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Clean European Rail-Diesel

D 4.6.3 – Evaluation of the field test

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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EXECUTIVE SUMMARY

The intention of SP4-Light Weight is to gather data of a propulsion system complying with the emission standard EU Stage IIIB. The locomotive BR225 008-2 used in SP4 is 40 years old and does not comply with any emission regulation standard. Within the scope of the fourth sub project (SP4) of CleanER-D, the locomotive for cargo operation is equipped with a new propulsion system and is used during common service. The system consists of a prototype engine with diesel particulate filter.

The present report focuses on the process of Task 4.6.4, the evaluation of the field test. After the engine was calibrated to ensure proper operation with the exhaust after treatment system (EAT) for full passive operation, the emissions had been measured before field test to prove compliance to the requirements of Stage IIIB (→ D4.2.2). Afterwards it was adapted to the locomotive within WP4.3 and used for 683 hours during field test in common operation within WP4.5. Before engine and DPF were dismounted from locomotive (→ D4.6.1) an emission measuring campaign with mobile measurement equipment at four stationary operation points (notches) had been performed by APTL together with DB-AG and MTU (→ D4.5.1). Finally the DPF was inspected (→ D4.6.2).

In Task 4.6.4 all gathered data during test bench analysis and field test are evaluated and disseminated within CleanER-D. At least eight other deliverables are determined:

- D1.4.3 “Intermediate trial review“
- D4.2.1 “Development of IIIB with DPF system”
- D4.2.2 “Determination of engine set-up before field test“
- D4.2.3 “Verification of engine performance after field test“
- D4.5.1 “Measurement campaigns with mobile measurement equipment“
- D4.5.2 “Service of IIIB engine and DPF system“
- D4.6.2 “Inspection of DPF system“
- D4.7.4 “Evaluation of the field test”

During field test of 225 008-2 the IIIB system cumulated 683 hours in common operation. Miscellaneous NOx emission measurements at engine test bench, during field test and a special mobile emission measuring campaign demonstrates that NOx emission are stable and within requirements of Stage IIIB after field test. Since the average load of the engine was about 13% and exhaust temperature is quite low, due to high efficiency of the engine, the operation of DPF is another topic of interest. Analysis of field data with a EAT model showed that the resulting soot balance loadings are very low, so safe passive regeneration of DPF was ensured. This is the result of appropriate calibration of the engine and design of the DPF (e.g. thermal isolation). Also the very high filtration efficiency of the DPF could be shown. The course of backpressure during field test and inspection of DPF after field test gives a good indication that recommended service intervals can be reached. All specific IIIB technologies worked very reliable. Regarding life cycle costs, fuel and lube oil consumption during field test are in agreement with results from engine test bench, considering comparable boundary conditions.

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1. INTRODUCTION

The project Clean European Rail-Diesel (CleanER-D) is a European research project which is integrated in the seventh Framework Program. The objective of the project is to develop and test new propulsion systems for locomotives and railcars with regard to future emission standards like EU stage IIIB and beyond.

Within the scope of the fourth sub project (SP4) of CleanER-D, a team of representatives of international companies organizes a field test of a locomotive with a propulsion system compliant to emission standard EU stage IIIB. MTU Friedrichshafen GmbH, DB AG, SNCF, Voith AG and the institute CERTH/APTL participate in this sub project.

- MTU Friedrichshafen GmbH provides a IIIB compliant propulsion system.
- DB AG installs the IIIB compliant propulsion system into the existing locomotive and uses the rebuilt locomotive during common service.
- Voith AG supports the project regarding the gearbox.
- CERTH/APTL performs measurements on the locomotive during operation.
- SNCF purchases diesel particle filtering elements and shares experiences with such DPF systems in shunters.

The intention of SP4 is to equip a prototype propulsion system into an existing cargo locomotive and to perform a field test with 11 months of runtime. The data collected during the field test are a valuable contribution to the development of locomotives and railcars with low emission technologies. In addition, mobile emission measurement equipment is tested during the field test.

The objective of WP 4.6 is the evaluation of the field test and the conclusion of the experiences gained during the entire project. The present report focuses on the process of Task 4.6.4, the evaluation of the field test. All experiences and data gained during the project are summarized and conclusions are drawn.

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2. MOTIVATION

The objective of SP4 is to conduct a field test of a locomotive with an EU stage IIIB compliant engine. This emission standard came into force in 2012. In Figure 1 the devolution of emissions for rail engines with an output of more than 560 kW is displayed.

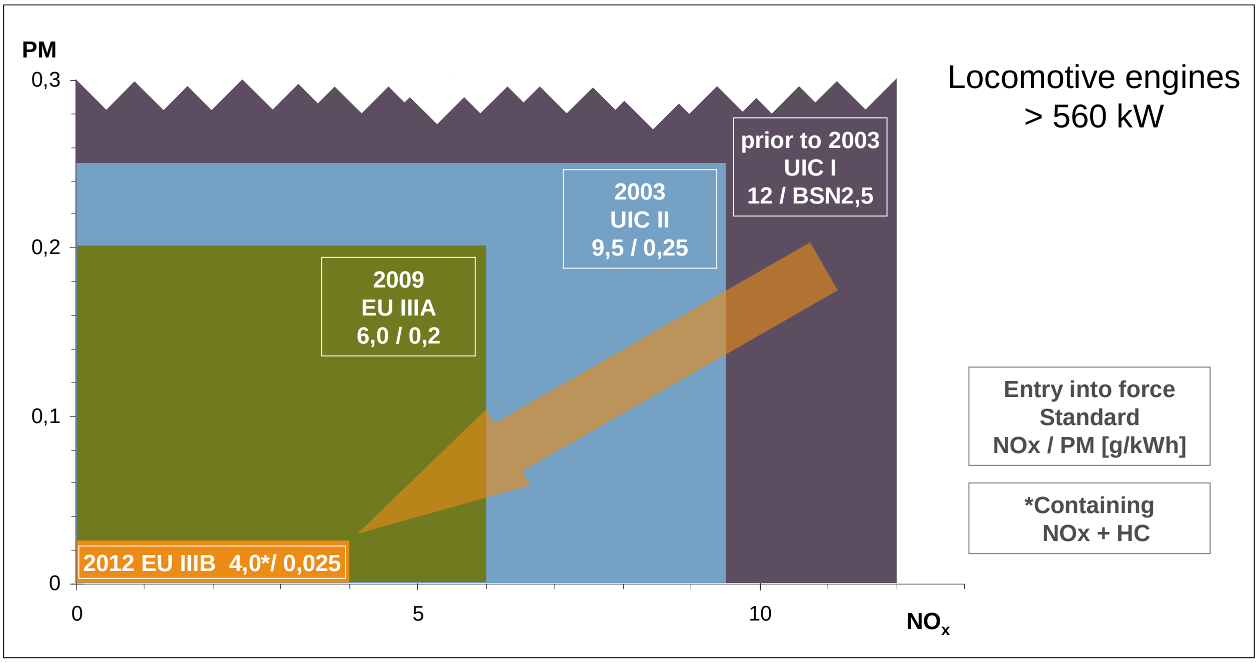

Figure 1: European Emission Limits for NOx and Particulates for Rail Traction

To meet the emission regulation EU Stage IIIB, MTU had developed a new generation of engine type series 4000. This new propulsion system is a further development stage of the former engine series 4000R43. To meet the emission regulation of Stage IIIB, the following engine technologies were developed and tested for the first time in a rail application within the scope of CleanER-D:

- variable additional cooled exhaust gas recirculation (EGR)
- variable two-stage turbo charging with intercoolers
- injection system with higher injection pressure
- enhanced low emission combustion system
- advanced functions in governor for engine and exhaust gas after treatment system (EAT)

3. GENERAL OVERVIEW

After the IIIB system from MTU was installed into the locomotive 225 008-2 from DB-AG in WP4.3 the field test was started (WP4.5). Following an overview of the operation of 225 008-2 during field test is given.

3.1 OPERATIONAL AREA

The locomotive 225 008-2 was used for freight transportation in the area of Ruhr and Sauerland. The base was the DB-AG workshop of Hagen-Vorhalle. The locomotive was used in different duties, mainly for steel, wood but also for other goods. Two typical daily routes are shown in Figure 2:

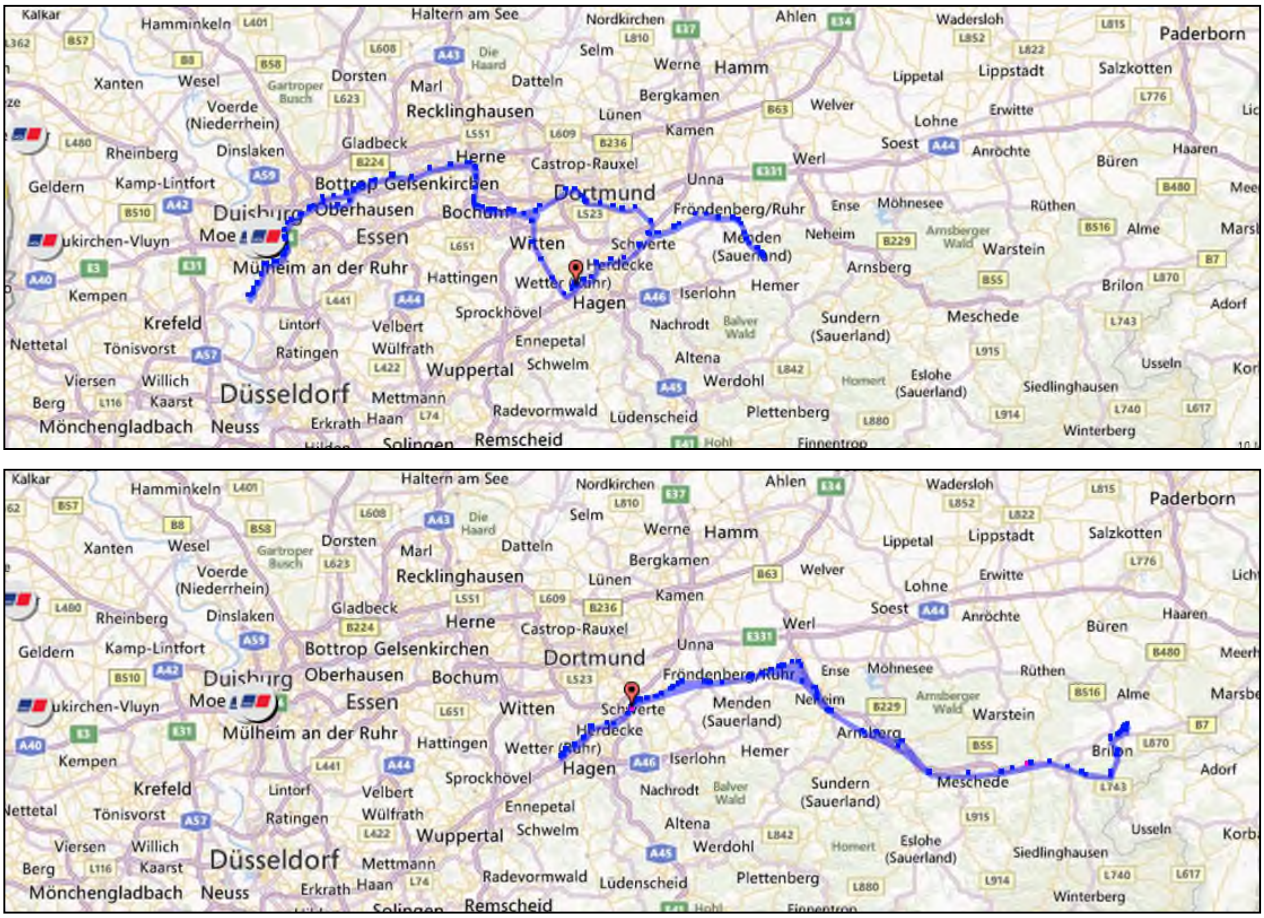

Figure 2: Main routes of 225 008-2 during field test

3.2.1 Statistical data

The 225 008-2 was operated from August 2012 until June 2013. In total the engine cumulated 683 hours in common operation, the DPF more than 1000 hours, when time for calibration of the engine at test bench is also considered (see also D4.6.2). The daily operation was up to 15 hours.

More details about performance of the engine are given in Chapter 3.2.2.

3.2.2 Engine operation

Figure 3 shows the operation points of the engine (red dots) during field test within the performance map. The operation of the engine is mainly along the n^3 curve (blue squares). Because of transient operation and varying power request of auxiliaries the given power is higher or lower than the power requested from gearbox in steady state. The load points of the F cycle are not reached in steady state during common operation because requested power is given by the gearbox at relevant speed (i.e. notch).

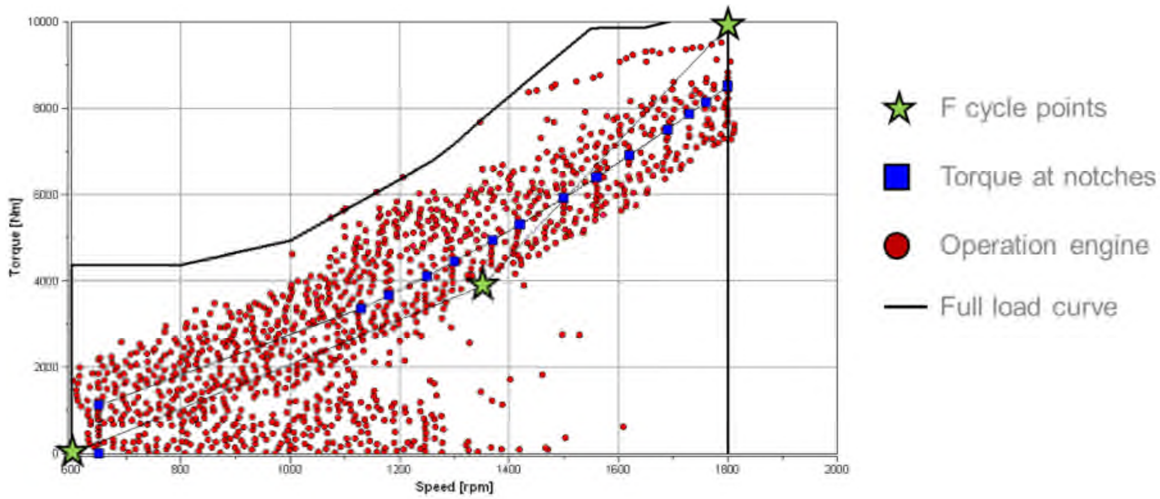

Figure 3: Operation points of 12V4000 CleanER-D

Figure 3 does not reflect the frequency of operation at each notch or load. A comparison of the load profiles of DB-AG 225 008-2 (mainline) and SNCF BB69419 (shunter) is given in Figure 4. It illustrates that both applications are quiet comparable, regarding the load profiles. More than 70% of time the engines are idling or operating at very low load (< 10% of power), only about 10% of time the engine is operating at more than 90% of full load. The average load of 225 008-2 is about 13%. This has an influence to the regeneration strategy of the DPF, which is shown in more detail in Chapter 3.2.3 and 4.2.1.

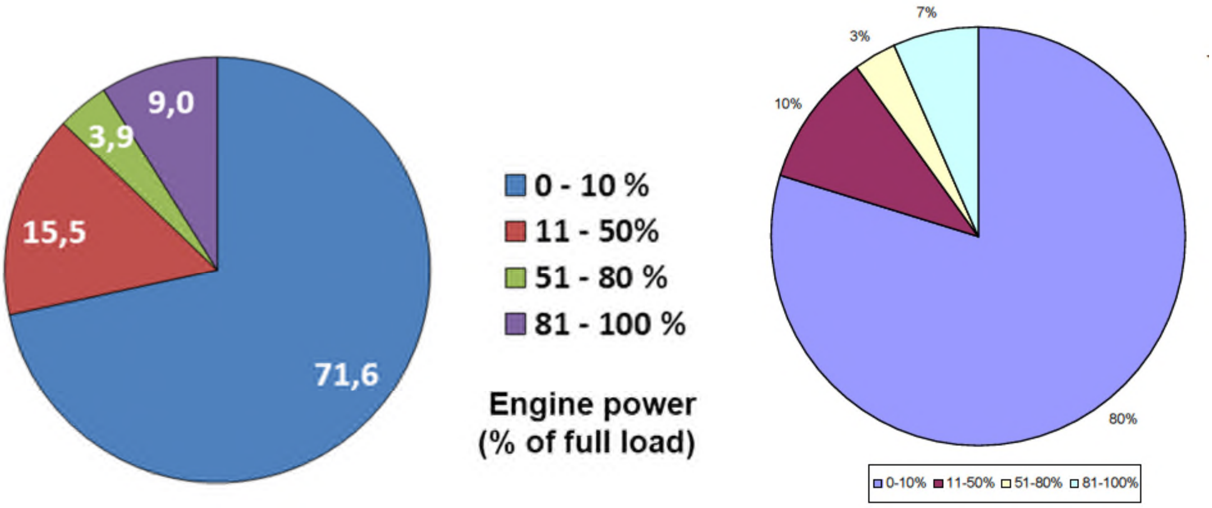

Figure 4: Load profiles of DB-AG 225 008-2 (left) and SNCF BB69419 (right)

3.2.3 Temperature distribution

Temperature at the inlet of the DPF has been recorded during common operation, which gives a good indication of regeneration ability of the DPF. In Figure 5 the temperature distribution is shown for one month (May 2013).

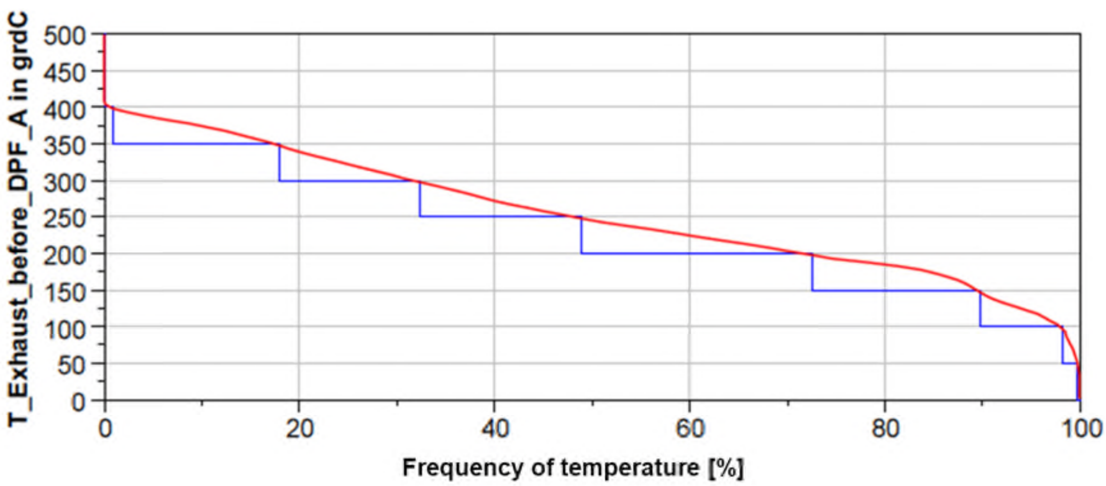

Figure 5: Temperature distribution before DPF (May 2013)

The chart illustrates that the temperature level is quite low, as a result of the high efficiency of the engine. The maximum temperature is about 400°C and only about 20% of time the DPF is warmer than 325°C.

4. EVALUATION OF FIELD TEST

Results from SP4 field test have already been introduced to the project and discussed during a SP1 workshop in Munich (17th July 2013) or published in other SP4 deliverables, so following only the key messages are described.

4.1 NOx EMISSION BEHAVIOUR

Limits of NOx emission of the engine are reached only by internal means by applying cooled EGR, so it is of interest how this IIIB technology performed with time.

Emission measurements have been performed at F cycle load points, but also at each notch before field test at an engine test bench under defined conditions (see also D4.2.2). During field test a NOx sensor, which is part of the IIIB system, measured NOx emissions, that have been recorded continuously with a data logger. The reliability of the NOx sensor has been checked before and after the field test and correlates well with equipment typically used for certification at engine test benches (CLD). At the end of the field test a measuring campaign was done at four selected notches which are close to F cycle load points. The 225 008-2 was braked during this operation by an electrical locomotive to ensure almost steady state operation of the engine. Gaseous emissions have been measured with a FTIR by APTL. The FTIR was also checked after field test at APTL´s engine test lab versus a CLD.

The validation of the obtained data showed that NOx emission after 683 hours of operation still meet the requirements of Stage IIIB. The course of NOx emissions from NOx sensor shows no drift at the chosen notches and is well in agreement with results from FTIR. Results from NOx sensor and FTIR are also comparable with measurements at the engine test bench before field test, considering the different boundary conditions. The whole procedure and results are described in more detail in D4.2.3 (MTU) and D4.5.1 (APTL).

4.2 OPERATION OF DPF

4.2.1 Temperature behaviour

Like already mentioned in Chapter 3.2.3 the maximum entrance temperature of the DPF is at about 400°C, so it is essential to avoid thermal losses and to enable rapid heat-up by good isolation of the DPF to ensure passive regeneration.

Figure 6 illustrates the heat-up of the DPF when changing the engine from idling to medium load. The temperature before DOC increases within 20 minutes from 100°C to 350°C, where passive regeneration is fast enough to oxidize filtered soot. Also the other temperatures (before and after DPF) are increasing very fast, with some delay. At almost steady state no temperature gradient is visible, proving the good isolation of the system.

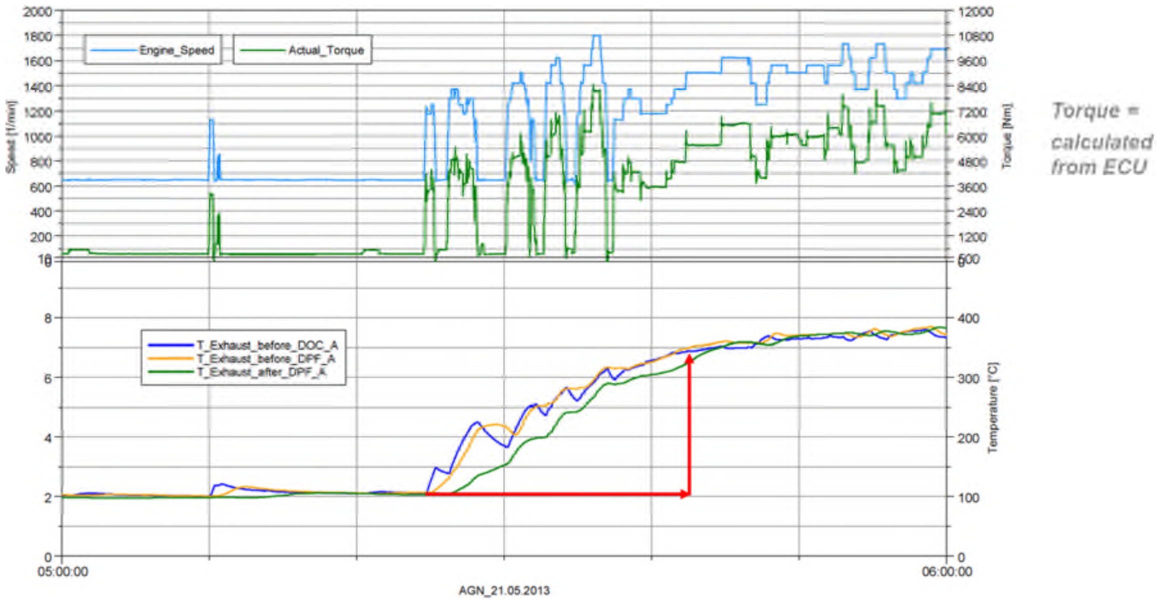

Figure 6: Heat-up of DPF (Idling → Medium load)

During common operation the engine is stopped quite often, so thermal losses should be very low.

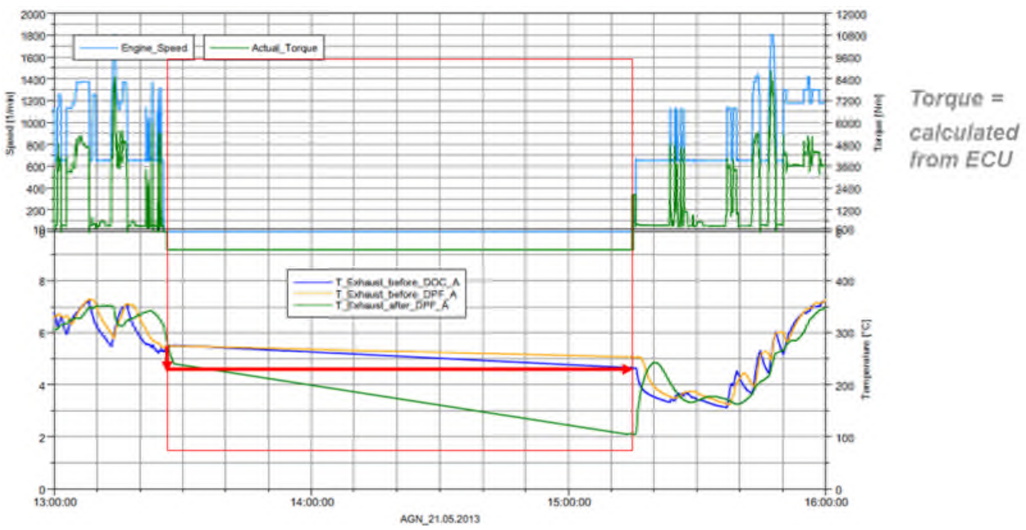

Figure 7: Thermal losses of DPF (Medium load → Engine stop)

Figure 7 illustrates the latter case. T before DPF at medium load is about 275°C, but within almost 2 hours after engine stop the temperature is still at 250°C, showing again the good isolation of the DPF. The steep decrease of T_Exaust_after_DPF_A is due to the position of the thermocouple close to the exhaust outlet, where cold ambient air affects the test result. After restarting the engine the temperature again increases very fast to the former level within 20 minutes.

For the case the engine changes from medium load to idling, like shown in Figure 8, the thermal losses are more distinct, leading to a temperature decrease from 400°C to 300°C within a few minutes. The reason for this is the fact that colder exhaust gas from the engine leads to a higher heat mass transfer, in contrary to the case the engine is stopped. But here again temperature before DPF increases as load is put again to the engine.

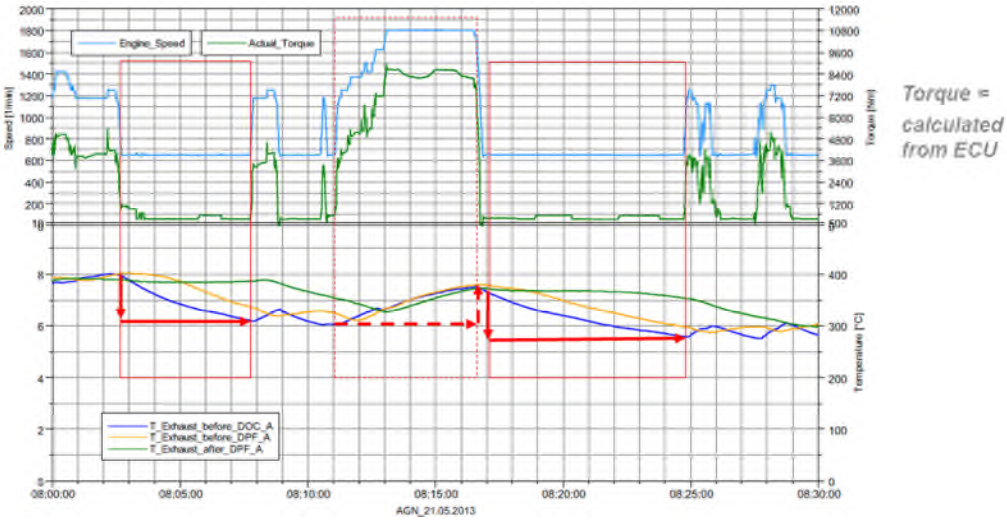

Figure 8: Thermal losses of DPF (Medium load → Engine idling)

4.2.2 Passive regeneration of DPF

Calibration of the engine was done to ensure passive regeneration of the DPF, avoiding additional measures. With the help of a model the behavior and soot loading of the DPF was simulated before field test, basing on data from other field tests. The model is able to predict temperature, emission and soot loading of the DPF by using different input data from sensors or ECU (see Figure 9) and was calibrated with data from test bench before field test.

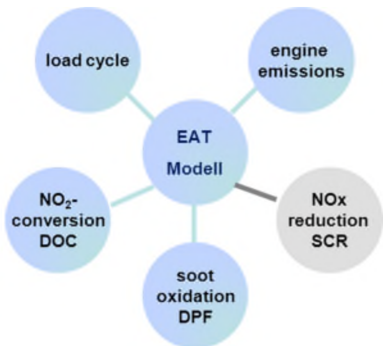

Figure 9: Principle of EAT model

To prove the ability of the applied DPF for passive regeneration during field test two scenarios have been calculated with the EAT model, using data from data logger (see Table 1).

Scenario	Low Load	High Load
Date	12.10.2012	24.05.2013
Power_Median	9,3 %	15,6 %
Speed_Median	833 1/min	901 1/min
Duration	9,1 h	13,0 h

Table 1: Boundary condition of two scenarios

The different load profiles have influence to the temperature distributions and thus to the regeneration of the DPF.

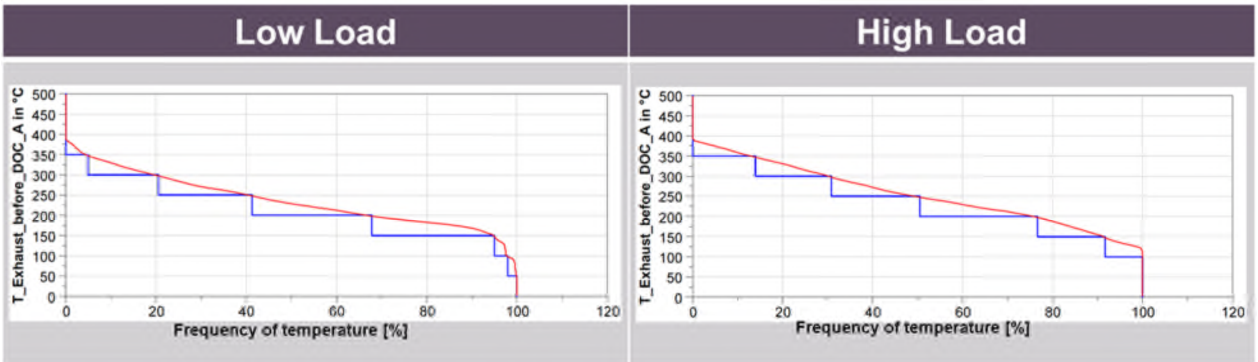

Figure 10: Temperature distribution of the two scenarios

Figure 10 demonstrates that the low load scenario is colder than for higher load. Percentage of temperature higher than 300°C is 20% for low load, compared to about 30% for high load.

For analysis of the scenarios the model assumed that the DPF was not loaded when the operation of the locomotive started. To get the soot balance load level of the DPF the calculation was repeated several times.

In Figure 11 the results of the calculations are shown. The green lines show the level of balance soot loading in relation to the limits (L1 and L2), were internal measures to force the regeneration of the DPF are started (thermal management). For both scenarios the distance to the first level L1 is far, so it can be assumed that thermal management never has been applied during field test. At first glance this might surprise. But looking into the EAT model in more detail, it makes clear that soot loading of the DPF is not only a function of temperature, but also of engine NOx raw emission, oxidation rate of NO to NO2 at the DOC and soot input. This has been well balanced during engine set-up at test bench before field test, so that operation of DPF is safe under typical operation of mainline locomotives.

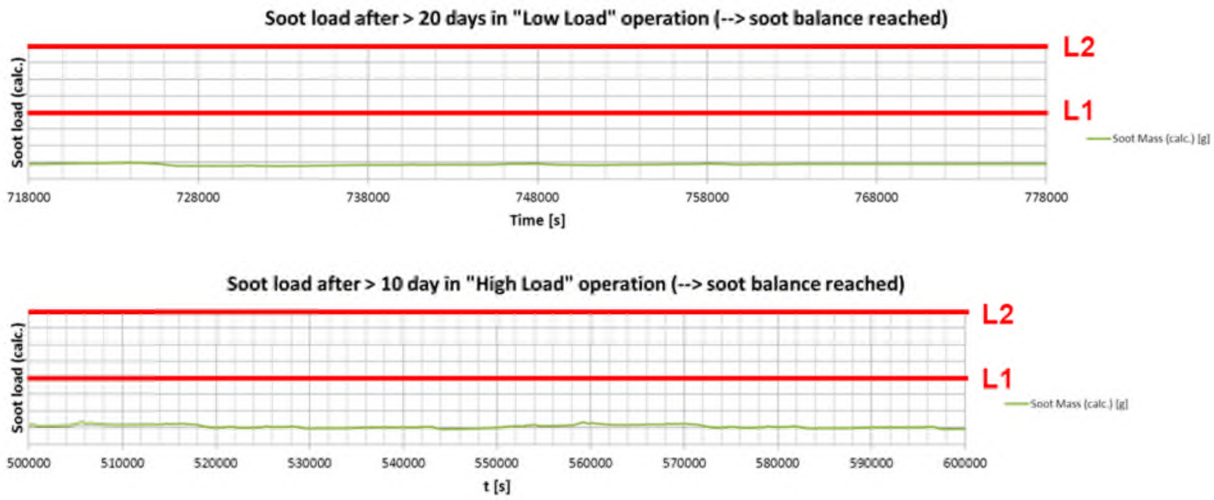

Figure 11: Calculation of soot balance loading (low and high load)

4.2.3 Backpressure behaviour

Contrary to soot, ash from engine oil or fuel can´t be burned off in DPF and cumulates with time of operation. This leads to an increase in backpressure that makes cleaning or replacement of the DPF necessary after certain time of operation. The procedure of service and recommended maintenance intervals are already described in D4.5.2.

In 225 008-2 the differential pressure (dp) of the DPF was continuously logged during field test and the course of dp at full load is shown in Figure 12.

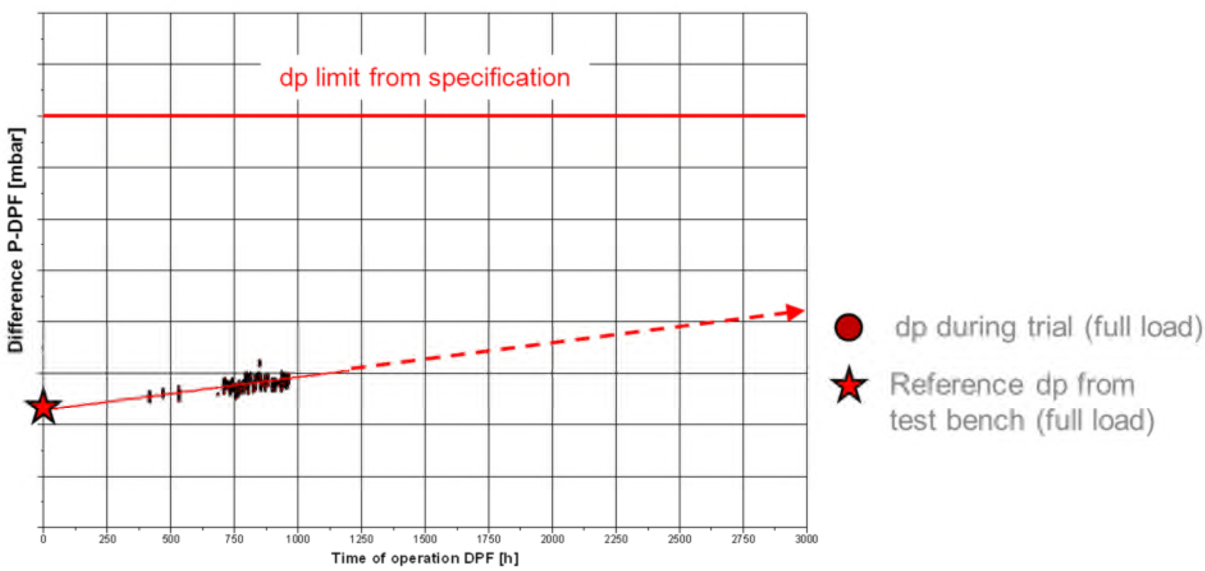

Figure 12: Backpressure of DPF

The backpressure increases continuously during field test up to 1000 hours. This is a typical behaviour known from literature. But the level is still far below the dp limit from specification were cleaning of the DPF would be mandatory. When dp behaviour would be the same up to 3000 hours (extrapolation with dotted arrow) it would still be below the limit, so these results give a good indication that maintenance interval can be reached, like it was specified before the field test.

4.2.4 Filtration efficiency

The functionality of the DPF has been proved during the mobile emission measurement of APTL at four stationary operation points (see also D4.5.1 and D4.2.3). Particle emissions (soot mass, particle number) have been measured up- and downstream the DPF and so filtration efficiency was calculated. The filtration efficiencies for particles at all chosen notches were much higher than measured for PM during engine test bench phase before field test (see D4.2.2), proving compliance of PM to limits of Stage IIIB. This clearly demonstrates that the DPF is working well and there is no indication of any malfunction.

4.3 Reliability of IIIB system

4.3.1 Service of IIIB system

Within the first 3000 h there are no differences in the maintenance plan between IIIA and IIIB engines, so efforts didn´t change with the new technologies. The course of the backpressure (see Figure 12) gives no indication that maintenance interval might not be reached. During the 683 hours of operation in 225 008-2 none of the IIIB specific engine technologies showed any problem.

4.3.2 Inspection of DPF system

After the DPF was removed from locomotive after field test an intensive inspection has been performed (see D4.6.2). The inspection of the prototype DPF from 225 008-2 after more than 1000 hours of operation gives no indication of aging of the system. Inner frame and outer shell are well in shape, all welding seams are fine. The fixations of the substrates in the cassettes and the cassettes in the inner frame are stable and gas proof. The substrates (DOC and DPF) show no cracks or damages, approving the results of filtration efficiency from 4.2.4.

4.4 Economic of IIIB system

4.4.1 Fuel consumption

Fuel consumption of the 12V4000 R84 engine was calculated from ECU at four notches during emission measuring campaign of APTL. Before field test the fuel consumption map was measured at the engine test bench for stationary load points and also for these four notches. Since power demand from engine in the locomotive at one notch depends whether auxiliaries are active or not, what isn´t known, both cases have been measured at the test bench.

In Figure 13 fuel consumption, calculated from ECU, at four notches (i.e. stationary operation) is set to 100% (blue bars). Fuel consumption at the same speed measured at the engine test bench with (= highest power) and without (=lowest power) auxiliaries are shown relative to it (red lines).

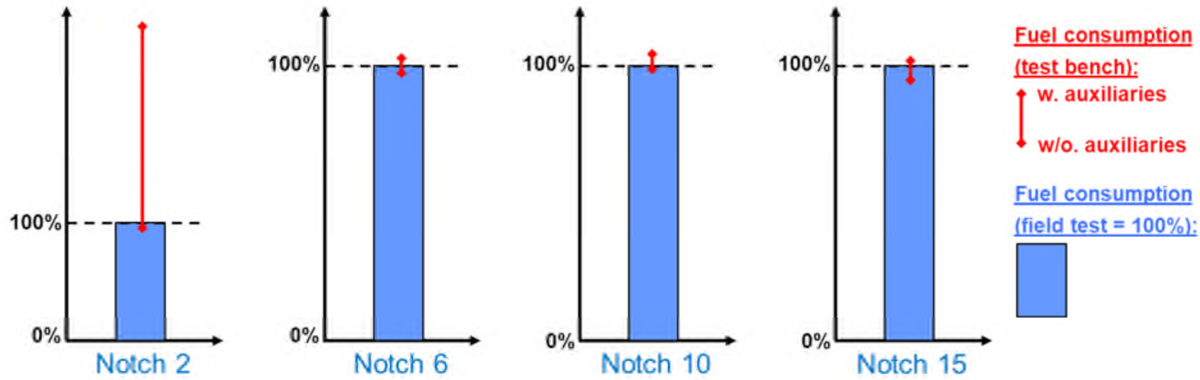

Figure 13: Fuel consumption in 225 008-2 compared to engine test bench

Higher power demand, due to auxiliaries, leads to higher fuel consumption. In summary the fuel consumption in steady state operation during field test is well within range of test bench (w./ w/o. auxiliaries) and meets the specification of the engine.

4.4.2 Lube oil consumption

Refilled lube oil during field test has been protocolled by DB-AG. The relation to fuel consumption calculated from ECU in the same period of time, gives the lube oil consumption. Based on available data the lube oil consumption is well within or even better than demonstrated during engine set-up before field test in D4.2.2.

5. CONCLUSION

The verification of the field test demonstrates that emissions are still in agreement with the requirements of Stage IIIB. The special IIIB technologies from engine and after treatment passed successfully the field test and met the requirement specified in D4.1.1 and proved in D4.2.2.

In summary the intensive cooperation of all partners involved in Sub-project 4 enabled to complete successfully a challenging project and proved performance of new emission control technologies for cleaner rail vehicles.

6. OUTLOOK

With approval of this deliverable the operational work in SP4 is finished.