million / year	2.3	2.3	2.3	2.3	2.3
Existing Vac Cost	$Million / year	242	299	356	412	469
New Vac Cost	$Million / year	128	128	128	128	128
Cost Savings	$Million / year	**114**	**171**	**228**	**284**	**341**

NOTE: Fouling Rates based on average of tests conducted by BNL and CETC

Figure 3-8

Figures 3-7 supplies useful information about current service intervals and costs, and how low sulfur fuel oil can extend the time between vacuum cleanings, producing cost savings. The NAOSHM / Beckett survey indicates that the average interval between vacuum cleaning is about 21 months for boilers, furnaces, and water heaters. The average time for vacuum cleaning is 1.10 hours, with an average cost of $55.80.

Figure 3-8 supplies valuable information on the potential cost savings by using low sulfur fuel oil based on the baseline information in Figure 3-7. For an initial sulfur content of 0.25% (which was typical several years ago) the fouling rate drops from 3.5 pounds per thousand gallons of fuel, to 1.2 pounds per thousand gallons. This permits the average vacuum cleaning interval to be extended from 21 months to 58 months (about 5 years). This translates to a potential service cost savings of **$228 million a year**. For an initial fuel oil sulfur content of 0.20%, the annual cost savings is **$171 million a year**. The actual savings in vacuum cleaning costs is expected to fall somewhere between $171 million and $228 million a year when all oil heating equipment is operated with low sulfur fuel oil.

The Figure that follows shows the calculated cost savings from less vacuum cleanings as the initial fuel sulfur varies. If the origin fuel sulfur content is higher, annual cost savings are also higher.

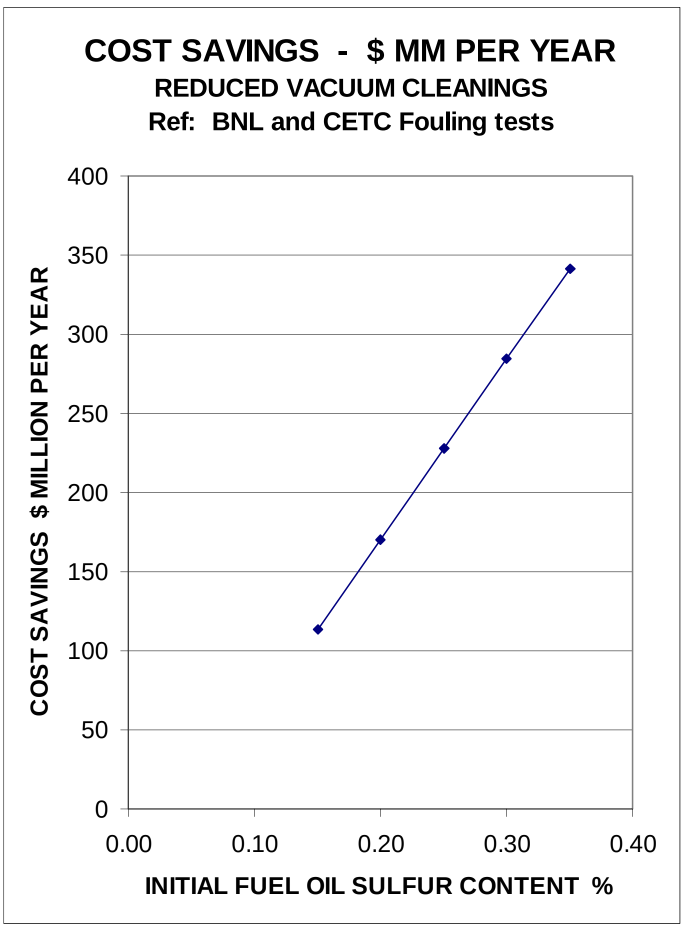


Figure 3-9

4. Fuel Stability and Sulfur in Distillate Fuels

In the ongoing NORA research project related to maximizing fuel quality and performance (**Ref 7**) BNL is investigating the nature of fuel quality issues and will provide the oilheat industry with guidelines to resolve these concerns. These issues are related to fuel instability, sludge formation, filter and nozzle fouling. Together they represent the largest number of unscheduled service calls in the oilheat industry. These problems are the result of many contributing factors, many of which are beyond the scope of this report. The instability of fuel oil and sludge formation are related issues that can not be separated. Contamination due to exposure to air, dust, humidity and other environmental factors combine with the chemical nature (and inherent instability) of the fuel as it was refined. Stability always degrades with time, it is a related to the inherent instability of the product, how fast it is transported, the storage time and the use or nonuse of fuel stabilizers. Product roll-over and mixing with older product is also a factor. However, part of the problem is related to variations in the fuel chemistry including the feed stocks at the refinery (the source and type of crude). The type of the refinery processing that the fuel is exposed to is yet another factor as is the use of cracked stocks in blending the heating fuel product. The production of other products, refined for other markets such as gasoline, how the barrel of crude is cut up, is another factor, which can vary seasonally. These factors all can have an affect on the chemical stability of the heating fuel. One of the ways chemical degradation can occur is related to the reactive compounds based on sulfur and nitrogen found in the fuel. Although the exact mechanisms are still not known, reactive hydrocarbons, sulfur and nitrogen compounds contribute to fuel instability. Hydrotreating is currently the most viable refining process for removing sulfur in diesel; nitrogen containing compounds are also removed by this process. Known or anticipated effects of hydrotreating on fuel properties include improvement in fuel storage.

In the NORA/BNL fuel performance research project, test results reported to date indicate that **low sulfur** (less than 0.05% sulfur by weight) fuels are **more stable** and generate less particulate matter than normal sulfur content fuels. The sulfur content of the fuel appears to be an indicator of the chemical stability of the fuel. In addition, the fuels treated with after-market stabilizing additives of the same sulfur classification were more stable and generated less particulate matter than untreated fuels of the same sulfur classification. In all cases reported, stability numbers for the low sulfur content fuel samples fell within the higher (more stable) end of the range of stability tests. A definitive conclusion has not yet been drawn.

The study is not yet complete and only a few marketers in the nation currently market low sulfur heating fuel. However, all evidence collected to date does support the conclusion. The use of low sulfur fuels will not eliminate all fuel stability problems and will not resolve many fuel related service calls. As stated earlier, many factors other than fuel chemistry contribute to fuel stability problems. The stability tests that exist are more comparative then predictive. The basic conclusion that lower sulfur levels do correlate to better fuel stability has been reported in other end use sectors as well as reported in several references. Again, the correlation indicates a comparative trend not a predictive one. At this time all available data indicate that the use of low sulfur fuels will help improve the fuel quality.

5. Environmental Costs and Externalities for Low Sulfur Fuel Oil and Other Sources

Environmental costs, sometimes called externalities, were developed in order to evaluate the impact of electric power generation on the environment. Environmental cost factors are evaluated by calculating the impact of various air pollutants on the environment by assigning a cost value (in dollars per pound) for each air pollutant that is emitted. These cost factors sometimes reflect measured values such as crop damage and other times are based on other values such as a cost of control equipment to reduce air pollutant omissions. These "environmental costs factors" are then added together and compared to evaluate the overall impact of all air emissions from different combustion sources.

This is a complex subject matter has been evaluated for many years by groups including the Pace University Center for Environmental Legal Studies, the New York State Energy Office and the Massachusetts Department of Public Utilities. Each air pollutant is assigned a cost estimate in dollars per pound of air pollutant. For example, Particulate Matter is assigned the value of $1.19 per pound. These cost factors, in dollars per pound, are then combined with actual emission factors in pounds per million BTUs of fuel consumed to determine the overall environmental costs in dollar per million BTU of fuel burned. The total environmental impact of various fuels is then be compared in terms other their *dollars per million BTU*. Fuels with lower environmental costs are better for the environment then fuels with higher costs.

This interim report uses environmental cost factors that were reported in the Oilheat Advantages Project (**Ref 8**). These environmental cost factors are as follows:

AIR POLLUTANT	ENV COST $/POUND
Particulate Matter	1.19
Nitrogen Oxides	0.82
Carbon Dioxide	0.0068
Sulfur Oxides	2.03
Carbon Monoxide	0.43
Hydrocarbons	2.65
Methane	0.92

The table that follows shows environmental costs for various combustion sources based on the above environmental cost factors, in dollars per pound, and actual emissions rates of all air pollutants by each fuel. The actual emission rates are based on publications by the U.S. Environmental Protection Agency and test conducted by Brookhaven National Laboratory.

ENVIRONMENTAL COSTS FOR VARIOUS COMBUSTION SOURCES

POLLUTANT	ENVIRON COSTS $/LB	REF	#2 OIL 0.25%S (2) #/MB	$/MB	#2 OIL 0.05%S (2) #/MB	$/MB	NAT GAS (4) (6) #/MB	$/MB	DIESEL ENG (4) #/MB	$/MB	#6 OIL 2%S (3) #/MB	$/MB	COAL 3%S (5) #/MB	$/MB	GAS ENG (4) #/MB	$/MB	WOOD STOVE (4) #/MB	$/MB
PARTICUALTE MATTER	1.19	1A	0.0027	0.0032	0.0013	0.0015	0.0030	0.0036	0.2420	0.2880	0.163	0.19	2.45	2.92	0.052	0.06	3.33	3.96
NITROGEN OXIDES	0.82	1A	0.15	0.1230	0.135	0.1107	0.1000	0.0820	3.38	2.772	0.357	0.29	0.57	0.47	0.827	0.68	0.222	0.18
CARBON DIOXIDE	0.0068	1A	164	1.1152	164	1.1152	116	0.7888	164	1.115	169	1.15	209	1.42	155	1.05	221	1.50
SULFUR OXIDES	2.03	1A	0.26	0.5278	0.05	0.1015	0.0060	0.0122	0.225	0.457	2.25	4.57	4.8	9.74	0.043	0.09	0.03	0.06
CARBON MONOXIDE	0.43	1B	0.026	0.0112	0.026	0.0112	0.0200	0.0086	0.735	0.316	0.033	0.01	0.20	0.09	31.94	13.73	20.63	8.87
HYDROCARBONS	2.65	1B	0.0017	0.0045	0.0017	0.0045	0.0053	0.0140	0.27	0.7155	0.005	0.01	0.003	0.01	1.07	2.84	7.94	21.04
METHANE	0.92	1C	0.013	0.0120	0.013	0.0120	0.8020	0.7378		0.000	0.002	0.00	0.001	0.00		0.00	0.079	0.07
TOTAL				**1.80**		**1.36**		**1.65**		**5.66**		**6.23**		**14.64**		**18.45**		**35.69**
TOTAL w/o CO2				**0.68**		**0.24**		**0.86**		**4.55**		**5.08**		**13.22**		**17.40**		**34.19**

NOTES:

(1) ENVIRONMENTAL COSTS ($/lb) FROM:

(a) PACE UNIVERSITY - "ENVIRONMENTAL COSTS OF ELECTRICITY" - 1991

(b) MASS DEPT OF PUBLIC UTILITES - DOCKET #89-239

(c) AVERAGE VALUES FROM ABRAHAMSON AND PLC STUDIES

(2) EMISSION FACTORS FROM BROOKHAVEN NATIONAL LABORATORY AND USEPA AP-42

(3) EMISSION FACTORS (LBS/MILLION BTU) FROM PACE UNIVERSITY AND (4)

(4) EMISSION FACTORS (LBS/MILLION BTU) FROM USEPA AP-42

(5) UNCONTROLLED EMISSIONS FROM SPREADER STOKER WITH 3% SULFUR FUEL

(6) INCLUDES 2% GAS LEAKAGE DURING TRANSMISSION AND DISTRIBUTION

Figure 5-1

The spreadsheet compares the Environmental Costs of various fuel in $ per Million BTU of fuel consumed. The lowest values are: Low sulfur #2 oil at $1.36, natural gas at $1.65, and #2 fuel oil (0.25% sulfur) at $1.80 per Million BTU of fuel consumed. These are all much lower than most other combustion sources, and, therefore, produce the least environmental damage. Diesel engines and #6 fuel oil are higher in the range of $5 to $6 per Million BTU. Coal and gasoline powered engines are much higher at $14.64 and $18.45 per million BTU. The highest environmental cost is for wood stoves at $35.69 per million BTU, which is 20 to 25 times higher than oil or natural gas equipment. Clearly #2 oil and natural gas equipment produce comparable and very low environmental impact, and are much cleaner than all other combustion source that were evaluated. In fact, when the methane leakage from gas pipelines is included, low sulfur #2 oil has an environmental cost that is slightly lower than natural gas.

These environmental costs for low sulfur fuel oil and other fuels are compared in the Figure that follows. The emission rates and cost factors will be further evaluated in the final report.

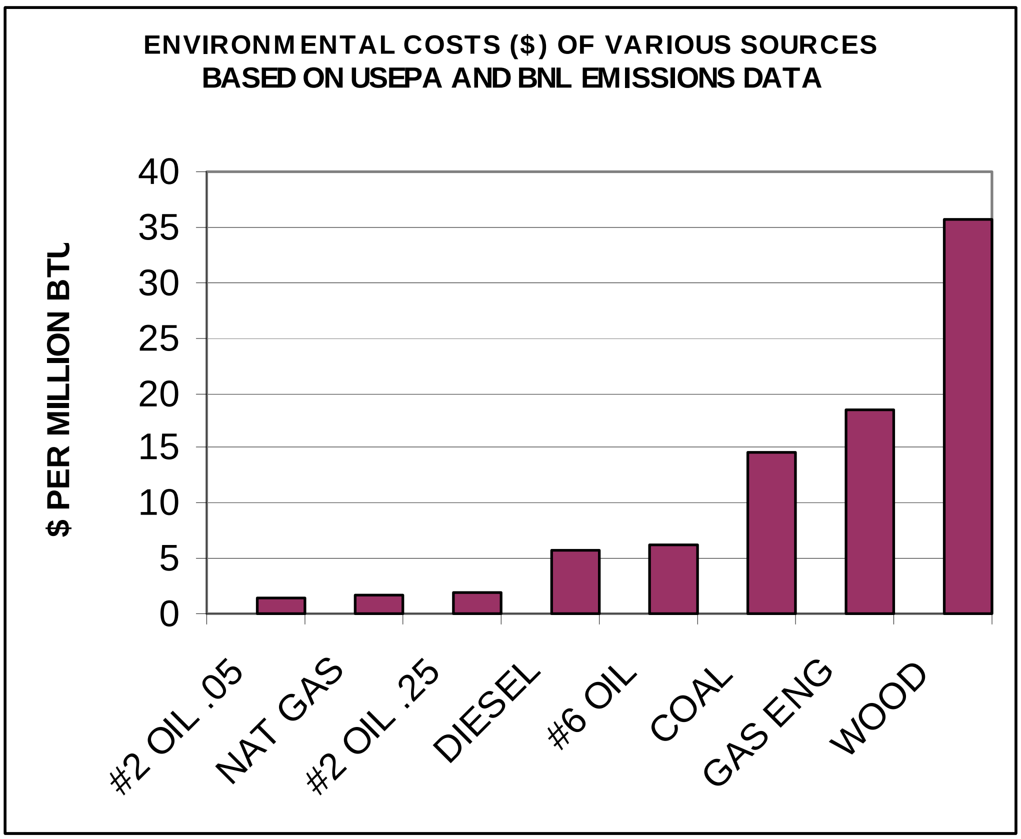


Figure 5-2

6. Emission Reduction Credits and Allowances Produced by Using Low Sulfur Oil

Emission trading is a program that allows facilities that emit controlled air pollutants including sulfur oxides, nitrogen oxides, particulate matter, and other pollutants, to meet their emission limits as required by the US EPA by purchasing emission credits. Facilities or any emission source can create and sell emission reduction credits (ERCs) that are generated when a firm voluntarily reduces their emissions of a controlled pollutant below the level required by law. For example, if a large industrial facility must reduce its emission by 25% to meet a state or federal regulation, but instead invests in added controls that lower emissions by 35%, the excess reduction in emissions can create emission reduction credits, ERCs. These credits can be banked and used by the facility at another location, or they can be sold to other facilities through a credit trading program.

It is possible that the oilheat industry could generate sulfur oxide and nitrogen oxide Emission Reduction Credits by using low sulfur fuel oil, and the revenue generated could then be used by NORA to fund their R&D program. This would be another important advantage of using low sulfur fuel oil in homes.

The current price for Sulfur Dioxide (SO_2) credits is approximately $140 a ton based on recent discussions with a major emissions trading company. This ranges from about $110 to $220 a ton. Initial calculations indicate that if all oil-heated homes switched from 0.20% to 0.05% sulfur oil, on the order of $10 million a year in Emission Reduction Credits could be generated. Taking into account time delays in the use of the lower sulfur oil, and costs associated with implementing the credits, it is possible that the oilheat industry could receive from $1 million to $5 million a year for research and development activities over the next several years. This would greatly enhance the rate of new technology development that is needed for increasing oilheat's market share and establishing new applications for home heating oil. Additional Emission Reduction Credits also could be generated by the reduced nitrogen oxide emissions from the lower sulfur fuel oil. These credits range in prices from $600 to more than $7500 a ton, and will be increasing in 2004.

Several criteria are needed for ERCs to be created and traded. The credits must be real, quantifiable, and acceptable to state and federal regulatory agencies. The final report will address the prospects of Emission Reduction Credit generation and trading in more detail. If allowable, ERCs can offer an important incentive for oil dealers to aggressively market low sulfur fuel oil.

7. Preliminary Cost-Benefit Analysis: Savings with Low Sulfur Fuel Oil

The cost savings potentials for the low sulfur oil (by less frequent vacuum cleaning) developed in section 3 of this interim report are combined with the added fuel price for the low sulfur oil to calculate an expected cost-benefit ratio. This demonstrates the economic advantage of the lower sulfur fuel to homeowners and fuel marketers. Expanded analyses will be prepared for the final report to follow.

The following input was used in this preliminary calculation:

- Annual fuel consumption rate of 865 gallons a year
- Cleaning cost of $55.80 (based on Beckett/NAOHSM survey)
- A vacuum cleaning interval of 58 months with the low sulfur (0.05%) fuel oil
- Added fuel costs ranging from $0.0025 to $0.015 per gallon for low Sulfur oil
- Starting fuel oil sulfur contents ranging from 0.15 percent to 0.40 percent

The results of this interim analysis follow for prior vacuum cleaning intervals of 12 months and 18 months respectively. For an existing interval of 12 months between vacuum cleanings, the net cost savings, and ratio of cost savings to added fuel costs are shown in **Figures 7-1 and 7-2**.

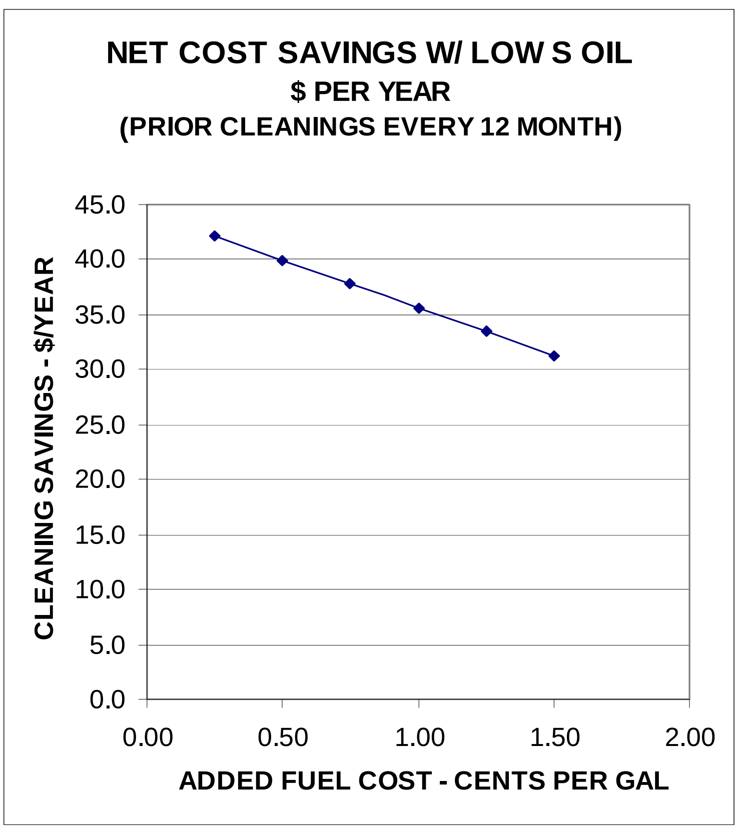


Figure 7-1

Figure 7-1 shows that the net cost savings by using the lower sulfur oil varies from $42.10 per year to $31.30 as the added price for the low sulfur oil increases from $0.0025 per gallon to $0.015 per gallon. This is based on a prior vacuum cleaning interval of every 12 months. The ratio of added fuel cost to vacuum cost savings is shown in **Figure 7-2** and ranges from **19.5 – to -1** to **2.4 – to – 1** as the added fuel price increases from 0.25 cents to 1.5 cents per gallon. At an added fuel price of **1 cent per gallon**, the ratio of dollars saved in lower cleaning costs to added fuel costs is more than **4 – to -1**.

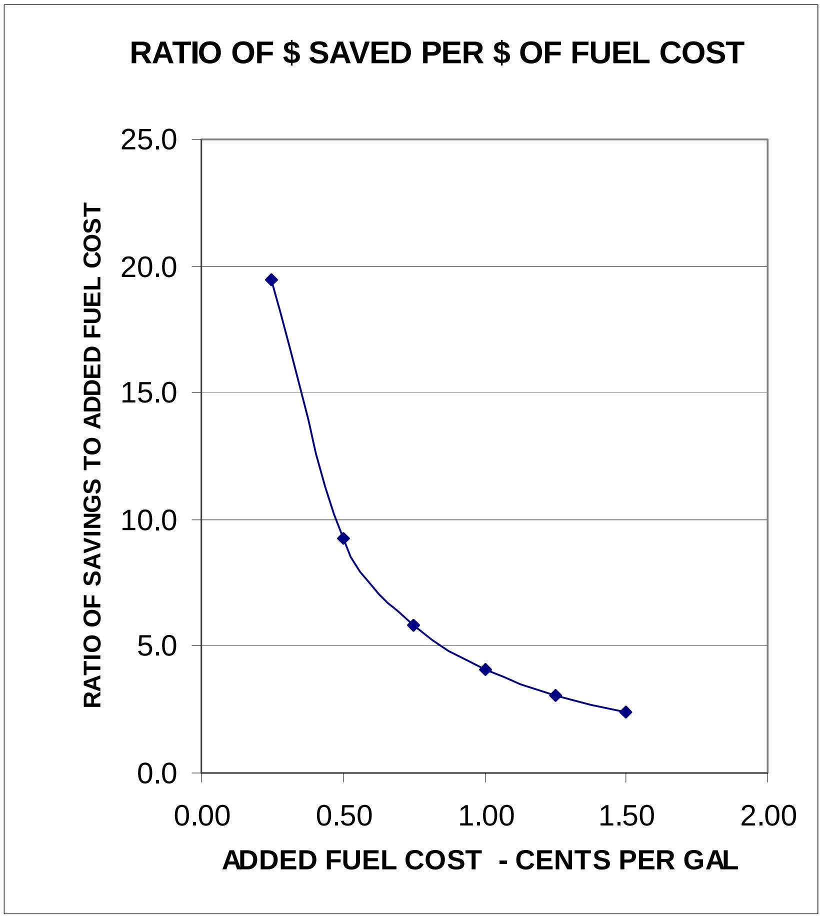


Figure 7-2

These preliminary calculations show that excellent economic benefits are possible by using lower sulfur fuel oil, if the vacuum cleaning interval can be extended as shown by the laboratory and field investigations. If the existing vacuum cleaning intervals are less frequent, then the cost savings are reduced. However, even with an existing vacuum cleaning interval of 18 months, the annual cost savings per home range from $23.50 a year to $12.70 a year, which is economically attractive.

Additional cost savings and cost-benefit ratio calculations will be presented in the final report that will address a range of added fuel prices and service intervals.

8. References (partial listing)

Ref 1. Heating Oils, 2001, Cheryl L. Dickson, July 2001, TRW-221 PPS 01/4
Note: TRW Petroleum was formerly the National Institute for Petroleum and Energy Research (NIPER)

Ref 2. Proceedings of the 2002 National Oilheat Research Alliance technology Symposium, BNL report 52670, August 2002, Paper No. 02-13, Assessing $PM_{2.5}$ Emissions from Distillate Fuel Oil Heating, S. Win Lee, I He, T. Herage, E. Kelly and B. Young, CANMET Energy Technology Center-Ottawa, Natural resources Canada

Ref 3. United States Environmental Agency
AP-42, Fifth Edition, Volume 1, Chapter 1: External Combustion Sources
Table 1.3-1 Criteria Pollutant Emission Factors for Fuel-oil Combustion
Table 1.3-2 Condensable Particulate Matter Emission Factors for Fuel-Oil Combustion

Ref 4. Proceedings of the 2002 National Oilheat Research Alliance (NORA) Technical Symposium, BNL Report 52670, August 2002, Paper No. 02-10, Factors Affecting Oil Burner NOx Emissions, Victor Turk, R.W. Beckett Corporation, August 19-20, 2002.

Ref 5. Fouling of Heat Transfer Surfaces in Domestic Oil-Fired Heating Boilers, BNL 64833, T. Butcher, W.L. Litzke, Y. Celebi, Brookhaven National Laboratory and S. W. Lee CANMET Energy Technology Center-Ottawa, Natural resources Canada (Reprinted within BNL 52558 as part of the Proceedings of the 1999 Oil Heat Technology Conference and Workshop, April 1999).

Ref 6. Letter to ASTM Subcommittee EW Chairman, from Vic Turk of the RW Beckett Corporation, dated December 2, 1999, regarding proposed revisions to fuel oil specifications, and supporting engineering analyses of the impact on heating equipment cleaning intervals of lower sulfur oil.

Ref 7. Proceedings of the 2002 National Oilheat Research Alliance (NORA) Technology Symposium, BNL report 52670, August 2002, Paper No. 02-03, Maximizing Fuel Oil Quality and Heating System Performance, Wai Lin Litzke, Brookhaven National Laboratory and associated presentation viewgraphs provided at the NORA Technology Symposium at the Oilheat Visions Conference, August 19-20, 2002

Ref 8. Oilheat Advantages Project – Engineering Analysis and Documentation Report by J.E. Batey and R. Hedden, Copyright 1995 by the Oilheat Manufacturers Association