Final report

1.1 Project details

Project title	High Pressure Boiler (HPB)
Project identification (program abbrev. and file)	EUDP-13-II HPB project, Journalnr.: 64013-0551
Name of the programme which has funded the project	EUDP Energistyrelsen
Project managing company/institution (name and address)	MAN Diesel & Turbo SE LDF5 Michael Witt Teglholmsgade 41 2450 København SV
Project partners	Alfa Laval, Aalborg Maersk, København Aalborg University, Aalborg
CVR (central business register)	39661314
Date for submission	18. May 2017 rev1

1.2 Short description of project objective and results

The HPB project was kicked-off in March 2014 by the partners MAN Diesel & Turbo (MDT), Maersk, Alfa Laval (AL) and Aalborg University (AAU). The project aimed for a product development and prototype installation of a so called high pressure boiler in combination with an exhaust gas recirculation (EGR) system on a large 2-stroke Diesel engine. The project partner Maersk supported the installation on board their container vessel “Maersk Cardiff”, so that a full functional in service demonstration and validation could be performed.
A scientific support with a thermodynamic modelling was provided by Aalborg University along the project duration.
The HPB boiler purpose is to boost the power output of the already installed Waste Heat Recovery (WHR) system, which generates electric power by a Steam Turbine for on board electricity demand, and thereby to reduce the overall fuel consumption, thus reduce the CO_2 emissions of the vessel.
A design integration evaluation of the HPB next to the main diesel-engine was the last part of the development project.
The HPB development, installation and testing on board Maersk Cardiff was after approx. 400 in service operating hours in summer 2016 successfully completed.

1.3 Executive summary

The project team developed, installed and tested successfully a new boiler element (HPB), which was integrated in the latest emission reduction technology (EGR) for large 2-stroke diesel engines (IMO Tier III emission relevant level). Due to the participation of Maersk in this project it was possible to test the new equipment and to validate the performance enhancement on the medium size container vessel Maersk Cardiff. The system was commis-

sioned and optimized in approx. 400 operating hours on Maersk Cardiff, there a team of Maersk, MDT and AL engineers joined the vessel.
The project overall budget was ca. 14 mio DKK, therein ca. 4 mio DKK was funded by Energistyrelsen (EUDP). The project was successfully closed in 2016. MDT as well as AL expect to have that product ready for commercial use by end of 2017 and will promote that product in both of their market portfolio.

1.4 Project objectives

The project objectives can be summarized in following line items:

- Design, development and installation of HPB prototype on “Maersk Cardiff”
- In service testing, performance data evaluation
- Investigation of best HPB design integration towards engine
- Development of a modelling tool development for energy optimization

Process schema as illustrated in figure 1.4_1 illustrate the HPB integration and task into a state of the art modern 2-stroke engine with an EGR emission reduction technology.

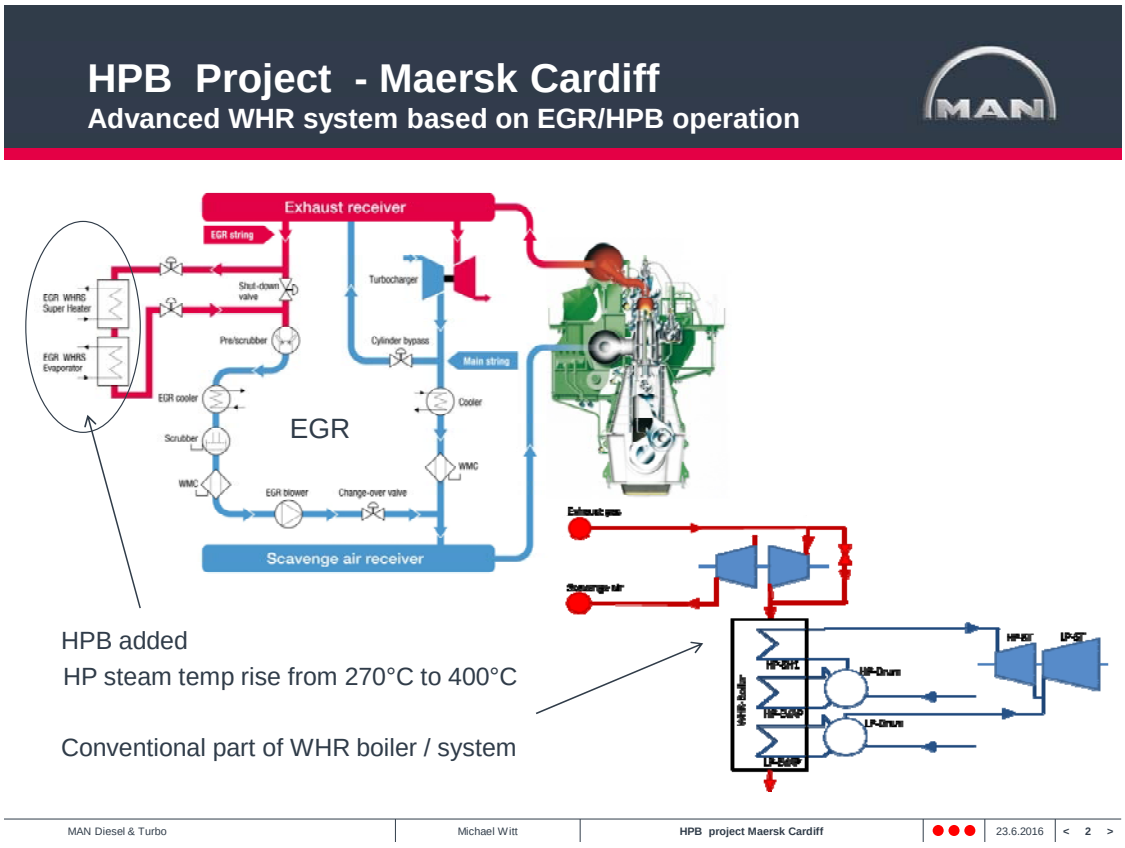

Figure 1.4_1

The project was realized in close project cooperation with Maersk along their container vessel “Maersk Cardiff”. Figure 1.4_2 and figure 1.4_3 illustrates the vessel as well as the installation of the system in main engine room.
It was for the project team a big challenge to plan all activities for implementation and testing of the equipment in close coordination with vessel operation at Maersk, since the vessel schedule in terms of commercial vessel operation had some priority and needed to be maintained. Installation took mainly place during various terminal stops at Singapore and testing of the new installation with attendance of MDT and AL engineers on board the vessel took place during sea-voyage between Singapore and China ports.

Figure 1.4_2

Figure 1.4_3

1.5 Project results and dissemination of results

The project implementation phase was performed within the given time frame. For the benefit of some system optimization for best performance, means best fuel and CO_2 saving the testing phase on the in service vessel was slightly extended and so also successfully completed. The system installed on the vessel is still available for use and it has been agreed with Maersk to use further 12 months to run the system continuously to gain more long term experience as well as to utilize the good results in commercial vessel operation.

Figure 1.5_1 illustrates the enhance power generation output due to use of the HPB boiler, thus enhanced steam production in Tier III mode operation.
For example: At a given engine load of 73% engine power about plus 540KW in power generation is provided by the system, utilizing the HPB boiler in the EGR system in Tier III mode. This extra power generation output from the Waste Heat Recovery System have not only no further fuel consumption required, it is moreover possible to cut down required auxiliary diesel-generator operation and thereby save fuel, thus reduce the total amount of CO_2 emissions.
The HPB boiler performance even over-fulfilled pre-calculated expectations by designer and maker Alfa Laval. Along the engine process MDT evaluated in all required details that the process stability in the Exhaust Gas Recirculating system is fully given with the HPB boiler in service

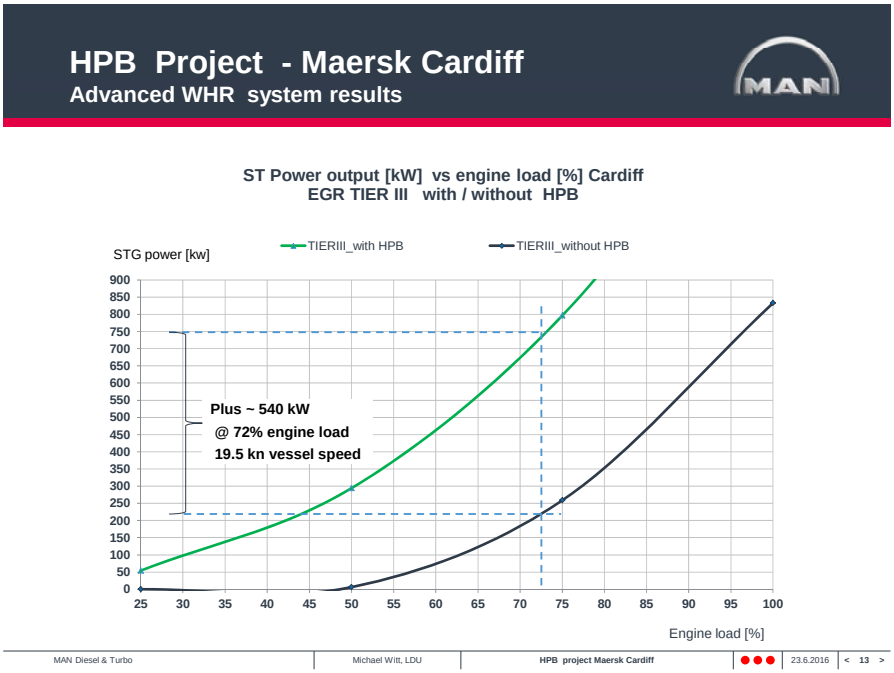

Figure 1.5_1

The last part of the project scope was an engineering study and assessment of a proper design integration of the HPB boiler element close to the engine frame, which shall be considered for near future product marketing.
As illustrated in figure 1.5_2 the HPB boiler element (blue component) is very close integrated on the main engine frame. All required engineering evaluation in terms of design, vibration levels and resonance free operation have been in depth evaluated. FEM calculation methods and simulations have been carried out to verify that an integrated system fulfil all given technical requirements.

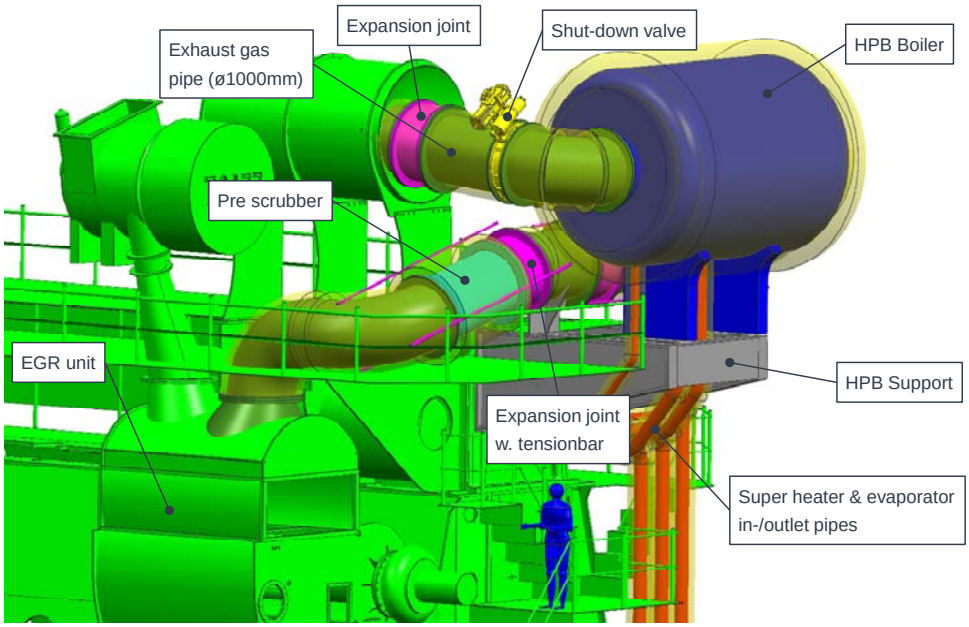

Figure 1.5_2

Along the project a few disseminations have been published (see details in Annex).
A technology update was given in yearly CIMAC conference in 2016 in Helsinki and Aalborg University also published in 2016 a paper.
Further project related documents about results, thermodynamic details and data evaluation are available, however those documents and results has to be treated within the project team as confidential and not public information. As defined in the project at the very start and publication beyond up to date status requires a written confirmation from all involved projects partners, coordinated by MDT.

1.6 Utilization of project results

Based on the successful demonstration of the new component HPB within the EGR engine concept of a Tier III compliant 2-stroke engine equipped with a Waste Heat Recovery system both Alfa Laval and MDT have mutually agreed to continue working on a market implementation. Prepared design integration study and basic arrangement concept developed within this project marks the foundation for further steps. Both parties (AL) and (MDT) will coordinate to issue marketing material and will promote in both companies this energy efficient solution towards the maritime industry. Project partner Maersk gained first time and frontrunner experience with that advanced system and is reviewing to which extend such improved WHR system shall be considered in any upcoming new-building specification in near future.

MDT large 2-stroke engines are the only ones who use EGR system on the high pressure part of the 2-stroke engine process and thereby can utilize this HPB waste heat recovery system. Competitors are using on the low pressure exhaust part some EGR systems, which cannot utilize an advantage from a very compact HPB.

Figure 1.6_1 illustrates a 3-D model for marketing purpose of near future integrated HPB boiler (AL) on a large 2-stroke engine (MDT).

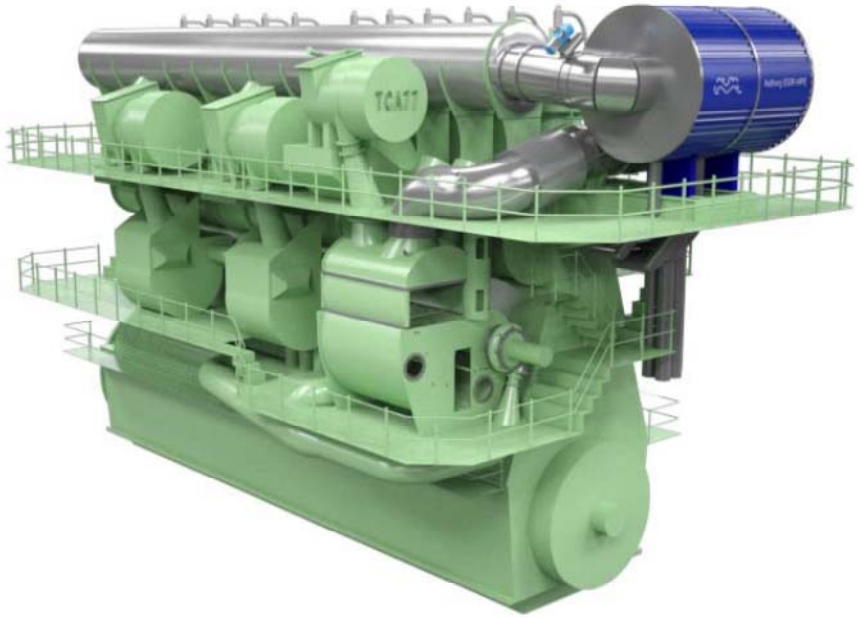

Figure 1.6_1

1.7 Project conclusion and perspective

The partners in this project fulfilled all tasks and completed successful the intended product prototype validation. The opportunity to run operational testing under day to day in service vessel operation in close cooperation with the partner Maersk was for the project of great benefit, so that this prototype testing is more than just a typical R&D test-rig scope.
Alfa Laval as the HPB product owner and MDT as the engine designer and engine process responsible have agreed on a further close cooperation to offer both this new product to the maritime market.
As currently the fuel-prize is more on the low level end the market implementation phase along new-building projects can be expected to be delayed. All involved parties expect however, that owners interest will be increasing again in view of rising fuel-cost as well as more Tier III technology implementation specifications, due to updated IMO legislation rules coming into force by 2010/2021

Finally I like to thank all project team involved for their great project contribution and commitment. Special thanks goes in this context to Energistyrelsen (EUDP) for making that project possible.

On behalf of the project team
Michael Witt (MDT)

Annex

- Project economy final report (attached as pdf file)

EUDP - High pressure boiler_P4_final.xlsx

- EUDP Afslutningsskema / evaluation (attached as pdf file)

a_afslutningsskema.docx

<u>Dissemination:</u>

CIMAC conference 2016 paper:

CIMAC_2016.pdf

EGR/HPE product info press-release:

Press_release.pdf

Aalborg University 2016 paper:

AAU_modelling.pdf

Project specific results / confidential documentation (not for public distribution)

Aalborg University simulation tool specification:

HPB_simulation-tool specification.pdf

MAN Diesel& Turbo project closing summary presentation

Maersk_Cardiff_HPB _EGR_closing_meetin

Design integration technical evaluation:

Presentation May 2016 - 11S90ME-C9 H

HPB boiler / engine interface specification (summary):

HPB_Spec_006.docx