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# Analysis of Emissions from Residential Oil Furnaces

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## INTRODUCTION

In North America the four chief home heating fuels are, in descending order of importance, natural gas, oil, electricity, and wood. Each of these methods has its environmental drawbacks. Electric heating devices, such as heat pumps, can be sources of ozone-layer-depleting CFCs (chlorofluorocarbons), and the otherwise clean-burning natural gas can add tons of carbon dioxide to the atmospheric burden, thereby accelerating global warming. This paper deals primarily with oil furnaces. Data are presented on the total mass, extractable organics, filterable particulate emissions, and mutagenicity of the organic fraction from an oil furnace study run in a laboratory as part of the Integrated Air Cancer Project's (IACP's) Roanoke study. This discussion will point out the difference in emission rates for oil furnaces when the newer retention head burners are used. The filterable particulate data are compared to values in the literature. The paper also presents preliminary results from the oil furnaces studied in the Roanoke IACP field study.

## DISCUSSION

The most frequently used home heating oil in North America is No. 2 fuel oil. As reported previously[1] No. 2 fuel oil may be loosely defined as the cut in the distillation of crude oil that lies between 375 and 625° F (190 and 330° C) (the higher the number of the oil, the less volatile it is). It is a mixture of four main groups of compounds: a homologous series of normal alkanes; a related group of substituted alkanes; a homologous series of alkyl benzenes; and, most importantly, a homologous series of substituted naphthalenes. A number of olefins are also present. When properly tuned, residential oil furnaces are relatively clean burning, especially as compared to woodstoves. Under typical tuned conditions, oil furnaces emit soot, unburned fuel, and a range of hydrocarbons related to the fuel.

### IACP Laboratory Study

Two types of residential oil furnace burners were used in this study: a pre-1970 design atomizing-gun ABC Model 45 burner and a modern design Thermo-Pride Model M-SR retention head burner. The burners were installed and operated in a Williamson Model 1167-15 residential oil furnace purchased in the late 1960s. For all tests, a 2.84 L/hr (0.75 gal./hr) fuel nozzle was used with fuel at a pressure of 690 kPa (100 psi) on No. 2 fuel oil. Results are shown in Table I.

The mutagenicity values shown in Table I were determined using the microsuspension assay[2] (MSA) using strain TA98 with rat liver homogenate (+S9) activation. It is convenient to use

the MSA assay as it requires much less sample than the standard Ames plate incorporation assay. These preliminary results are based on duplicate assays on the sample set. These analyses need to be repeated on this and other sample sets to improve confidence in the results. Samples from the same set also need to be analyzed using the Ames plate incorporation assay to allow comparison with Ames data in the literature.

**Oil and Gas Furnace Data in Literature**

The particulate data presented in the literature were obtained primarily in the field, not the laboratory[3,4]. For the oil furnace, 13 furnaces were tested representing a variety of burner and furnace models. All used high pressure gun-type burners, seven conventional head, five retention head, and one shell head. The burner age ranges were 2 to 20 years and <1 to 5 years old for the conventional and retention head burners, respectively. The shell head burner was 2 years old. Each was tested as found and again after tuning. During the tests reported here, the furnaces were operated on a 10 minute on, 20 minute off cycle. Average filterable particulate emissions (EPA Method 5 front half) were 7.5 mg/MJ as found and 6.9 mg/MJ after tuning. Average Bacharach smoke numbers were 1.3 and <1, respectively. There was no significant difference in the average emission factor and smoke number for the three types of burners tested.

For the gas furnaces, filterable particulate values are 0.26 and 0.36 mg/MJ for sample periods one and two, respectively[3]. Bacharach smoke number was not measured.

**Comparison of Laboratory and Literature Oil Furnace Data**

The oil furnace particle emissions and smoke number values presented in the literature can be compared to the corresponding values in Table I. First, a comparison of Bacharach smoke numbers shows that the laboratory furnace was producing more smoke. Even with the new technology burner under best tune conditions, the smoke number was higher (2) than the "as found" average field smoke number (1.3). Smoke number and particulate emission rate would be expected to be directly related in a general sense (i.e., if one increases, so does the other) for a given burner. This may not be true when comparing burners since start-up and shutdown can dominate particulate emission generation while having no significant effect on full cycle smoke readings.

**Filterable Particulate**. A direct comparison of particulate emission factors is more complex. The only possible comparison is between the laboratory filterable particulate data in Table I

and the field filterable particulate oil furnace data in the literature. The field data are based on EPA Method 5 front half. Since the filter and probe were heated above 100 °C, most unburned fuel would pass through the filter. The laboratory study used a dilution sampler[5,6] which extracts the sample from the stack through a heated probe and then dilutes it with filtered ambient air in an unheated dilution chamber before passing the diluted mixture through an unheated filter. Thus the

Table I. Residential distillate oil combustion laboratory test results[1].

| Burner type[a] | Bacharach smoke No. | Furnace condition | Filterable particulate mg/MJ[b] | Extractable organics, mg/MJ Filter | XAD | $C_o/C_E$[c] | Mutagenicity (MSA + S9), rev/MJ[d] |
|---|---|---|---|---|---|---|---|
| O | 8 | poorly tuned | 6.80 | -[e] | 7.20 | 1.02 | - |
| O | 8 | poorly tuned | 5.56 | 1.13 | 5.43 | 0.83 | 29,800 |
| N | 3 | typically tuned | 1.10 | 0.42 | 1.22 | 15.8 | 3,900 |
| N | 2 | best tuned | 1.66 | 1.03 | 1.79 | 24.2 | 7,900 |
| O | 4 | best tuned | 8.36 | 2.92 | 3.79 | 1.08 | 16,800 |

(a) O = pre-1970 type, N = new, retention head type.
(b) Fuel flowrate = 2.84 L/hr (0.75 gal./hr) for all tests (fuel HHV = 53.2 MJ/L). Burner cycle = 10 minutes on, 20 minutes off.
(c) $C_o$ = % organic carbon, $C_E$ = % elemental carbon, PM2.5 fraction.
(d) XAD and filter combined.
(e) Filter sample lost. See text for estimated rev/MJ.

dilution sampler filter collects more organics than the heated Method 5 filter.

One approach to comparing these data is to assume that the Method 5 filter catch consisted primarily of elemental carbon. One can then adjust the dilution sampler filter catches by the organic to elemental carbon ratios[7] in Table I to arrive at values which may be more comparable to the Method 5 front half. Applying this adjustment to the filterable particulate values for the five tests in Table I yields values of 3.37, 3.04, 0.065,

0.066, and 4.02 mg/MJ, respectively. This approach suggests that the old technology burners in the laboratory and in the field emitted about the same quantity of filterable particulate while the new technology retention head burner in the laboratory emitted about 2 orders of magnitude less than the retention head burners tested in the field. By this approach, the gas furnaces tested in the field emitted about one order of magnitude less filterable particulates than the laboratory oil furnace with the old burner and about 6 times more than with the new technology retention head burner. This latter comparison makes this approach suspect.

An alternative approach to comparing the field and laboratory results is to assume that the Method 5 filter catch is analogous to the nonextractable material on the dilution sampler filter (filterable particulate minus filter extractable organics in Table I). The Table I nonextractable averages for the conventional and retention head burners are 4.94 and 0.66 mg/MJ, respectively. By this second approach, the old technology conventional burner in the laboratory produced about the same emission factor as the conventional burners tested in the field while the new technology retention head burner in the laboratory emitted about an order of magnitude less filterable particulate than the retention head burners tested in the field. By this approach, the gas furnaces tested in the field emitted about one order of magnitude less filterable particulates than the laboratory oil furnace with the old burner and about half that from the new technology retention head burner. This approach seems to produce a more valid comparison although there is still a major difference between the data for the retention head burners.

The two approaches described above suggest that (1) a more valid comparison can be made between the EPA Method 5 filterable particulate and the nonextractable material on the dilution sampler filter and (2) the conventional technology burners had similar emission factors but the retention head burner operated in the laboratory had a significantly lower emission factor than the retention head burners tested in the field. One cannot say whether these differences are due to the different sampling methodologies, to real differences between the burners tested, or to a combination of these factors. Preliminary results from the IACP Roanoke study, presented later in this paper, address further the question of representativeness.

**Mutagenicity**. The literature contains one reference to mutagenicity of oil furnace emissions[8] where emission particles were collected in the laboratory by a Massive Air Volume Sampler, and an Ames mutagenicity assessment showed 2500 revertants

(rev)/MJ. In comparison, the MSA mutagenicity values presented in Table I are the sum of the separate values from filter and XAD extracts for each test except as noted. The percentage of the mutagenicity due to the filter extracts ranged from only 37.3 to 50.8%, with an average of 46.1%. The mutagenicity of the filter extracts ranged from 1,981 to 14,393 rev/MJ, which encompasses the value in the literature. However, it should be noted that the relationship between the standard Ames assay and the microsuspension assay (MSA) employed in these experiments has not been determined for this set of oil samples.

The mutagenicity of the emissions from the first test in Table I can be estimated using the above average percentage of the total mutagenicity found on the filters. The mutagenicity of the XAD extract was 21,600 rev/MJ. Assuming the mutagenicity of the filter extract would have represented 46.1% of the combined filter and XAD extracts, the estimated total mutagenicity would have been 40,000 rev/MJ.

Noting that the highest mutagenicities are associated with the highest smoke number leads to the obvious conclusion that poorly tuned furnaces are emitting not only more soot but also greater quantities of mutagenic compounds and/or the compounds emitted are more mutagenic. No mutagenicity data were found in the literature for gas furnace emissions.

**Comparison of Oil Furnace and Woodstove Mutagenicity Data**

The IACP's first major emphasis was on residential wood combustion, and the results have been widely published[1,9]. Mutagenicity of woodstove source emissions has been shown to vary over a wide range -- from < 1 to > 10 rev/µg total extractable organics (filter plus XAD). On a per unit of heat value in the wood, these data show that mutagenicity varies from 350,000 to 3,888,000 rev/MJ using the MSA. Comparing these values to the MSA oil furnace data in Table I, it can be seen that woodburning contributes 1-3 orders of magnitude more mutagenic potential to the ambient air than burning oil in an oil furnace for the same fuel heat input. The highest mutagenicity value for oil furnaces is an order of magnitude less than the lowest mutagenicity value for woodstoves. All of the woodsmoke mutagenicity results are for emissions from conventional, uncontrolled units.

**Preliminary IACP Roanoke Source Test Results**

During the 1988-89 winter, IACP conducted an extensive field study in Roanoke, VA, to study the mutagenic impact of residential oil furnaces on ambient air. Secondarily, impacts of motor vehicles and woodstoves were also investigated. The field study included sampling emissions from the oil furnaces in 10

residences. The study design called for each oil furnace house to be paired with a gas or electric heated house. A summary of the oil furnaces tested is presented in Table II. At least six

Table II. Summary of furnaces tested in Roanoke IACP field study.

| House code | Furnace description | Stack gases, % | | Bacharach smoke number | Stack draft, in. $H_2O$[a] | Efficiency, % |
|---|---|---|---|---|---|---|
| | | $CO_2$ | $O_2$ | | | |
| R01 | Climate Control, burner model 72-6, 30 yrs old, 1.27 MJ rating | 6.3 | 12.5 | 3-4 | 0.04 | 76.2 |
| R04 | (no model data), 40 yrs old, 4.2 L/hr fuel nozzle | 8.5 | 8.0 | 0 | 0.10 | - |
| R07 | Lennox model CC-358-363, burner model LD1-75, 40 yrs old | 8.3 | 9.8 | 1-2 | 0.03 | 79.2 |
| R10 | Homart furnace and burner, >30 yrs old | 7.5 | 10.3 | 10 | 0.05 | 71.0 |
| R13 | Mueller Climatrol model 227-110, burner model 487-75, >30 yrs old, 9.3 MJ rating | 9.0 | 8.8 | 2 | 0.03 | 74.0 |
| R16 | ARCO Flame model A1-3, no burner model No., | 7.5 | 11.0 | 5 | 0.045 | 70.5 |
| R19 | Kewanee model VT-510, Series 2X, burner Petro model P-9-70-KA, installed in 1951 | 8.3 | 9.6 | 2-3 | 0.04 | 79.5 |
| R22 | Heil, burner Wayne model M-SR, 1.1 MJ rating, new furnace | 12.5 | 4.2 | <1 | 0.03 | 81.5 |
| R25 | Airtemp, burner model 5813-1, 3.8 L/hr fuel nozzle, 20 yrs old | 9.0 | 9.5 | <1 | 0.03 | 72.2 |
| R28 | Mueller Climatrol, burner model 88-88, 2.5 L/hr fuel nozzle | 6.5 | 12.6 | 1-2 | 0.05 | 67.0 |

(a) One inch of water pressure = 249 Pa

of the oil furnaces tested in Roanoke were more than 30 years old while one was new. Smoke numbers covered the full range of the scale (1-10); more than half had smoke numbers of 2 or below while one was at the top of the scale.

Comparing Table II to the laboratory test results and the data from the literature suggests that the laboratory furnace probably had higher emissions than the field units, especially with the old burner in the poorly tuned condition. The laboratory furnace was much dirtier (on a smoke number basis) than the literature furnaces. The Roanoke field study furnaces' average smoke number was 2.8 compared to 1.3 for the furnaces reported in the literature[3] in the as found condition. One would therefore expect higher emissions from the Roanoke furnaces (these data are currently being reduced and will be reported at a later date).

## SUMMARY AND CONCLUSIONS

Emissions data gathered on a residential oil furnace operated with two types of burners in the laboratory have been compared to field data and to uncontrolled woodstove emissions. Preliminary oil furnace data gathered in the IACP field study in Roanoke, VA, have been presented. Major conclusions from this analysis follow:

- Smoke number is a qualitative indicator of relative particulate emissions from a given oil burner/furnace combination. This may not be true when comparing across burner/furnace combinations.
- Mutagenicity of oil furnace emissions in revertants per megajoule increases as particulate emissions increase.
- Oil furnace emissions are 1-3 orders of magnitude less mutagenic than wood smoke from conventional, uncontrolled woodstoves on a per unit of fuel energy value (revertants per megajoule).

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