

Locomotive Exhaust Emissions Field Tests

by

G.R. Cataldi, AAR Research & Test Department
S.G. Fritz, V.O. Markworth, and
R.L. Mason, Southwest Research Institute

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Summary

Tests conducted on 27 revenue-service locomotives representative of the current fleet support earlier results that indicate that retarding the fuel injection timing by 4 degrees is a very effective technique for reducing oxides of nitrogen (NOx), the component of exhaust emissions of most concern to state and federal regulators. For 10 of 12 engine models tested, NOx was reduced by 24 to 31 percent. However, this short-term approach for reducing NOx must be weighed against increases in particulates, smoke opacity, and fuel consumption.

At this time, EPA has not finalized a proposal for emissions limits for the current fleet. Therefore, it is not possible to recommend a specific strategy for emissions-reduction. But it appears that some locomotive engines would meet the currently expected EPA emissions limits simply by retarding fuel injection timing by 4 degrees. However, there is not enough data to identify those models.

These tests are part of a railroad and locomotive supply industry effort to achieve cost-effective locomotive exhaust emissions regulations. The tests provide a database of locomotive emissions to determine the baseline for emissions reduction and to show the efficacy of retarding fuel injection timing on NOx emissions levels.

These findings are based on tests of 27 revenue-service locomotives covering 12 diesel engine models in switcher, passenger, and freight locomotives manufactured by EMD, General Electric, and Republic. The emissions measured included NOx, carbon dioxide (CO), hydrocarbons (HC), particulate matter (PM), and smoke opacity. There are no standardized emissions measurement procedures for locomotive engines as yet. These tests were conducted following procedures developed by Southwest Research (SwRI) for the AAR.

All testing was coordinated with the engine manufacturers to assure that the engines were in proper configuration and proper working order.

Suggested Distribution

Operating/Mechanical Department —
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INTRODUCTION AND CONCLUSIONS

The U.S. Environmental Protection Agency (EPA) is required by the Federal Clean Air Act Amendments of 1990 to promulgate locomotive emissions regulations in 1995. At this writing, it appears that EPA will require command-and-control emissions limits nationwide that apply to both freshly manufactured engines starting in the year 2000 or later, and "remanufactured" engines that were originally manufactured in some years prior to 2000.

AAR established a field test program to characterize the present-day locomotive fleet's exhaust emissions rates and to determine the efficacy of retarding fuel injection timing by 4 degrees to reduce NO_x.

The findings are summarized in Table 1. Emissions levels are given for NO_x, CO, HC, and (where data was collected) for PM. The data are presented in ranges that represent the 95 percent confidence intervals for those engine models with 4 or 5 samples, based upon an engine duty cycle developed by AAR. This duty cycle is different than the one likely to be adopted by EPA, but most of the data were collected before EPA suggested a more comprehensive approach than AAR's. NO_x has been shown to change very little or not at all, no matter what locomotive duty cycle is used. The other emittants are more sensitive to duty cycle weightings, but EPA has made it clear that NO_x reduction is the only objective for existing engines, so the weighted averages for the other emittants are not as important.

The "std" columns in Table 1 show the AAR duty cycle-weighted emissions levels with the engines set up at manufacturer-recommended specifications. The emission levels are representative of the fleet operating today, within several constraints: (1) some existing engine models are not included; (2) each railroad has its own set of technology retrofits and parts vendors that may impact emissions levels; and (3) data were collected at San Antonio's low altitude and mild climate with fuel taken from two

western railroads' suppliers. The "retard" columns show the emissions levels with fuel injection timing retarded by 4 degrees.

The EPA has not finalized the emissions levels that will have to be met by these engine models, but they have suggested that the limits would be (all in grams/brake horsepower-hour) 9.6 for NO_x, 0.6 for PM, 0.9 for HC, and 4.8 for CO. (These are 14.1, 1.0, 1.8, and 6.1 respectively for switchers.) It appears that simply retarding fuel injection timing would allow some locomotives to meet the possible EPA regulations for NO_x and PM. CO and HC are sensitive to the duty cycle, so it is not possible to compare these results to proposed limits. Nevertheless, it appears that one or both of these gases may pose a problem if the NO_x limit is met by simply retarding fuel injection timing.

With only one sample for most of the engine models, conclusions about those models' fleets are difficult to make. There is a general consistency to all of the results that gives some non-statistical confidence in predicting the fleet characteristics.

The data in Table 1 are expressed in the original units of measurement, namely AAR 3x3 duty-cycle weighted average g/bhp-hr for the emissions. The difference in the average NO_x for the MP15AC is -3.6 g/bhp-hr and is calculated by subtracting the standard timing weighted average NO_x of 11.5 g/bhp-hr from the retarded timing weighted average NO_x of 7.9 g/bhp-hr. Some readers may desire to represent the effect of the 4 degree timing retard as a percentage change from the standard timing baseline. The percent difference is obtained as follows:

$$\begin{aligned} \% \text{ Difference NO}_x &= [(7.9 - 11.5) / 11.5] \times \\ 100\% &= -31\% \end{aligned}$$

Thus, there is a 31 percent observed average decrease in NO_x from the standard timing average with 4 degree retarded timing for the EMD MP15AC locomotive.



TABLE 1. Summary of locomotive exhaust emissions at standard engine set-up and with fuel injection timing retarded by 4 degrees. AAR 3x3 average composite emissions (g/bhp-hr)^a

Loco Model	Engine Model	No. Tested	HC Std	HC Retard	CO Std	CO Retard	NOx Std	NOx Retard	PM Std	PM Retard
EMD										
SD40-2	16-645E3B	5	.23 - .32	.18 - .30	1.0 - 1.8	1.1 - 1.9	11.6 - 12.8	8.7 - 9.8	nd	nd
SD40-2	16-645E3	4	.69 - 1.0	.73 - 1.1	1.5 - 2.2	1.6 - 2.7	10.9 - 11.3	8.0 - 8.6	nd	nd
MP15AC Note b	12-645E	5	.60 - .78	.63 - 1.26	3.5 - 4.6	4.3 - 5.7	10.5 - 12.5	7.2 - 8.5	.49 - .62	.68 - .83
SD60	16-710G3	2	0.26	.26	2	1.6	10.2	7.6	0.24	.28
GP35	16-645D3A	1	0.51	.59	2.8	2.8	7.4	5.6	0.45	.54
F40-PH	16-645E3B	1	0.27	.29	0.5	.6	11.9	8.8	0.28	.30
F59-PH Note c	12-710G3A	1	0.3	.3	0.9	.6	11.6	8.4	0.2	.25
GE										
C40-8	7FDL16	4	.40 - .56	.43 - .51	4.2 - 5.4	4.5 - 5.5	11.9 - 12.9	8.8 - 10.5	nd	nd
B32-8	7FDL12	1	0.54	.51	3.1	3.3	12.5	10.4	0.43	.47
AMD-103	7FDL16N6	1	0.4	.4	1.5	1.9	12.1	10.5	0.35	.35
C44-9	7FDL16EFI	1	0.21	.22	1.4	1.6	11.3	8.2	0.12	.16
Republic										
RE-20	DDC 16V-149	1	0.37	.34	2.4	2.9	13.4	10.2	.15	.21

Notes: a - Ranges are 95 percent confidence intervals based upon 4 or 5 engines in each engine model. No confidence intervals are given for models with one or two samples. nd means no data collected.

b - The MP15AC PM ranges are for 4 of the 5 locomotives tested.

c - Data for the EMD F59-PH locomotive funded by Caltrans.

Approximate confidence intervals on the percent differences corresponding to the significant emissions values are given in Table 1. A summary of the emissions results, plus the change in fuel brake specific fuel consumption (bsfc), is shown in Table 2 for the 4 engine models with at least 4 samples tested.

For the MP15AC locomotives, the data in Table 2 indicate that retarding the fuel injection timing by 4 degrees will result in a 28 to 34 percent reduction in

NOx emissions. However, all other emissions increase significantly, with average HC emissions increasing by 0 to 72 percent, CO by 15 to 33 percent, and PM by 17 to 53 percent. Average bsfc also increased by 0.9 to 4.1 percent. Note the wide confidence intervals. It may be necessary to measure the emissions on more samples of this engine model before manufacturers and railroads finalize the design of retrofit packages to meet EPA emissions limits.



The other engine models shown in Table 2 have mixed results. They show a mostly narrow confidence interval around a 25 percent reduction in NO_x, but HC and CO changes follow no pattern, going up or down, or not changing significantly. All 3 models had increases in bsfc. PM was not measured on these engines.

METHODS TO REDUCE EXHAUST EMISSIONS

Retarding fuel injection timing is an effective way to reduce NO_x from any diesel engine, but it has limitations. Fuel consumption increases, as does smoke and PM. HC and CO may also increase. Furthermore, severe retardation shortens engine life drastically. Locomotive engine manufacturers consider 4 degrees of retardation to be the maximum feasible on most engine models. Another very effective method to reduce NO_x is to cool down the inlet air to the combustion chamber. Cooling reduces NO_x and fuel consumption, usually without any increase in smoke or PM. Some locomotives can be retrofit with higher capacity aftercoolers ("4-pass" replacing "2-pass") and/or the air cooling system can be separated from the water and lube oil cooling ("split cooling"). For those locomotives, a relatively inexpensive retrofit

can reduce NO_x while improving fuel economy. Locomotives without extra radiator capacity would be prohibitively expensive to retrofit.

Other NO_x (and PM) reduction methods tend to be costly, especially for retrofits. But some of them may be necessary in combination with increased cooling and retarded injection timing to meet likely EPA emissions limits. These methods include:

- Electronic fuel injection to optimize fuel economy and/or emissions for each throttle position at different altitudes.
- More efficient turbochargers to increase the amount of inlet air, especially at intermediate throttle positions, should improve combustion, lower smoke and PM, and allow other NO_x reduction methods to work better.
- Redesigned piston ring-packs to reduce the amount of lube oil that escapes in the exhaust. That "blow-by" adds to PM and smoke.
- Exhaust gas treatment with catalysts and plasmas in the exhaust manifold to reduce one or more emittants, usually NO_x. No practical technology is available today.

TABLE 2. Effect of retarding fuel injection timing by 4 degrees percent change^a.

Loco Model	Engine Model	No. Tested	HC	CO	NO _x	PM	bsfc
SD40-2	16-645E3B	5	-13 ± 12	NS	-25 ± 2	nd	+1 ± 1
SD40-2	16-645E3	4	+9 ± 8	+17 ± 8	-25 ± 1	nd	+2 ± 1
MP15AC	12-645E	5	+36 ± 36	+24 ± 9	-31 ± 3	+35 ± 18 ^b	+2.5 ± 1.6
C40-8	7FDL16	4	NS	NS	-24 ± 6	nd	+1 ± 1

- Notes:
- a - Approximate 84 percent confidence intervals for percent change in average emissions for AAR 3x3 duty-cycle weighting. Intervals are presented only for those cases where the average emissions between standard and retarded timing were significantly different at the 16 percent significance level. NS implies no statistically significant difference. nd means no data collected.
 - b - The MP15AC PM ranges are for 4 of the 5 locomotives tested.

Note: Contact R. Cataldi at (202) 639-2261 with questions or comments about this document.

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