

Summary of Current DPF Technology for Locomotive Applications in the United States and Europe

Provided by the Union Pacific Railroad, BNSF Railway and Southwest Research Institute

Overview

Development of Diesel Particulate Filter (DPF) technology for the on-road and mobile non-road sectors has led to logical attempts to adapt that technology to diesel locomotives. Work has begun in both the US and in Europe, particularly Switzerland, to apply DPF technology to both new and existing in-use switching locomotives. To date, DPF's manufactured by Hug Engineering (Hug) are in various stages of adaptation to 4 different locomotive models, including:

- The California Emissions Program (CEP) is retrofitting Hug filters to two existing 1,500 HP, 2-stroke EMD MP15DC locomotives in 2006;
- Hug DPF's have been installed by the locomotive OEM on 73 new 2,000HP locomotives operating in Switzerland;
- The retrofit of six (6) Hug DPF's on existing 1,200HP locomotives in Switzerland; and
- One (1) Hug DPF has been installed by the locomotive OEM on a prototype sales demonstration 3,600HP locomotive in Germany.

This paper looks at the details of these 4 applications and provides information on additional emission reduction technologies that are currently being developed and/or evaluated in the U.S. and Europe.

1. California Emissions Program (CEP)

In 2001, the California Air Resources Board (CARB) and the two Class 1 Freight Railroads operating in California, Union Pacific Railroad (UP) and BNSF Railway (BNSF), entered into a voluntary agreement to invest up to \$5M to test the feasibility of applying DPF technology to locomotives. Over the last 4 years, the Association of American Railroads (funded by UP and BNSF), with direction from CARB, has overseen the California Emissions Program (CEP) whereby Southwest Research Institute (SwRI) in San Antonio, Texas has led an effort to evaluate candidate retrofit oxidation catalyst and DPF systems on a 2,000HP roots blown (i.e., non-turbo charged), 2-stroke, EMD 16-645E switcher locomotive engine. This engine size and locomotive type was chosen for the following reasons.

- Essentially all switcher locomotives in the U.S. and Canada use this EMD roots-blown (i.e., non-turbo charged) engine in either a 12-cylinder 1,500HP configuration or a 16-cylinder 2,000HP configuration.

- EPA Tier 0 emission standards mainly focused on NO_x emissions. Retrofitting switch locomotives with DPF could supplement EPA's standards by reducing PM emissions.
- Development of DPF's for existing switch locomotives that operate in railyards could provide immediate health benefits to those living near railyards.
- Roots-blown EMD switch engines are some of the oldest engines in the fleet and have some of the highest g/bhp-hr PM emissions.
- Development of retrofit technology for the older set of roots blown engines was not likely to occur by the OEM's since the number of these units in the fleet is small (low return on investment). Therefore, the railroads would likely need to fund development of the technology if this set of locomotives were to be retrofitted.
- It was generally agreed that a retrofit DPF could not be installed on existing turbo-charged locomotives due to carbody space constraints – there simply was no room for the DPF on the locomotive.
- Development of retrofit DPF technology could provide important supplementary data that could be then used by OEMs for development of U.S. EPA Tier III locomotives.
- The OEM's, not the railroads, are responsible for development of new technologies for new locomotives.

Summary of SwRI work to date.

- SwRI has spent more than 2 years screening commercially available cylinder kits (pistons, cylinder liners and piston ring sets) to identify those that offered the lowest lubricating oil consumption. Rebuilding these EMD engines with cylinder kits that use less lubricating oil will result in lower engine-out PM emissions, will reduce the burden on any aftertreatment system, and will reduce the lubricating oil ash loading on the aftertreatment system. Seven different cylinder kit configurations were tested on a 2,000 HP EMD 16-645E engine installed specifically for the CEP at SwRI.
- CEP focused on evaluating oxidation catalyst and DPF systems for locomotives using conventional non-synthetic lubricating oil and low oil-consumption power assemblies (Swiss DPF applications use only synthetic oil).
- SwRI screened more than 14 oxidation catalyst and DPF candidates on the 2-stroke EMD engine. Each of the suppliers' first attempts required refinement and subsequent re-testing.
- SwRI tested for engine performance and 500-hour system durability for 3 candidate aftertreatment systems in an engine test cell.
- SwRI performed emissions testing in a test cell and will perform in-use emissions testing as well. (There is no in-use testing in Europe – see footnote 2 on page 3.)
- The CEP screening tests showed that the Hug DPF technology was the best currently available candidate (same technology used in Switzerland)
- The first two 1,500HP switchers to be retrofitted with Hug DPF are scheduled for revenue testing (testing in actual freight service as opposed to on a test track) in southern California by mid-2006. The long lead time needed to manufacture the specialty HUG equipment is the main reason the locomotive will not be operable

before mid year. The activity between now and June is mainly for designing, ordering, receiving, and installing the DPF from Hug. After successful testing of the first 2 retrofits, 2 additional units will be retrofitted in late 2006.

2. DPF Applications for New and Retrofit Locomotives in Switzerland and Europe

Switzerland has embarked on a program to install DPF technologies on its relatively small fleet of diesel-hydraulic freight locomotives. Over 95 percent of locomotives in Switzerland are electric powered using overhead catenary wires. Unlike the CEP, which is focusing on retrofit of DPF technology, the primary focus in Switzerland was the application of DPF filters for new low horsepower (2,000HP) switcher locomotives. Switzerland also has retrofitted 6 existing 1,200HP units with DPF systems in the last year. While new conventional EMD switchers have not been built or purchased in the U.S. for over 20 years¹, the Swiss railroad system still demands new locomotives of this type.

Swiss rail freight is moved by a company named SBB, which has two divisions – SBB Cargo and SBB Infrastructure. SBB operates a combined fleet of approximately 450 high power (2,500HP-10,000HP) electric road locomotives, 73 low horsepower (2,000HP) new diesel units equipped with Hug DPF's, 40 low horsepower (1,200HP) existing diesel units (6 of which have been retrofitted with Hug DPFs) and 40 electric switchers (1,200HP). Thus, of the 603 total locomotives used to move freight in Switzerland, 113 are diesel powered. Of those, 73 new low HP units are fitted with DPFs, while 6 of the 40 existing low HP units have been retrofitted with DPFs.

SBB also operates approximately 200 diesel maintenance of way diesel powered non-road vehicles which are capable of running on rail. 50 of these low horsepower (approximately 600HP) diesel maintenance units have been retrofitted with DPFs.

a. Vossloh 1700 Series Locomotive (Am843 in Switzerland)

Vossloh Locomotive GmbH (Vossloh) (formerly Krupp Mak Maschinenbau GmbH) is the major diesel-hydraulic locomotive manufacturer in Europe and produces the MaK1700 series locomotive (in Switzerland, this locomotive is identified as an Am843) that is powered by a Caterpillar 3512 4-stroke diesel engine (1,500kW/2,000HP). In 2004, SBB began delivery of new 73 Am843 locomotives and required that all locomotives in this series be equipped with DPFs. The Swiss Caterpillar dealer worked with Vossloh and Hug Engineering to integrate the DPF into the locomotive. No in-use exhaust emissions testing was performed² or was required, thus it is difficult to assess actual emissions

¹ Mass-manufacture of conventional technology diesel switching locomotives in the U.S. essentially ended around 1982. The exception has been a small number (about 50) of Cat-powered switchers around 1999-2000 and the recent purchase of 13 Tier 2 switchers in 2006. New switcher construction is very limited and is now focused on new technology hybrids and genset switchers. See Attachment 1– North American New Locomotives '72 – '05. Switcher locomotives are represented by the magenta bars at the bottom.

² Almost all diesel-powered locomotives in Europe use a hydro-mechanical transmission between the diesel engine and the wheels, a configuration that does not allow for testing. In contrast, North American

reductions achieved (although the general consensus is that the PM emissions will be quite low as the Hug DPF system was VERT approved). The DPF's increased the acquisition cost per locomotive by approximately CHF 100,000 (~\$76,000 US). The same Vossloh units being sold in Switzerland with DPFs are also being sold throughout the rest of Europe without DPFs, largely due to the fact that the Caterpillar engine meets applicable exhaust emission regulations without a DPF.

b. Vossloh Am841 Locomotives

The 1,200HP Am841 locomotive is Vossloh's smaller predecessor to the Am843. The Am841 locomotives are equipped with MTU 396 engines, were built without DPFs, and there are 40 such units currently operating in Switzerland and many more elsewhere in Europe. SBB recently retrofit 6 out of their 40 units with Hug Filters, with the first three as prototypes where the DPF was added to the roof of the locomotive, downstream of the existing muffler. For the next three retrofits, the HUG DPF was packaged within the carbody, replacing the mufflers. SBB does not have sufficient funding to pay for more retrofits which have an estimated cost of 100,000 CHF/unit (~\$76,000 US).

For both the Am841 and the Am843:

- Only synthetic engine lube oil (low ash) can be used. (This will not be the case for the CEP locomotive). It is our understanding that only the Swiss use synthetic oil in locomotive applications, which makes their locomotives unique in Europe and in the world.
- Low-sulfur (<300ppm) diesel fuel is used.
- SBB has no DPF maintenance responsibility until the manufacturer's warranty expires. Upon expiration of the warranty, SBB plans to purchase a full service contract with Hug to continue to maintain the DPFs.
- In-service DPF exhaust emissions testing has not been performed and is not planned for either the new Am843 or the retrofitted Am841 locomotives.

c. New Vossloh 2000 Prototype Locomotive

The MaK2000BB is a prototype new high horsepower (3,600HP) locomotive equipped with an MTU 20V-4000 engine that was developed with a Hug DPF integrated into the carbody. Vossloh replaced the muffler with a DPF integrated into the original design. Two burners are used to regenerate the filter. The DPF is offered as an option on this new locomotive in selected European markets. To date, none have been ordered or delivered. There are no emission test results for this engine/DPF package.

d. Vossloh Euro 4000

The Vossloh Euro 4000 is scheduled for introduction in Europe in 2006. This locomotive is a joint product between EMD and Vossloh. It will utilize a 4,000HP EMD engine and

locomotives are all diesel-electric powered and capable of electrically-loading the diesel engine for "load testing" purposes.

it is targeted for markets in Germany, Holland, Belgium, etc. It will be powered by an EMD 16-710G3C engine (similar to US EMD SD70M and SD70ACe units) to meet the newest European Standards (UIC 2), which are roughly equivalent to current U.S. EPA Tier 2 standards, and as such, it will not be required to be equipped with a DPF.

3. The US Freight Railroad Focus for the Future

The US freight railroads are making significant changes in their approach to the development and implementation of new technology. While DPF is certainly a technology to be explored, there are other exciting opportunities as well, several are discussed below.

a. Developments For Road Power (3,600HP – 6,000HP)

EMD and GE have both indicated that they are investigating DPF technology for potential EPA Tier 3 road locomotive use and utilizing data and findings from the CEP. There is general consensus that there is not enough room in the carbody (engine housing) to accommodate DPF technology as a retrofit application.

In addition, oxidation catalytic converters (oxycats) are now being developed which will also reduce particulate emissions. U.S. EPA, SwRI and UP are currently evaluating an oxycat that will be located within the exhaust manifold on one (1) 3,800HP EMD SD60. Installation and exhaust emissions testing is scheduled to occur in February 2006. In-use durability will be assessed during revenue service operation in the Los Angeles basin starting in the second quarter of 2006.

b. Developments For Local Power (2,000HP – 3,000HP)

Unlike in Switzerland and Europe, new locomotives of this size are no longer being ordered or manufactured in the US. There is also general consensus that there is not enough room in the carbody to accommodate DPF technology as a retrofit application.

c. Developments For Switch Power (1,200HP – 2,000HP)

The U.S. focus for this class of locomotive has changed significantly, and new conventional switcher locomotives are not being ordered or manufactured. The development of new technology hybrids and genset switchers, which both utilize Tier 3 non-road low-emission truck-derivative diesel engines, appears to be a better investment than the conventional switcher design. It is expected that this will lead to significant emission reductions and potentially ULEL certification levels. Both UP and BNSF have made a significant commitment to these new switcher locomotives. In the U.S., 1 genset switcher is currently operating and 103 more are on order. Furthermore, there are 18 hybrid electric switchers operating in the U.S. and 13 more are on order.

Regarding retrofit of existing switcher locomotives, as noted above, the CEP will test up to 4 Hug DPF retrofits in 2006 on 1,500HP EMD MP15 locomotives from both BNSF and UP.

4. Summary

The DPF technologies being utilized and tested in Europe are the same as those being studied and implemented in the United States. Furthermore, new technologies such as hybrids and genset switchers, which are not being utilized in Europe, are currently being developed and implemented in the US, and will position the US rail industry ahead of their European counterparts.

For new local (switcher) locomotives, Switzerland is ahead of the US on implementing Hug DPF filters on their 73 new 2,000HP Am843 switcher locomotives. However, conventional large bore medium speed “old style” switchers with 645E type engines are no longer being ordered by or manufactured for US railroads. The current switchers of choice in the US appear to be genset switchers or hybrids.

For new high horsepower locomotives, there is only one (1) prototype new locomotive with DPF in Europe. However, it does not appear that this prototype will be produced as the largest European manufacturer is now partnering with EMD to use a US Tier 2 type engine without DPF.

For existing high-horsepower locomotives, DPF retrofits are not being investigated in Europe or the US as there is general agreement that there is not sufficient space on the locomotive. In the U.S., an oxycat retrofit will be tested on a 3,800HP road locomotive in Los Angeles in the second quarter of 2006. No such tests are planned in Europe to our knowledge.

For existing low-horsepower locomotives, DPF's have been retrofitted on 6 locomotives in Switzerland, and will be retrofit on up to 4 in the U.S. in 2006. In the U.S., the focus has shifted to genset switcher and hybrid electric switchers which are currently operating and more on order.

UP, BNSF, and SwRI made a PowerPoint presentation to ARB staff summarizing the current state of DPF and other technology developments on December 7, 2005. A copy of this presentation, which includes much of the information contained in this paper, is attached to this summary as Attachment 2.

The US freight railroads are continuously looking to develop or partner in the development of technologies for reducing locomotive emissions. They are also closely following the advancements occurring throughout the world and analyzing whether technologies developed abroad can be applied to US operations. A continued effort to forge ahead with the newest technologies is expected to continue.

Attachment 1: North American New Locomotives '72 - '05 (est.)

Attachment 2: Presentation on DPF technology made to the California Air Resources Board on December 7, 2005 by UP, BNSF and Southwest Research.