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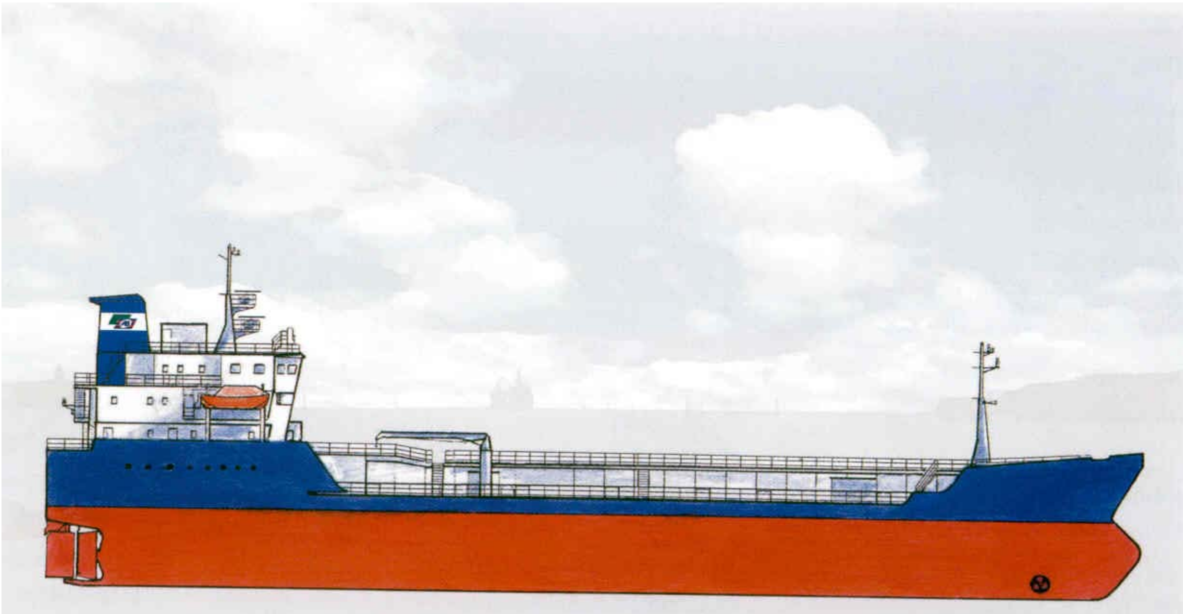
U-905B

Sulphur emission monitoring on board *Bro Atland*



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2004-02-20

IVL

Organisation/Organization	**RAPPORTSAMMANFATTNING** **Report Summary**
IVL Svenska Miljöinstitutet AB IVL Swedish Environmental Research Institute Ltd.	**Projekttitel/Project title** DEMO Project (Monitoring and verification of tradable emission reductions from sea going ships): Phase 2b
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Rapportens titel och undertitel/Title and subtitle of the report

Sulphur emission monitoring on board *Bro Atland*

Sammanfattning/Summary

IVL Swedish Environmental Research Institute Ltd. has demonstrated continuous engine load measurement via turbocharger speed and fuel logging on board a ship sailing in European waters. The study was aimed to provide a practical demonstration of the feasibility of using continuous power registration to verify fuel consumption as a basis for sulphur trading purposes.

The demonstration was undertaken on the product tanker *Bro Atland*, on a 21-hr voyage from Antwerpen (Neherlands) to Le Havre (France) during 18th-19th December, 2003.

In general, the measurement equipment and calculation routines outlined in the Phase 1 draft report of this project (DEMO Project) were shown to be suitable.

Nyckelord samt ev. Anknytning till geografiskt område eller näringsgren/Keywords

Ship emissions, Sulphur, SO_2, continual emission monitoring, marketable reduction

Bibliografiska uppgifter/Bibliographic data

Arkivnr U-905B

CONTENTS

Contents 1
1 Introduction 1
1.1 Background 1
1.2 Objective 1
2 Methodology 2
2.1 Technical ship data 2
2.2 Conditions 2
2.3 Equipment 3
2.4 Fuel system and sampling 3
2.3 Evaluation 4
3 Results 6
4 Discussion 8
5 References 10
Appendix 1 11
Appendix 2 12
Appendix 3 13

1 INTRODUCTION

1.1 Background

PriceWaterhouseCoopers AB have initiated a multi-phase project (DEMO Project) financed by several stakeholders in the shipping industry aimed at demonstrating that monitoring and verification of emission reductions from ships are feasible and may serve as a basis for emissions trading. In turn, the Swedish Environmental Research Institute has been contracted to outline suitable shipboard monitoring techniques and calculation routines (Phase 1), and secondly to provide practical demonstrations at sea (Phase 2).

This study (Phase 2b) focuses on demonstrating techniques for monitoring fuel consumption and fuel analyses to enable quantification of sulphur emissions from ships. An earlier study (Phase 2a), reported in IVL report U-826, has shown the feasibility of monitoring NO_x-emissions on board two ships using two different kinds of NO_x abatement methodology.

1.2 Objective

The objective of these measurements was to demonstrate the simultaneous monitoring of fuel consumption by two independent methods to obtain verifiable data on total sulphur emissions from a ship. Fuel samples were taken and analysed in an independent laboratory. This refers back to the methodology suggested in the draft Phase 1 report (Hansén *et al.*, 2003).

2 METHODOLOGY

2.1 Technical ship data

Technical data for the ship in question are presented in Table I.

Table I Technical data for the measurement ship

Ship name	***Bro Atland***
Signal	SJTA
Length and width, m	144,1 x 23
Dead-weight, tonnes	16 326
GT	11 377
Capacity	19 550 m^3
Engines	1 ME and 4 AEs
Service speed, knot	19
Year of delivery	1999
Classification	DNV +1A1 Tanker for Oil Products and Chemicals ESP E0 ETC HL(1.54) W1-OC ICE-1A
Main engines (ME)	MAN B&W 9L 40/54, 6 480 kW @ 550 r/min (2 stroke slow speed diesel)
Auxiliary engines (AEs)	Volvo MD162, 390 kW (4 stroke medium speed diesel)
Fuel type	ME use Heavy Fuel Oil (HFO/IF380) AEs use Marine Gasoil (GO)

Bro Atland operates in Western Europe shipping oil products between refineries and depots.

2.2 Conditions

The measurements were undertaken during 21-hr voyage from Antwerpen (Netherlands) to Le Havre (France). Logging started upon main engine startup when leaving the outer lock in Antwerpen and ended after main engine shutdown in Le Havre. (20:00 18th December to 17:00 19th December). Weather conditions were extremely good with no swell and air temperature of ca. 0 – 15 °C.

At sea the auxiliaries are usually turned off and a shaft generator on the main engine produces the electricity. The original intention was to register the power signal from one of the auxiliary generators, which is available, to monitor the auxiliary engines. However due to a malfunction in the equipment, unnoticed due to very short preparation time for the test, only one channel was available on the data logger and this was used for the main engine. This makes little difference as the auxiliary engines were shut down 10 minutes after the start of the test period and were restarted on low load only about 2 hours before the end of the measurement.

The voyage was an empty one, meaning that no logging could be undertaken during unloading operation. (Unloading operation is dimensioning for the auxiliary engine power). A reading during the unloading indicates a total power need of about 600 kW.

Most of the voyage was done at 85 % ME load except for power reductions for the transfer of pilots and for avoiding traffic conflicts in the English Channel.

Due to short planning term and the difficulty of obtaining the desired fuel along the ship's route, no low-sulphur fuel was used in this demonstration. This is not of any major importance, as the main objective was the demonstration of fuel consumption monitoring techniques. The case with low sulphur fuel was thus only evaluated theoretically, see below.

2.3 Equipment

Fuel consumption of the main engine was monitored in two different ways: Taking periodical readings on the permanently installed fuel flow meter and the more approximate method of calculating the fuel consumption from a signal that varies with engine load.

The ship has no facilities for the direct monitoring of main engine load. The main engine is run as a constant speed unit meaning that load variation are taken up as changes in shaft torque which is very hard to monitor. Fuel rack position, which governs the injected fuel quantity, is only indicated on a mechanical scale on the main engine.

The chosen signal for monitoring engine load is the turbocharger speed. Power and fuel consumption are derived from the results of the engine's original bench test at the manufacturer. Turbocharger speed is not ideal as it varies with other factors beside engine load, such as the maintenance status of the turbocharger (friction and backpressure) and exhaust temperature.

Each month, the ship's main engine is run through a test of the cylinder pressure where the power is calculated from the pressure curve and the turbine speed is registered. This test may be used to periodically monitor the changes in turbine characteristics over time.

A signal for the turbocharger speed is available on the main engine control panel (4-20mA). This was connected to a data logger over a signal insulator. Measurements were done in 5-second intervals and averaged over 10-minute periods.

No direct calibration was possible of the turbocharger speed in order not to interrupt the ship's normal operation. The speed is registered by a magnetic pickup as a frequency and then converted into a current signal.

Fuel consumption was monitored by manual reading every hour from a mechanical flow counter on the main engine fuel line. (This is usually used only for daily reading of the fuel consumption.)

2.4 Fuel system and sampling

The ship has one main engine and two boilers running on HFO. Four auxiliary engines are fuelled with gasoil.

HFO is bunkered in three tanks. The fuel is pumped from these to two settling tanks and then via separators to two service tanks. Normally one pair of settling/service tanks is used for the main engine and one pair for the boilers. This allows the use of the boiler pair for small oil remainders, as the boilers are not sensitive to blended fuel qualities.

For the gasoil there are two bunker tanks and one service tank only. The service tank content is continuously circulated through a separator.

Bunkering is usually (98%) done to an empty tank to avoid unnecessary mixing of the fuels.
The tank level is measured with an air bubble device. The volume is then calculated with sounding tables. These are not based on actual measurements but are derived from drawings. Also the level readout is dependent on trim, movements etc. This leads to a fairly large error in the volume measurement.

No flow meter exists for the boilers. Instead the consumption is estimated from the running hours of the burners which is registered. The burners only have one power level and use a simple on/off regulation.

The usual routine for the transfer of HFO to the main engine is that the settling tank is filled from to 40 m3 once every day. Automatic transfer from the settling tank continuously holds the service tank at 27,9 m3 (according to the Norcontrol computerised management system screen).
Presently there are no openings suitable for sampling directly in the HFO tanks. If necessary, this could easily be incorporated according to the Chief Engineer. There is a sounding pipe, which is continuous from the top to the bottom of the tank, and a drain outlet pipe in the bottom.

The gasoil can be easily sampled through a centrally located pipe and tap used to extract GO for cleaning purposes (GO is used as a solvent for cleaning of components in the HFO-system).
Fuel samples were taken from two different positions in the HFO fuel system, both after the service tank, in the part of the fuel system leading up to the main engines, see Appendix 4. A gasoil sample was taken directly from the gasoil tank. For the laboratory results, see Appendices 1 a-c.

During the test, the fuel was continuously drawn from one single service tank, which could be monitored from tank level readings. Bunker tank levels were entered daily in the engine room logbook.

2.5 Evaluation

The relationship between turbine speed, engine power output and fuel consumption is derived from the engine test bench diagrams as seen in Appendix 2. The relationship between turbine speed (curve 10) and specific fuel consumption (SFC, curve 9) are thus obtained for the test conditions.

The latest cylinder pressure measurement, see Appendix 3 was used to obtain one recent calibration point for the turbocharger speed vs. engine load. This led to a correction factor of 0,94 to be applied to the actual turbine speed. This factor includes corrections for different fuel heat calorific values.

The diagram below describes the obtained relationship between turbine speed and fuel consumption. This curve is combined with the logged turbine speeds to arrive at the fuel consumption every 10th minute of the journey.

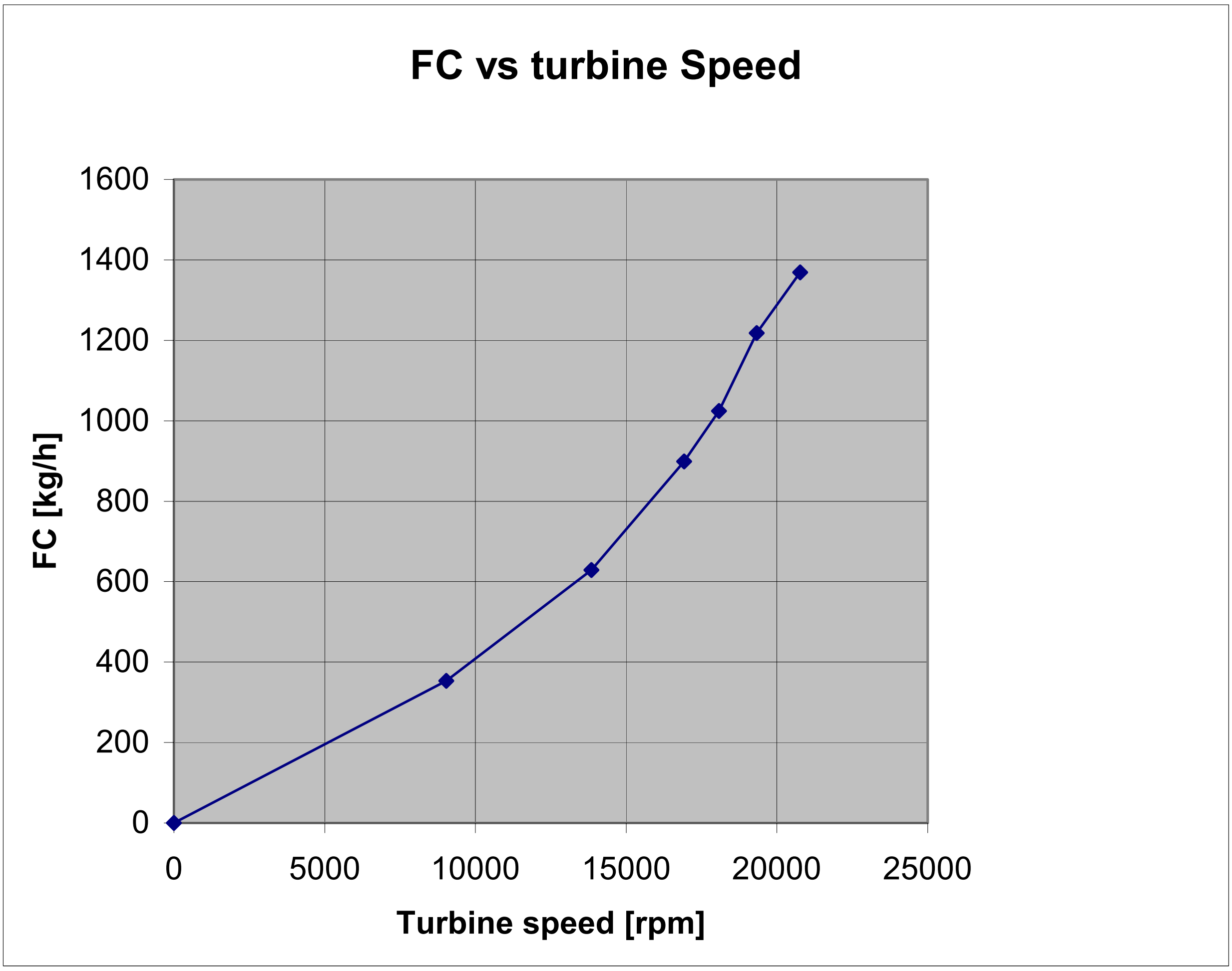

Figure 1. Relationship between turbine speed and fuel consumption, Bro Atland, main engine.

The fuel flow meter fuel gives readings in cubic meters that are converted to kg from the analysed density compensated for fuel temperature.

3 RESULTS

The turbine speed and main engine load over time is shown in Figures 2 & 3 below. Visible are periods of shallow water transit, effects of traffic and power reductions for the transfer of pilots.

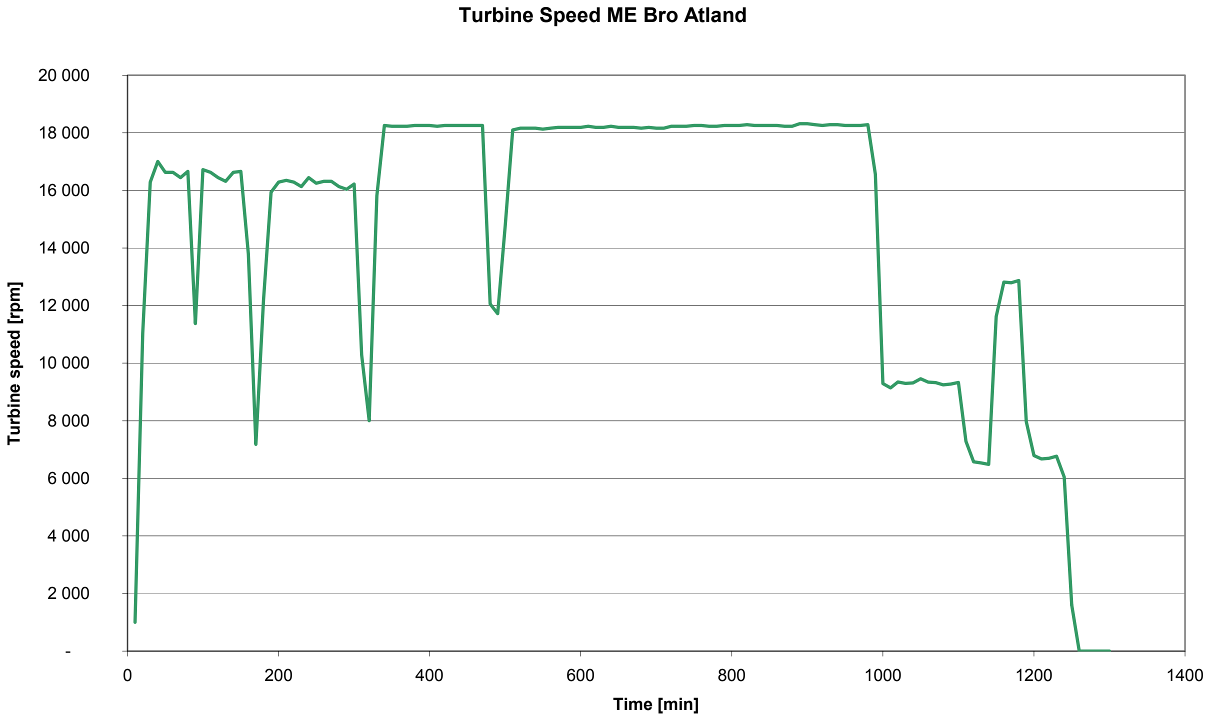

Figure 2. Main Engine, turbine speed over time, Bro Atland voyage Antwerpen-LeHavre, 18th-19th september 2003.

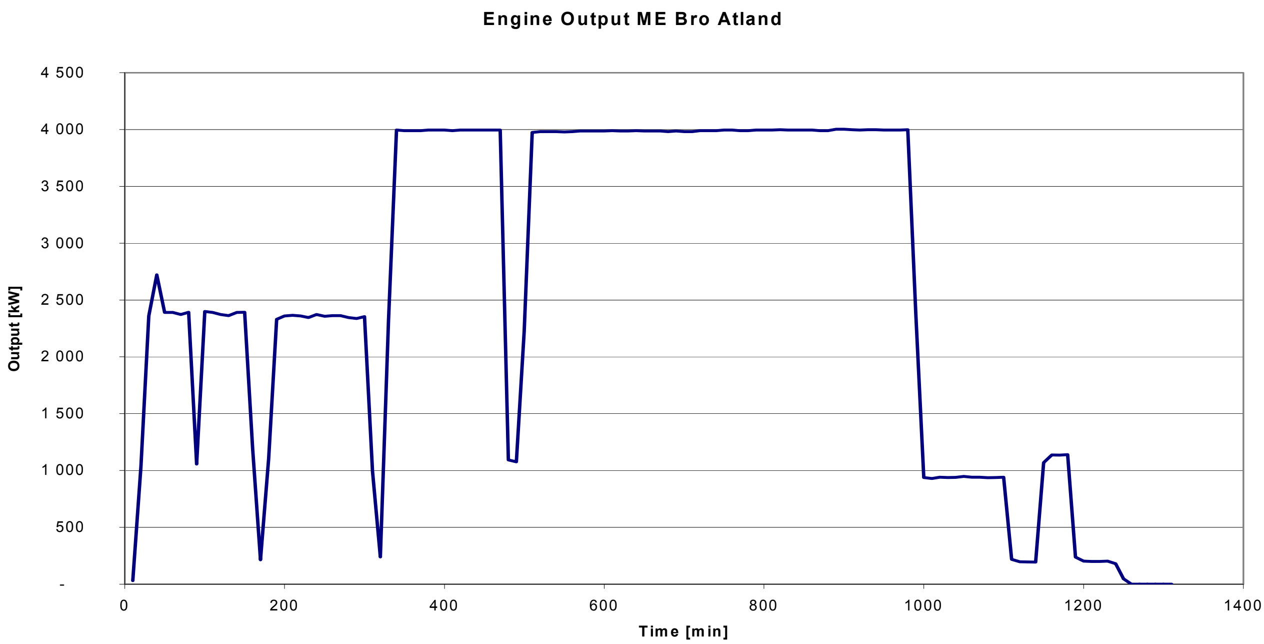

Figure 3. Main Engine, power output over time, Bro Atland voyage Antwerpen-LeHavre, 18th-19th September 2003.

In Figure 4, the two different methods of fuel consumption monitoring are compared. The results are highly proportional but a systematic difference of about 7,5 % remains. This can probably be improved upon with a single or periodical calibration between the methods and of the engine load measurement, something that wasn't possible within the frames of this project.

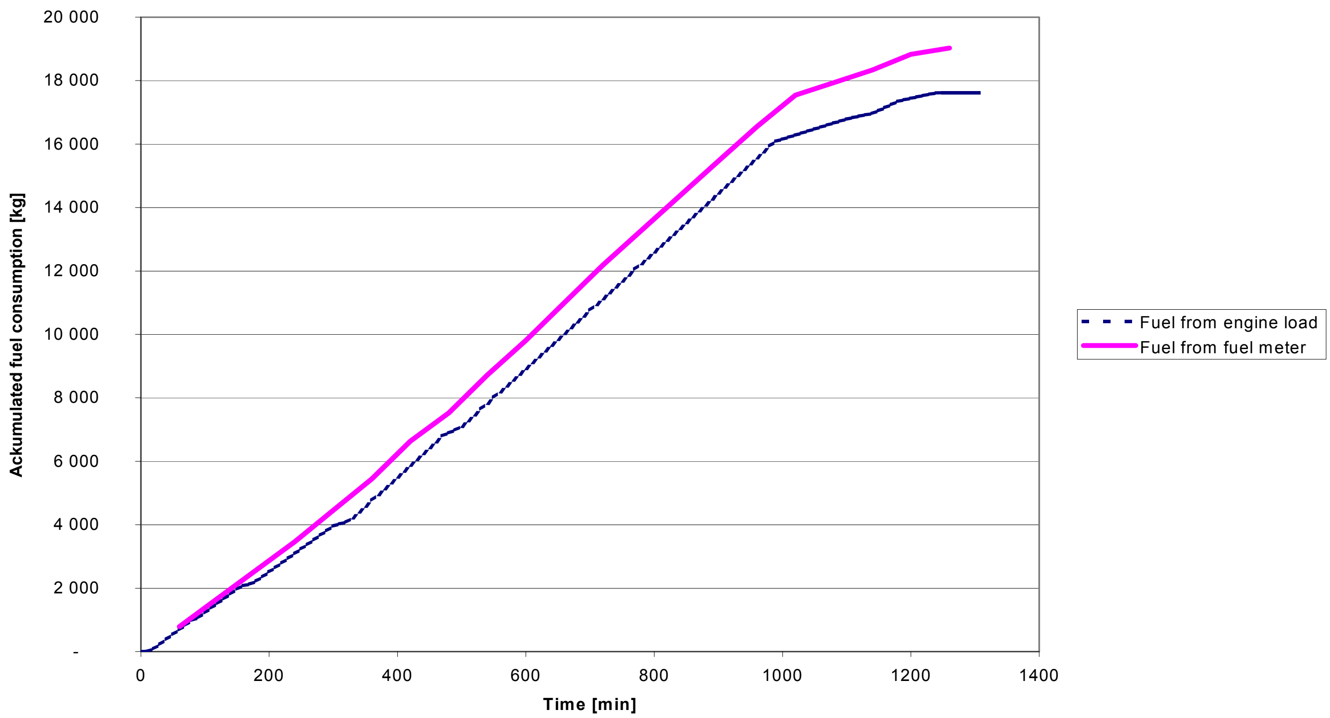

Figure 4. Accumulated fuel consumption, Bro Atland voyage Antwerpen-LeHavre, 18th-19th September 2003.

Using the analysed fuel sulphur content of 2,9 % and the fuel consumption from the fuel meter, the total emissions during the voyage may be calculated to 552 kg sulphur or 1 104 kg if counted as SO_2. The estimate based on engine load results in a figure of 511 kg sulphur corresponding to 1 022 kg SO_2.

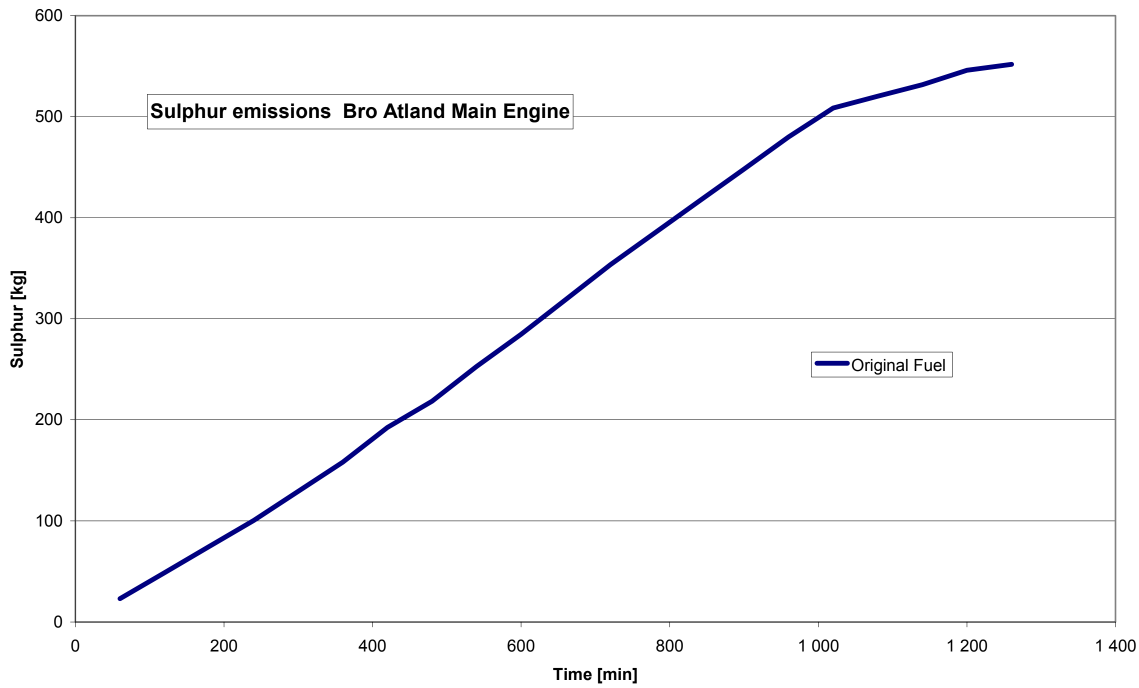

Figure 5. Accumulated sulphur emissions, Bro Atland voyage Antwerpen-LeHavre, 18th-19th September 2003.

The following diagram describes a hypothetical case where the ship is simulated to use fuel with 0,5 % sulphur. A fictive baseline of 1,5 % sulphur has also been assumed. In this case the reduction from baseline is about 190 kg of sulphur over 21 hours.

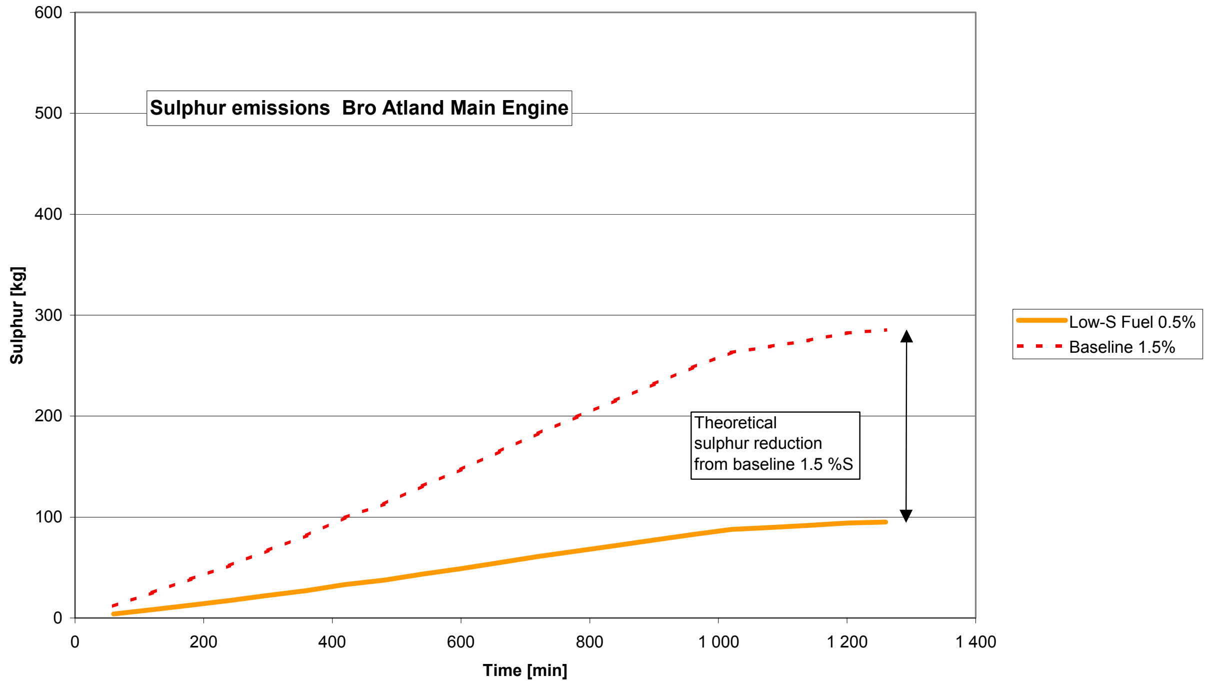

Figure 6. Accumulated sulphur emissions with assumed 0.5 % fuel sulphur compared to a fictive baseline of 1,5 % S, Bro Atland voyage Antwerpen-LeHavre, 18th-19th September 2003.

4 DISCUSSION

The feasibility has been shown to simultaneously monitor fuel consumption in more than one way, which enables independent verification of fuel use. The methodology as outlined in the Phase 1 draft report (Hansén *et al.*, 2003) has been demonstrated as suitable thus far. The level of accuracy and practicality may be increased considerably by use of calibration routines and simple registration devices.

The observed difference between the two methods of fuel consumption monitoring lies within the expected uncertainty range for the measurements as estimated in the Phase 1 report (5-15% for fuel consumption) despite the lack of calibration for some parameters.

Tank level measurements are generally not accurate enough for short-term fuel consumption measurement. Registration of tank level should however be sufficient to monitor which tank is in use when running on different fuels. This might be used to verify entries in, for example, a manual fuel log.

An interesting follow-up project to this work would be to conduct a more, long-term demonstration (6 –12 months) of a measurement system that is operated and calibrated entirely by the ship's crew and with true changes of fuel used.

5 REFERENCES

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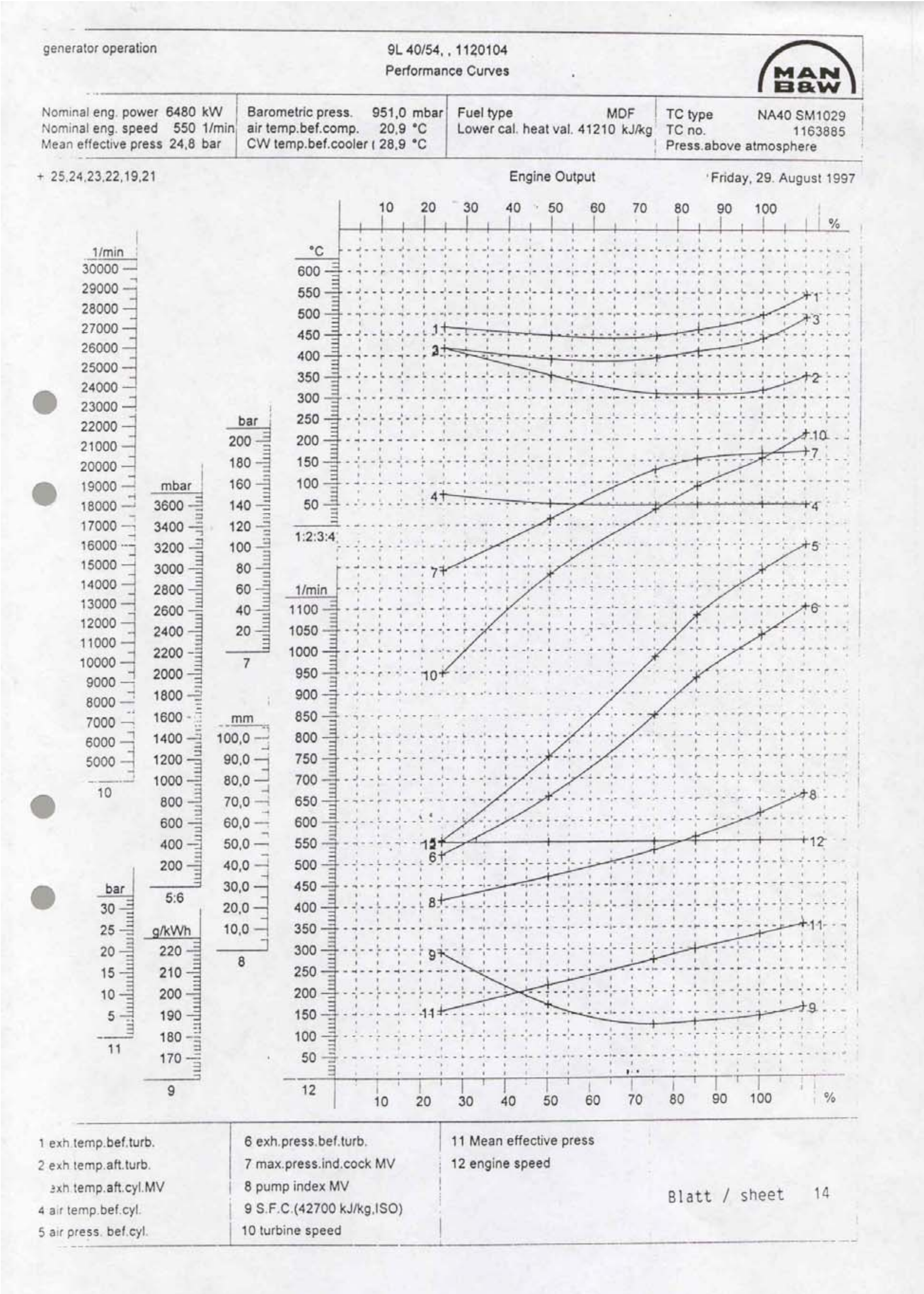
APPENDIX 1

APPENDIX 2


generator operation
9L 40/54, , 1120104
Performance Curves
MAN B&W
Nominal eng. power 6480 kW
Nominal eng. speed 550 1/min
Mean effective press 24,8 bar
Barometric press. 951,0 mbar
air temp.bef.comp. 20,9 °C
CW temp.bef.cooler 28,9 °C
Fuel type MDF
Lower cal. heat val. 41210 kJ/kg
TC type NA40 SM1029
TC no. 1163885
Press.above atmosphere
+ 25,24,23,22,19,21
Engine Output
Friday, 29. August 1997
1 exh.temp.bef.turb.
2 exh.temp.aft.turb.
exh.temp.aft.cyl.MV
4 air temp.bef.cyl.
5 air press. bef.cyl.
6 exh.press.bef.turb.
7 max.press.ind.cock MV
8 pump index MV
9 S.F.C.(42700 kJ/kg,ISO)
10 turbine speed
11 Mean effective press
12 engine speed
Blatt / sheet 14

APPENDIX 3

Imes Cylinder Pressure Measuring EPM-XS/XL

2003-12-18 09:38:51

Ship/PowerStation	Engine Type	Data read
		2003-11-11 16:17:53

Engine Power [kW]	Power A Side [kW]	Power B Side [kW]
5656		

Load	Scav.Air Temp	Scav.Air Press.	TC Speed I	TC Speed II	TC Press. I	TC Press. II
6,2	44,4	2,3	17900			

Angle at PComp	Angle at Injection Start	Angle at Inlet Valve Open	Angle at Exhaust Valve Open
0	0	0	50
	Angle at Exhaust Valve Close	Regulator Index	Sea Water Temp.
	40		11

Cylinders	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Pmaxmean	172	168	168	171	175	166	165	163	163											
Pmaxmax	173	170	169	173	176	168	166	165	164											
Pmaxmin	170	167	166	169	173	164	162	161	162											
T Exhaust	419	387	429	414	405	400	445	428	404											
Pump Index	52	52	52	52	52	52	52	52	52											
MIP	20.49	20.00	19.80	20.59	20.96	19.88	20.71	20.46	20.32											
Power [kW]	632	617	611	637	647	614	641	630	627											
RPM	546	546	546	547	546	547	548	545	546											
Cycles	10	10	10	10	10	10	10	10	10											
Alpha Pmax	13	12	11	12	11	12	12	13	13											
Pcomp	150	148	150	147	150	148	144	148	147											
Pinj	150	148	150	147	150	148	144	148	147											
PInl_open	150	148	150	147	150	148	144	148	147											
PExh_open	54	51	51	52	52	51	51	52	51											
PExh_close	75	71	70	72	72	71	70	72	71											
Max change	4.4	4.4	4.5	4.3	4.4	4.4	4.3	4.4	4.4											

APPENDIX 4

HFO Fuel System Sampling Points