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Technical Memorandum

To: Julie McDill, P.E., Mid-Atlantic Air Management Association, Inc.

From: John Barnes, P.E., Chief, Stationary Source Planning Section

RE: NOx Reductions – Low Sulfur Distillate Fuels

Date: April 15, 2016

Issue

Many states have adopted regulations requiring the use of low-sulfur (500 part per million (ppm) sulfur) or ultra-low sulfur distillate fuels (ULSD – 15 ppm sulfur). A side benefit to these regulations is a reduction in fuel-bound nitrogen in distillate fuels (No. 1 and No. 2 fuel oils). The purpose of this Technical Memorandum is to recommend control factors to be applied to the 2017 projection inventory being developed by the Mid-Atlantic Air Management Association (MARAMA) in support of State Implementation Plans being developed by Connecticut, New Jersey and New York.

Discussion

Fuel-Bound Nitrogen

The refining process used to remove sulfur from distillate fuels is called catalytic hydro-treating and has the benefit of stripping away not only sulfur but nitrogen from hydrocarbon fuels. Fuel-bound nitrogen contributes significantly to the formation of NOx in boilers and to a lesser extent in engines. Lowering the initial amount of chemically bound nitrogen in fuel results in lower NOx emissions. Currently the nitrogen content of conventional heating oil is around 100 - 170ppm (see Table 1).

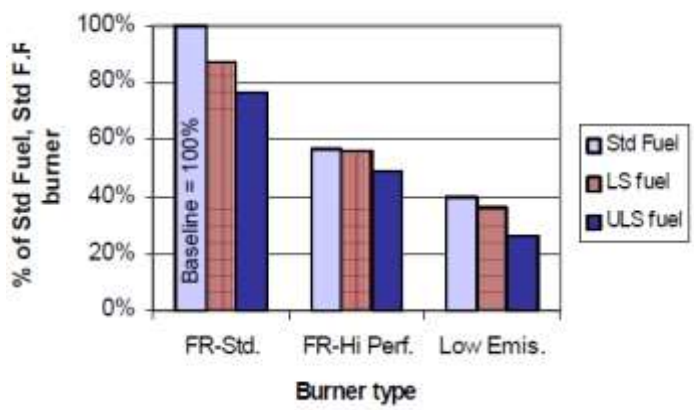
Table 1: Analysis of Sulfur and Nitrogen Content in Fuel Oil
Source: Paper No. 02-09, Feldman et al., presented at 2002 NORA Technical Symposium on Oil Heat

Fuel Type	Sulfur Content (ppm)	Nitrogen Content (ppm)
No. 2 Fuel Oil	2420	170
Low Sulfur Oil	343	29
Ultra-low Sulfur Oil	49	4

NOx Emissions from Boilers

Tests performed by Victor Turk at the R.W Becket Corporation accounted for differences in NOx emissions from different combustion devices by using three different oil burners: a standard flame retention oil burner, a high performance flame retention burner, and a low emissions burner. A standard heating oil, a low sulfur (500ppm) oil, and an ultra-low sulfur (15ppm) heating oil were burned and the NOx emissions analyzed. The figure below shows the reductions related to the fuel and burner type:

Figure 2: Fuel Sulfur Effects on NOx Formation
Source: R.W. Beckett Corporation (Turk & R.W. Beckett Corporation, 2002)



As expected using the standard flame retention oil burner resulted the highest NOx emissions and the low emissions burner generated the lowest NOx emissions. The reductions in NOx emissions related to fuel type carried over from burner to burner; as the fuel sulfur content decreased, the NOx emission rate also dropped. The low sulfur fuel reduced NOx by 5-10% compared to standard fuel and the ultra-low sulfur fuel reduced NOx by 20-30%. As discussed above, when using low sulfur oil, which initially contains less fuel bound nitrogen from the hydro-treating performed during refining, lower nitrogen oxide emissions are generated (Turk & R.W. Beckett Corporation, 2002) (NESCAUM, 2005).

In 2009, BNL published a report presenting NOx emissions data from the combustion of two No. 2 fuel oils containing 1900 ppm and 37 ppm sulfur, respectively, in a oil-fired condensing boiler with a nominal input rating of 81,250 British thermal units per hour. Six tests were conducted with each fuel (see Table 2):

Table 2: Stack Data (Mean Values) from the Combustion of No. 2 Fuel Oils (McDonald, 2009)

	1900 ppm S Distillate	37 ppm S Distillate
Stack Temperature (R)	627.57	634.07
O2 (%)	4.08	4.04
CO2 (%)	12.65	12.67
NOx (ppm)	84.3	65.4
Efficiency	91.7	91.7

Based on the data provided by BNL in the 2009 report, it appears that each of the tests were conducted in an identical manner. From the Ideal Gas Law, the ratio of V/T for the two fuels should be equal. The temperature ratio is 634.07/627.57 or 1.0103. Therefore, the volumetric flow rate of gas flowing through the stack during the testing of the 37 ppm sulfur fuel was 1.0103 times higher than that during the testing of the 1900 ppm sulfur fuel.

To calculate the NOx emission reduction due to the lower nitrogen content of the lower sulfur fuel, the following equation was used:

$$\text{NOx Reduction (\%)} = \frac{(84.3\text{ ppm} - 65.4\text{ ppm}) \times 1.0103 \times 100}{84.3\text{ ppm}}$$

$$= 22.65\%$$

This value is within the 20 – 30 percent NOx reduction range reported by NESCAUM (2005) for boilers.

NOx Emissions from Engines

NOx emissions from engines are primarily due to thermal NOx – NOx formed from nitrogen in the air used in the combustion process. The amount of excess air in the combustion chamber is another major factor. Fuel-bound nitrogen is also a source of NOx emissions (Schwerdt, 2006). As a result, the NOx emission factors for engines are as much as 30 times higher than those for boilers. For example (from FIREv625):

Table 3: Emission Factor Comparison – Boilers v. Engines

Source Classification Code	Source Category	NOx EF (lb/1000 gallons burned)
1-03-005-01	Boiler	20
2-03-001-01	Engine	604

<u>Recommendation</u>

The NYSDEC recommends that the control factors presented in Table 4 be used in the 2017 projection inventory under development by MARAMA:

Table 4: Recommended NOx Control Factors

Source Category	Regulatory Sulfur Limit (ppm)	NOx Reduction for 2017 Projection Inventory (%)
Boilers	15	22
	500	7
Engines	15	1
	500	0

The recommended NOx reductions for boilers resulting from converting from high sulfur distillate fuel oils to ULSD (22%) are based on the 2009 report prepared by BNL. For engines, the recommended NOx reduction was developed by multiplying the boiler NOx reduction by the ratio of emission factors for boilers/engines:

Engine Control Factor = (22.65%)x(20/604) = 0.75% (by rounding = 1%)

The recommended NOx reductions for boilers resulting from converting from high sulfur distillate fuel oils to low sulfur fuel oil (500 ppm S) are based on midpoint of the range of NOx reductions reported in the 2005 report prepared by NESCAUM. For engines, the recommended NOx reduction was developed by multiplying the boiler NOx reduction by the ratio of emission factors for boilers/engines:

Engine Control Factor = (7%)x(20/604) = 0.23% (by rounding = 0%)

References:

Feldman, C., Engley, D., Shayda, M., & Stadtlander, K. (2002). Low Cost / No cost techniques to reduce NOx in Residual Oil Burners. *Proceedings of the 2002 National Oilheat Research alliance (NORA) Technical Symposium* (pp. Paper No. 02-09). East Longmeadow, MA: Carlin Combustion Technology, Inc.

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United States Environmental Protection Agency, FIREv625 (2004).

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