Royal Boskalis Westminster nv

To	From	Date
Taskforce Emissions Coastway	C.G. Smits, B.P. Meijer	15th of December 2008

Engine performance Coastway: Influence of the fuel additive XBee

Location: Dilmunia project, Kingdom of Bahrain
Date: 19th of July 2008 and 15th of December 2008

Introduction

To verify whether the fuel additive XBee has a positive effect on engine performance and fuel consumption, areference engine performance test has been executed on the Coastway on July 19 2008. After using XBee for approximately 4 months, a second test has been performed on December 15th 2008.

This report is partly based on the reference report by Coen Smits from August 12 2008.

Engine specifications

Position	Starboard
Make	Wärtsilä
Type	W6L32B
Power	2760 kW
Serial number	21140

Measuring sequence

Reference Test

The measurements have been done according to the following sequence:

- Connect to floating line
- Discharge load
- Record humidity, outside temperature and pressure
- Execute 100% power level measurement
    - Wait approx. 5 minutes before exhaust gas temperatures are stabilized
    - Record engine parameters
    - Execute Premet to measure indicator pressures
    - Record engine parameters
    - Start exhaust gas data logging for 10 minutes
    - Record engine parameters
- Execute 75% power level measurement
    - Same as 100% power level measurement
- Disconnect pipeline
- Start sailing to borrow area
- Execute 50% power level measurement
    - Same as 100% power level measurement
- Execute 25% power level measurement
    - Same as 100% power level measurement

Verification Test

The measurements have been done according to the following sequence, which is slightly different from the reference test sequence. The procedure during the measurements is the same as above:

- Disconnect pipeline
- Start sailing to borrow area
- Record humidity, outside temperature and pressure
- Execute 50% power level measurement
- Execute 25% power level measurement
- Dredging and sailing loaded to pipeline
- Connect to floating line
- Before discharging load, pump water through the floating line
- Record humidity, outside temperature and pressure
- Execute 100% power level measurement
- Execute 75% power level measurement

General conditions

Reference Test

General data applicable for all power levels:

- Running hours 46348 [h]
- Humidity 65 [%]
- Outside temperature 36 [ºC]
- Outside pressure 996 [hPa]

All tests were executed with following settings besides the power level specific setting:

- Empty hopper
- Booster bypassed
- Propulsion starboard declutched

Pipeline specifications:

- Floating line 200 [m]
- Sinker line 1114 [m]
- Land line 896 [m]
- Total 2210 [m]

Verification Test

General data applicable for all power levels:

- Running hours 49516 [h]
- Outside temperature 20.5 [ºC]
- Outside pressure 1017 [hPa]

50% and 25% (low gear)

- Empty hopper
- Booster bypassed
- Propulsion clutched in, zero pitch
- Humidity: 64 %

100% and 75 %

- Full hopper;
- Booster running;
- Propulsion starboard declutched
- Humidity: 54 %

Pipeline specifications:

- Floating line 130 [m]
- Sinker line 830 [m]
- Land line 940 [m]
- Total 1900 [m]

Remarks

Operations schedule

To schedule the measurements in one trip, the 50% and 25% measurements have been performed before dredging and the 100% and 75% power tests before discharging the load. However, the hopper level has no significant impact on the engine performance.

Propulsion clutched in

During a test prior to the emission measurements, it was noted that the 50% power level could not be obtained without the propulsion shaft clutched in. Thus, the propulsion shaft is also clutched in for the low gear measurements, but with a zero pitch. This resulted in the same fuel racks on the systems as the previous test.

Fuel rack signal

Halfway during the actual experiments, it appeared that the fuel rack signal of the SB engine is about 6 mm lower than the actual fuel rack on the fuel pumps, thus the power indication in the systems on board is too low. This was not the case during the previous tests and there was no reason to assume this could be an issue. The result is that the actual power levels are higher than the previous test; due to clutching in the propulsion at the low gear and that the 100% setting resulted in an overload condition. The 75 % test is therefore the most equal test.

Comparison of Results

Several parameters can affect the test results, besides the fuel additive. To name a few:

- Climate conditions
- Power fluctuation
- Actual power level
- Cooling and lubricating system
- Fuel quality
- Fuel supply

To generalize the results, the NO_x Technical code can be used to calculate specific emission levels [g/kWh], refer to 'Measuring emissions on the Queen of the Netherlands'. Globally, from volume fractions of the dry exhaust gas (water is removed prior to the analysis) to emissions in [g/kWh], the following sequence has to be executed:

- Determine fuel mass flow [kg/hr]
- Calculate absolute humidity [g/kg]
- Calculate exhaust mass flow [kg/hr]
- Calculate correction factors [-]
- Compute emission mass flows [kg/hr]
- Determine specific emissions [g/kWh]
- Determine emission to fuel ratio [kg/MT]

	Power		Readings [ppm or %]					Specific [g/kWh]					Emission to fuel ratio [kg/MT]			
Emission data	[%]	[kW]	CO	CO2	NOx	O2	SO2	Fuel	CO	CO2	NOx	SO2	CO	CO2	NOx	SO2
	100%	2610	62.1	5.57	566.1	11.77	57.8	238.1	0.53	739.5	9.68	1.12	2.20	3106	40.66	4.68
	75%	2005	86.7	5.09	475.1	12.37	56.9	237.1	0.80	736.0	8.90	1.20	3.36	3105	37.55	5.05
Without Xbee	50%	1375	191.7	4.43	418.5	11.70	51.6	257.4	2.20	797.7	9.82	1.35	8.53	3099	38.14	5.25
July 19th 2008	25%	838	174.4	3.65	418.1	15.27	56.2	270.5	2.55	839.0	12.52	1.88	9.43	3102	46.27	6.95
E2 weighted average								254.1	1.81	788.0	10.20	1.40				
	100%	3029	63.4	6.79	797.8	12.20	9.2	229.3	0.43	717.3	8.30	0.14	1.86	3128	36.17	0.62
	75%	2034	60.5	6.28	679.9	12.70	62.9	233.7	0.45	731.1	7.79	1.07	1.92	3129	33.33	4.56
With Xbee	50%	1695	74.8	6.30	666.4	12.77	94.2	228.6	0.54	714.6	7.65	1.55	2.36	3126	33.45	6.80
December 15th 2008	25%	1195	119.4	5.97	567.3	13.15	72.7	226.4	0.90	707.2	6.80	1.25	3.98	3124	30.02	5.53
E2 weighted average								229.1	0.58	716.0	7.60	1.21				

Relative difference with Xbee		
	E2	75%
Fuel	-9.8%	-1.4%
CO	-67.8%	-43.8%
CO2	-9.1%	-0.7%
NOx	-25.5%	-11.0%

Remarks

- The 25 %, 50 %, 75 % and 100 % power levels are set points. The actual power levels are different for both tests as explained above.
- Since the onboard logger cannot log the actual power levels, just the pump powers, the power levels from PREMET is used, which is a summation from the induced power from each cylinder at a certain time interval during the experiment.
- The recorded power is thus not a 10 minute average, but the power level during the measuring of the pressures.
- As can be seen from the power loggings, the power fluctuates ± 50 kW, which makes the relative deviation smaller at higher power levels and thus more reliable.
- The first emission readings of 15^{th} December were performed with a wrong setting of the equipment. The first reading on the presented report is not taken into account, since the equipment was still stabilizing.
- The E2 weighted average weighs the results for each power levels according IMO standards. This is the following:

Power	Weighing factor
25 %	0.15
50 %	0.15
75 %	0.50
100 %	0.2

- The specific fuel consumption is based on the fuel rack diagram given below. Although this is higher than the fuel consumption according to the test bed results, it is a good indication of the relative difference in fuel consumption, assuming equal conditions of the fuel pumps.
- Besides the E2 average results, the difference of the 75 % power level is presented, since this is the most identical test.

Discussion of results

- The lack of full repeatability is the largest factor of uncertainty. Since the engine power levels are not equal in both cases, a straight forward comparison is difficult to present.
- Emission results are therefore normalized to [g/kWh]. The total engine power is the most determining factor and this is not available as a signal that can be logged.
- The SO_2 readings are not interesting, since XBee cannot reduce this component and it takes a long time for this component to stabilize.
- The E2 weighing is not fully correct, since the actual power levels during the verification test are higher than 25 %, 50 % and 100 %. Since specific fuel consumption and NO_x production is higher at low powers, the reference test thus gives a higher weighted average fuel consumption and NO_x production.
- Normally, it is to expect that the specific fuel consumption and the CO_2 change in the same manner. However, the CO_2 reduction is about 0.7 % smaller than the fuel reduction. This can indicate that more fuel is combusted to CO_2, causing less CO and less remaining hydrocarbons.
- NO_x formation is highly dependable on the humidity of the air. The humidity, temperature and pressure of the ambient air measured by the weather station are used to correct the readings to the IMO standard. A difference of a few percent in relative humidity also changes the corrected NO_x levels with a few percent. However, the reductions measured are quite high, thus there is reason to believe that a part of this reduction is the effect of XBee. E.g. peak temperatures in the cylinder can cause high NO_x levels. If e.g. a more smooth combustion occurs, the NO_x levels might be reduced.
- The bunkered fuel is practically equal. The calculated heating value of the fuel used during the verification test is just slightly lower, the difference is less than 1 %. Therefore, it is decided not to perform an extensive calorific test on the fuel sample of the verification test.
- The comparison table shows that a great reduction of CO is measured in combination with a reduction in specific fuel consumption and specific NO_x.
- The precision of the results is not high enough to fully trust the results. However, since the results for all power levels are consistent (reduction of CO, NO_x, fuel) and the accuracy can affect the results both negatively and positively, there is reason to consider that XBee can improve the combustion process, with the large measured reduction in CO at all power levels as the clearest indication.

Break-even point fuel price

Considering a certain fuel reduction and a price per litre of XBee, a break-even point of the fuel price can be determined using the next balance:

$$\eta_{XBee} \bullet \rho \bullet P_{fuel} = \lambda \bullet P_{XBee}$$

With:

η relative fuel reduction factor
ρ density of marine diesel oil ≈ 835 [MT/m^3]
P_{fuel} MDO price [$/MT]
λ volume mixing ratio XBee/fuel = 1/4000
P_{XBee} XBee price [$/m^3]

Assuming that a 1.4 % fuel reduction can be achieved, which was observed at 75 % power, the break-even point for the price of marine diesel can be determined once the price of XBee is known. The market price for a 208 L barrel of XBee is € 4549.-. Working with the US dollar, this leads to a realistic bulk price of $ 30,000 per m^3.

Example:

η 0.014
λ 1/4000
ρ 835 MT/m^3
P_{XBee} $ 30,000 / m^3

Break-even price fuel:

$$P_{fuel\_break-even} = \frac{\lambda \bullet P_{XBee}}{\eta \bullet \rho} = \frac{(1/4000) \bullet 30000}{0.014 \bullet 0.835} = \$\ 642.-$$

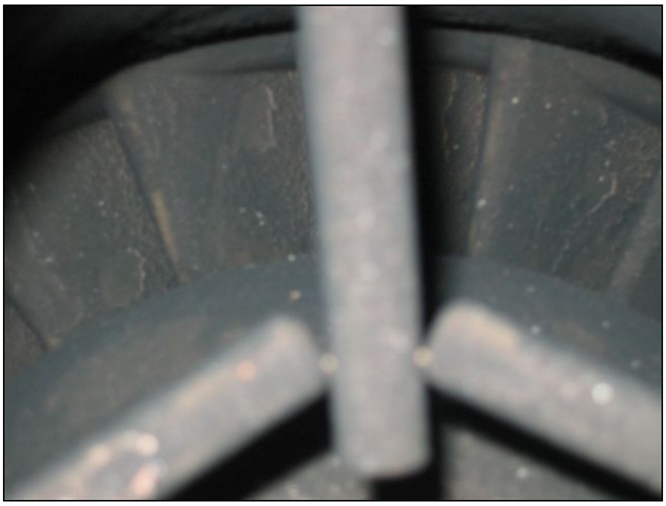
Thus, assuming the above fuel reduction, XBee can reduce fuel costs when the price for a bunkered metric ton of MDO is above $ 642.-.

Turbine and fuel injector inspection

Turbine

Turbine with XBee

Turbine detail



Turbine detail with XBee

Fuel injector

Fuel injector with XBee

Based on the images above and the opinion from the Chief Engineer, the engine does not seem to be in a cleaner condition than during the reference test.

Conclusions

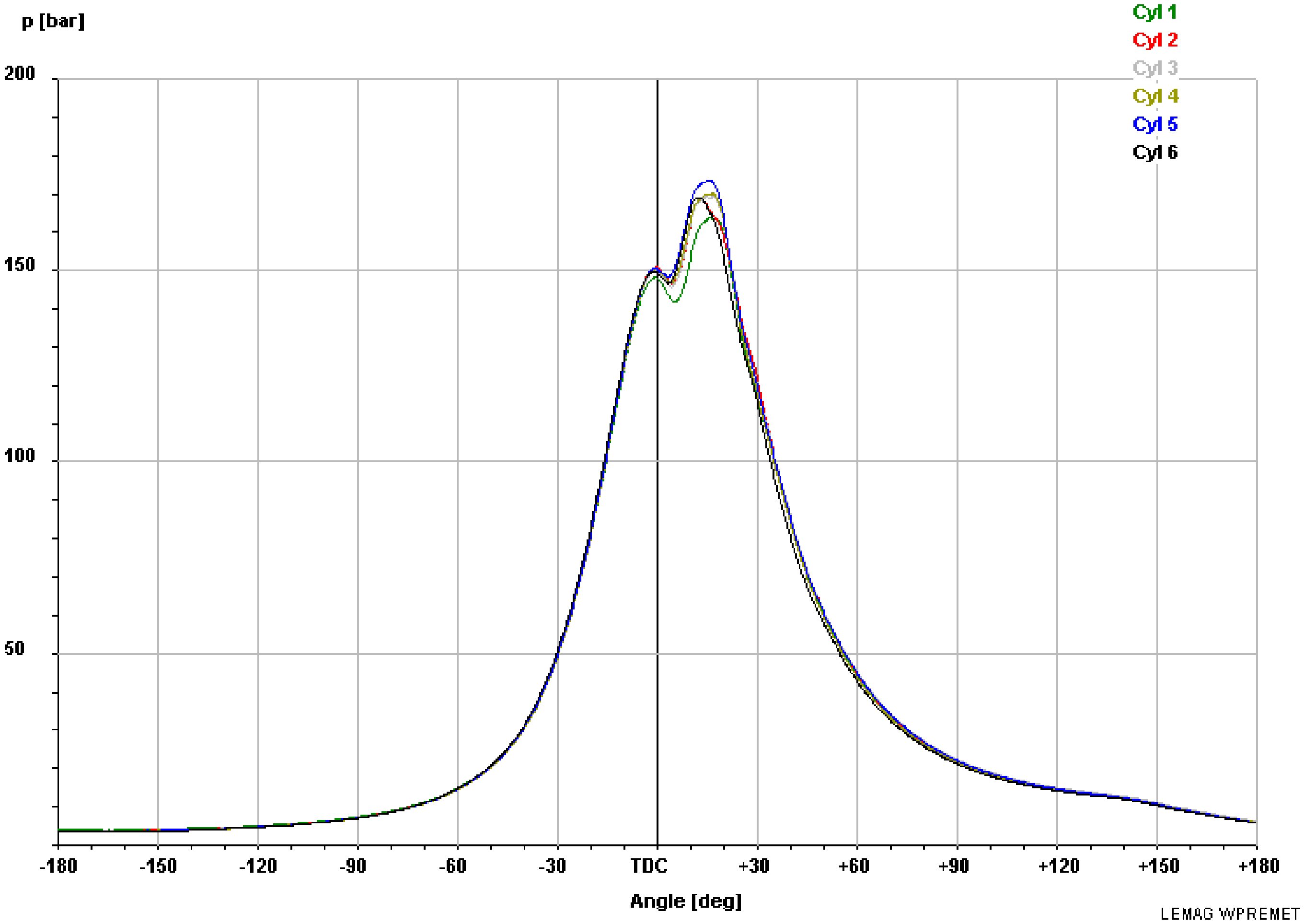
- Although the accuracy and repeatability of the performed tests is not fully satisfactory, the measurements indicate that the fuel additive XBee affects the engine performance in a positive manner.
- A large decrease of CO at all power levels is measured.
- The measured reduction of NO_x is significant, however this is a difficult component dependant on many variables, amongst others ambient conditions. A standard conversion has been applied to correct for these circumstances.
- The observed reduction in specific fuel consumption is questionable due to the accuracy of the measured power, fuel rack and fuel pump characteristics. However, the measurements also show that more CO_2 per MT fuel and less CO is produced, which can indicate that the fuel combusts more efficiently.
- The inspection of the turbine and fuel injectors do not clearly point out that the engine is cleaner.
- Assuming that the price of XBee is about $ 30,000.- per m^3 and that a reduction in fuel consumption of about 1.4 % can be achieved, XBee becomes financially attractive when the price for a delivered MT of MDO is higher than $ 642.-.

The next pages show the recorded engine performance data, emission data reports and fuel specifications.

Premet results

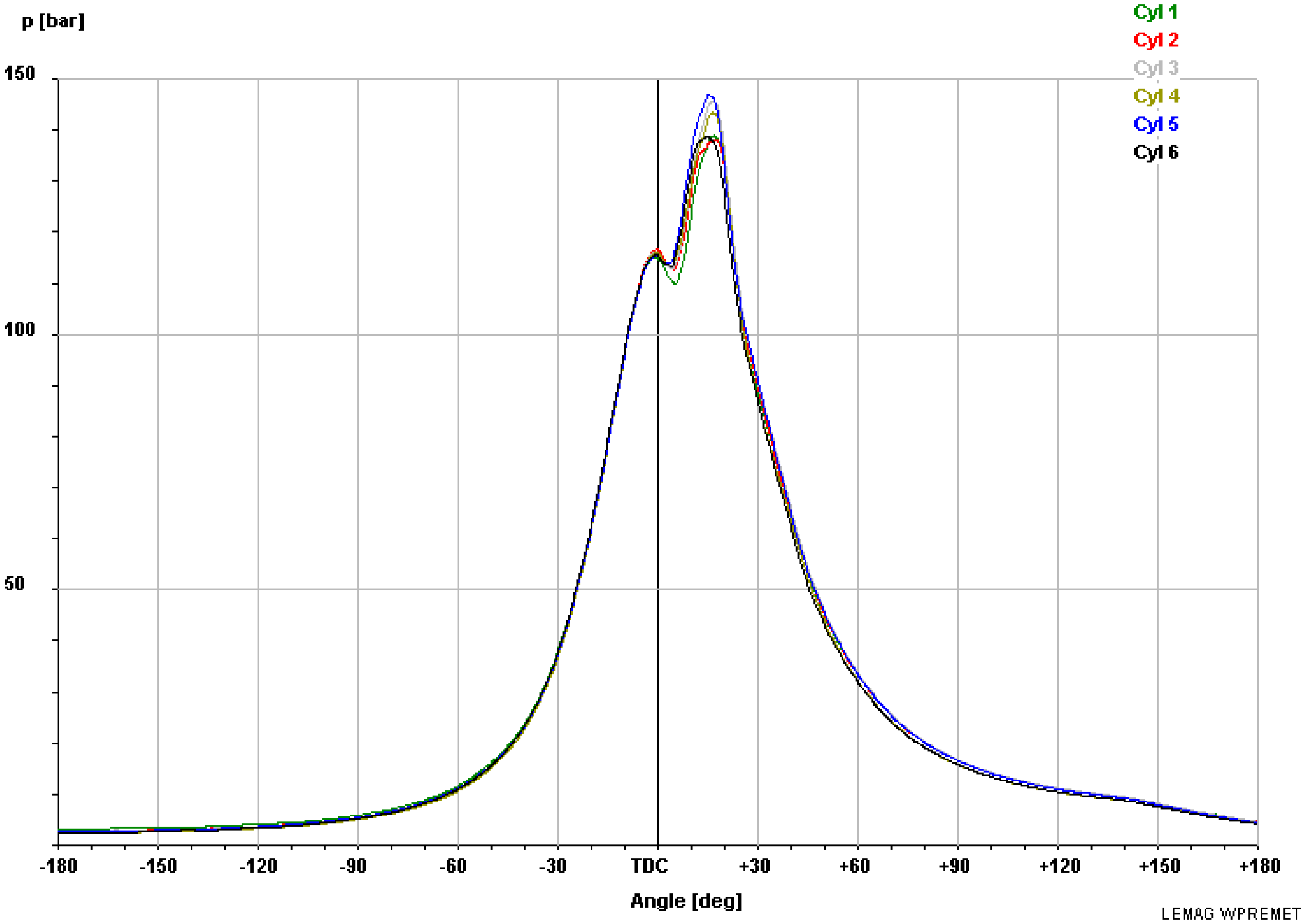
Reference test

100 %



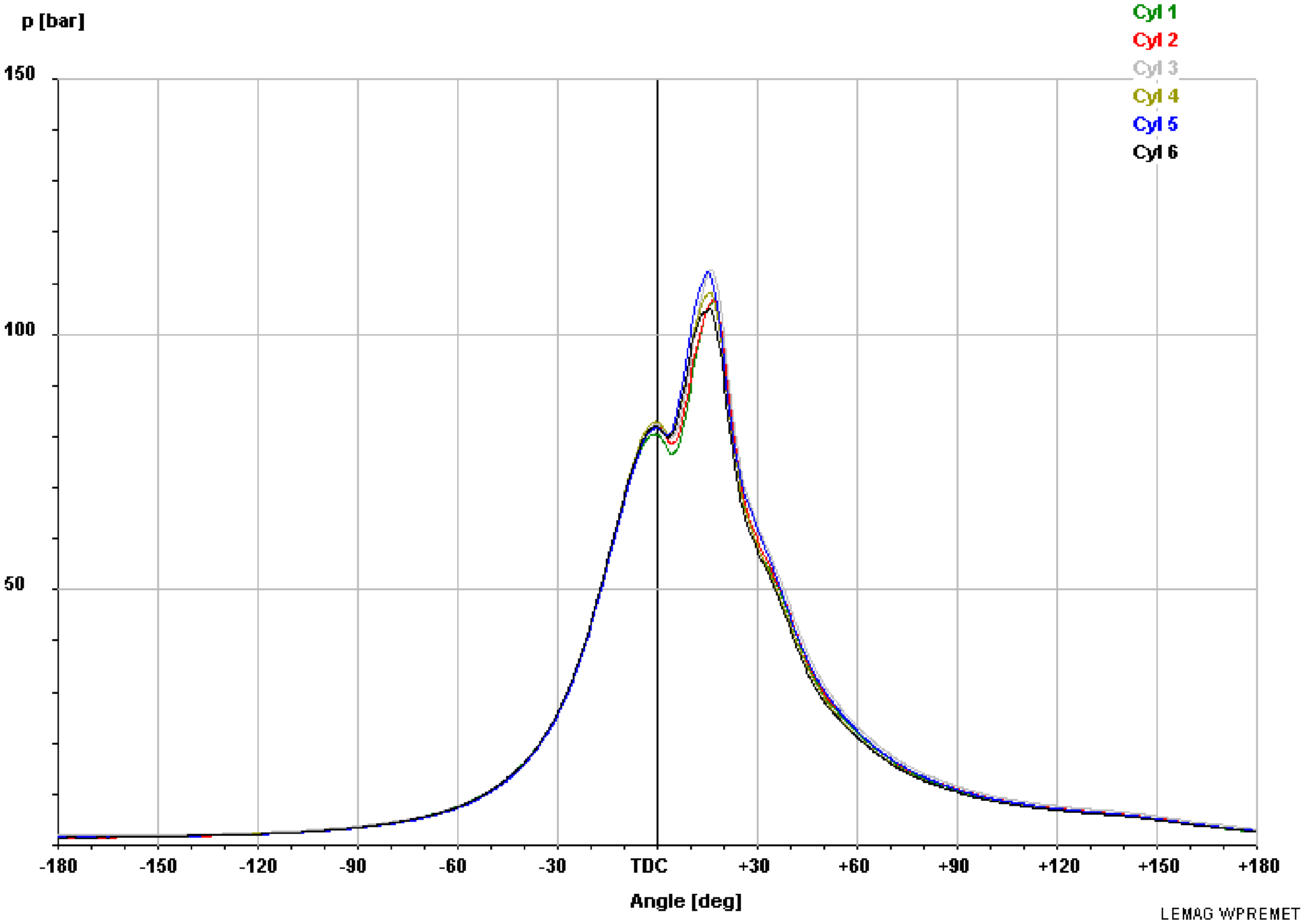
CYL	pTDC [bar]	pmax mean [bar]	apmax [deg]	pexp [bar]	pscav [bar]	rpm [1/min]	MIP [bar]	Pind [kW]	Texh [°C]	Frack	VIT
1	147.9	164.0	16.0	97.2	2.40	751	24.4	429	458	44.0	0.0
2	150.8	169.0	13.3	98.2	2.40	750	25.1	442	455	45.0	0.0
3	149.8	170.0	17.0	98.6	2.40	749	25.6	449	464	44.0	0.0
4	150.2	171.0	16.8	96.8	2.40	749	24.7	434	437	44.0	0.0
5	150.3	174.0	16.0	98.4	2.40	749	25.4	446	450	43.0	0.0
6	149.3	169.0	12.8	92.7	2.40	750	23.3	410	439	43.0	0.0
Mean	149.7	169.5	15.3	97.0	2.40	749.7	24.8	435	450.5	43.8	0.0
Psum								2610	Load = 95.0 %		

75 %



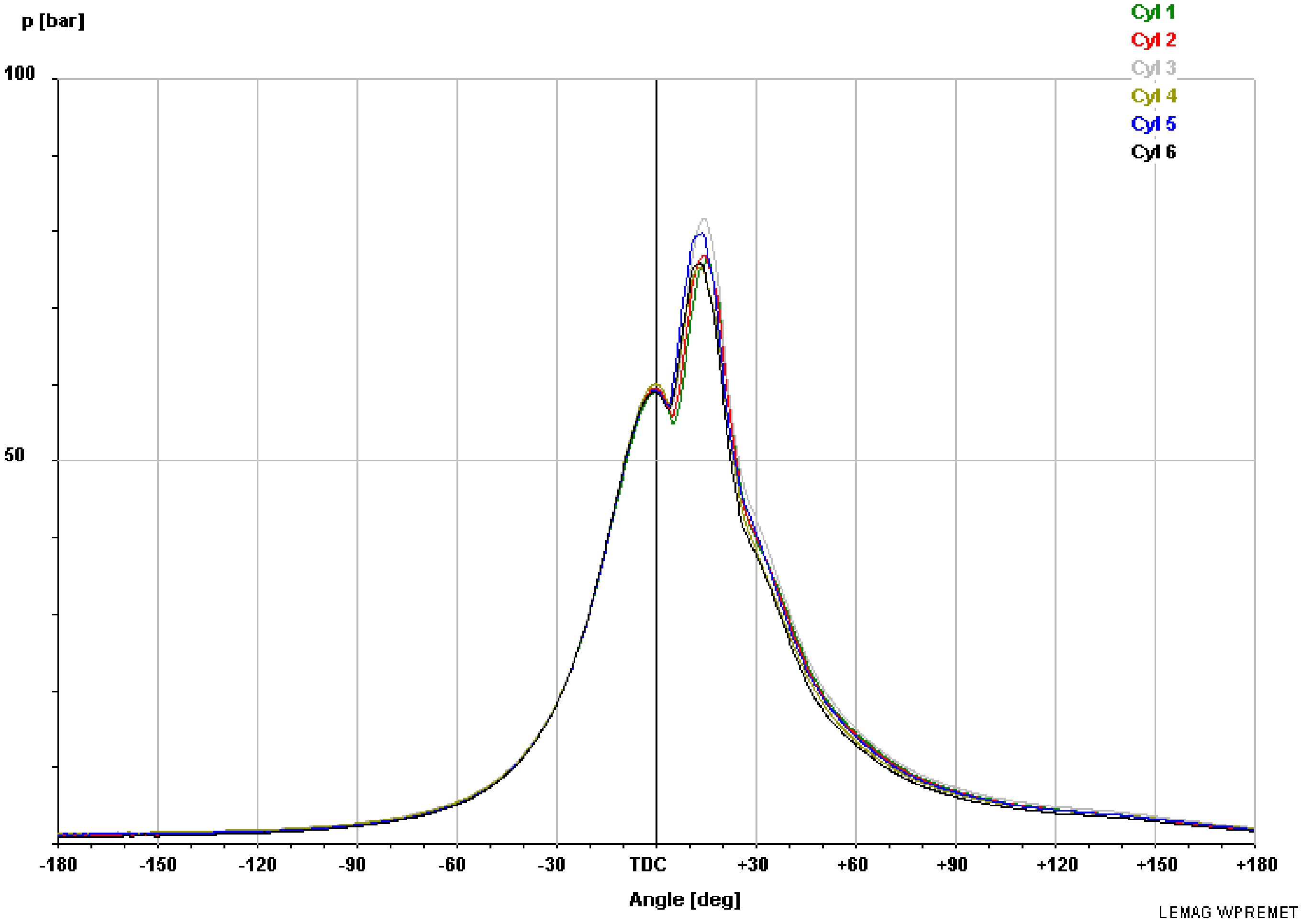
CYL	pTDC [bar]	pmax mean [bar]	apmax [deg]	pexp [bar]	pscav [bar]	rpm [1/min]	MIP [bar]	Pind [kW]	Texh [°C]	Frack	VIT
1	114.9	140.0	17.0	74.3	1.65	750	18.6	328	428	35.0	0.0
2	116.6	139.0	16.3	74.0	1.65	750	19.2	337	427	36.0	0.0
3	116.1	146.0	16.8	75.8	1.65	749	19.8	348	433	35.0	0.0
4	116.0	144.0	16.8	72.6	1.65	750	18.8	331	402	36.0	0.0
5	115.3	148.0	15.5	75.1	1.65	750	19.5	343	417	34.0	0.0
6	115.4	140.0	15.0	71.5	1.65	749	18.1	318	408	34.0	0.0
Mean	115.7	142.8	16.2	73.9	1.65	749.7	19.0	334	419.2	35.0	0.0
Psum								2005	Load = 75.0 %		

50 %



CYL	pTDC [bar]	pmax mean [bar]	apmax [deg]	pexp [bar]	pscav [bar]	rpm [1/min]	MIP [bar]	Pind [kW]	Texh [°C]	Frack	VIT
1	80.4	107.0	17.0	50.7	0.85	750	12.8	224	392	27.0	0.0
2	81.8	108.0	17.0	51.3	0.85	749	13.2	232	393	27.0	0.0
3	82.4	113.0	16.3	53.4	0.85	749	14.0	247	399	27.0	0.0
4	82.9	109.0	16.0	49.6	0.85	750	12.6	221	361	26.0	0.0
5	81.7	113.0	15.3	51.9	0.85	749	13.5	238	381	27.0	0.0
6	82.0	106.0	16.3	49.2	0.85	750	12.1	213	364	26.0	0.0
Mean	81.8	109.3	16.3	51.0	0.85	749.5	13.0	229	381.7	26.7	0.0
Psum								1375	Load = 50.0 %		

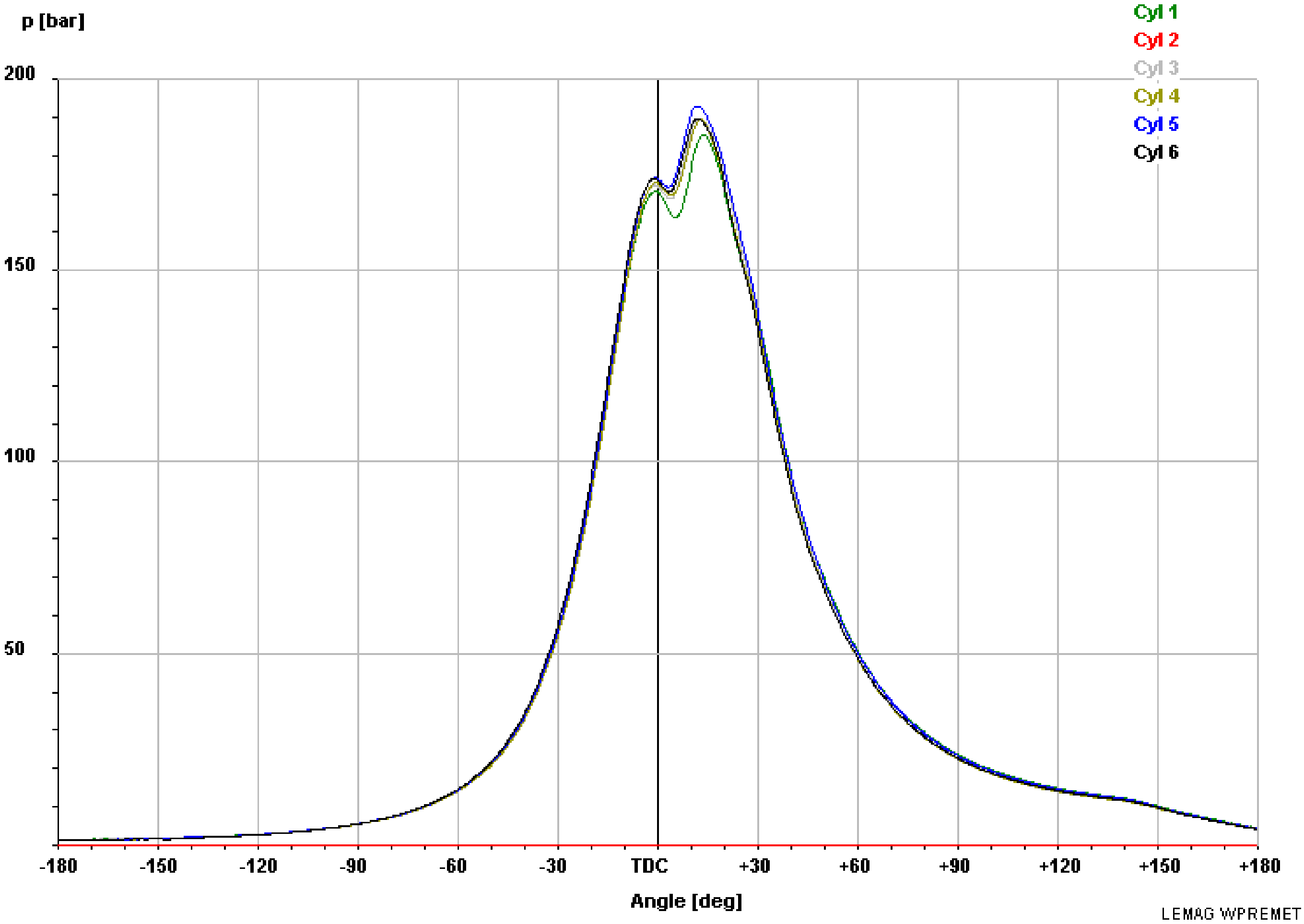
25 %



CYL	pTDC [bar]	pmax mean [bar]	apmax [deg]	pexp [bar]	pscav [bar]	rpm [1/min]	MIP [bar]	Pind [kW]	Texh [°C]	Frack	VIT
1	59.1	76.0	15.5	34.1	0.30	750	8.2	144	350	18.0	0.0
2	59.6	77.0	14.5	33.7	0.30	750	8.1	142	350	19.0	0.0
3	60.1	82.0	14.5	35.4	0.30	749	8.8	154	351	18.0	0.0
4	60.1	75.0	13.0	31.8	0.30	750	7.4	130	308	18.0	0.0
5	59.3	80.0	13.8	33.2	0.30	750	8.1	142	328	18.0	0.0
6	59.1	76.0	13.3	31.3	0.30	749	7.2	126	306	17.0	0.0
Mean	59.5	77.7	14.1	33.2	0.30	749.7	8.0	140	332.2	18.0	0.0
Psum								838	Load = 25.0 %		

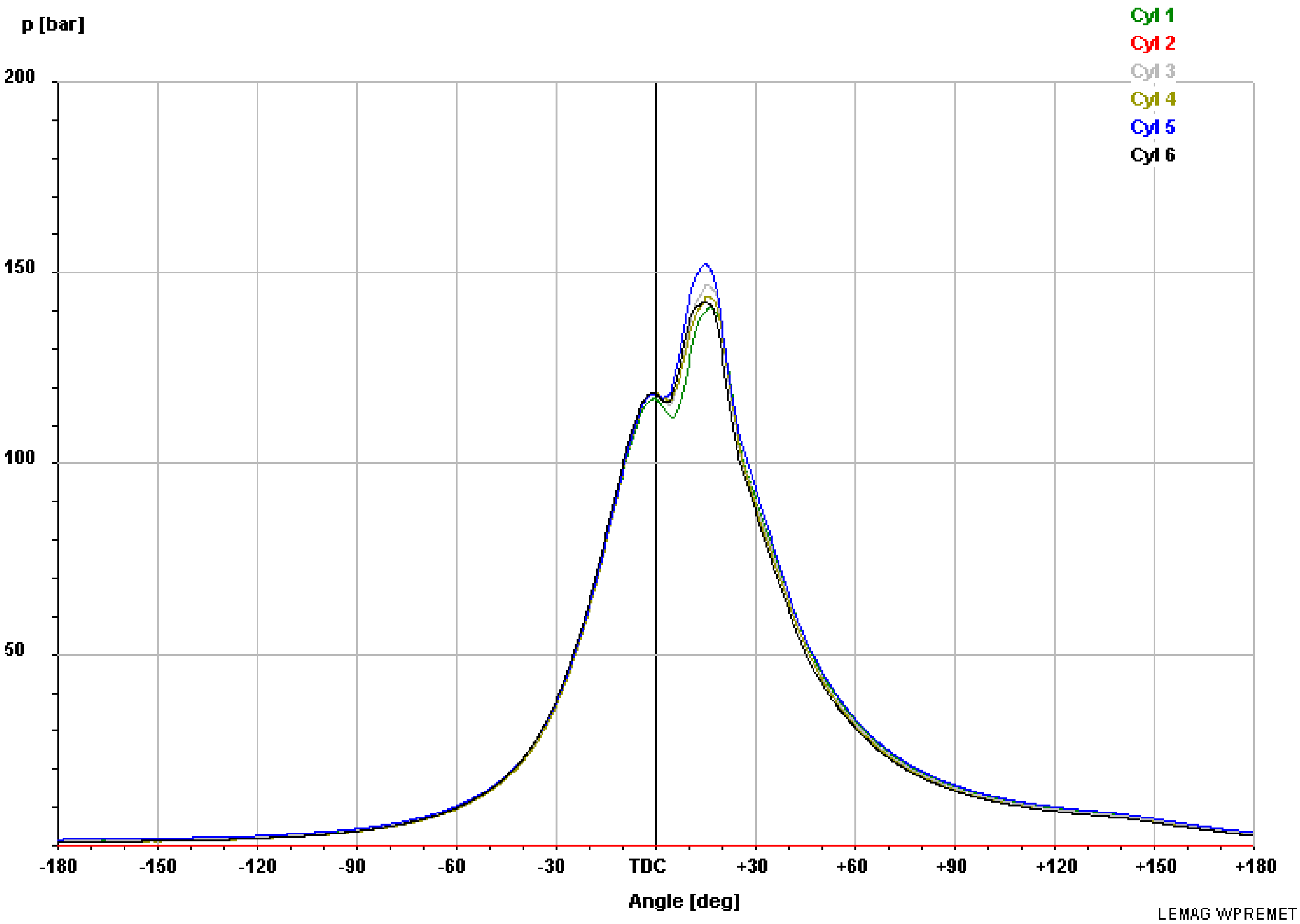
Verification test

100 %



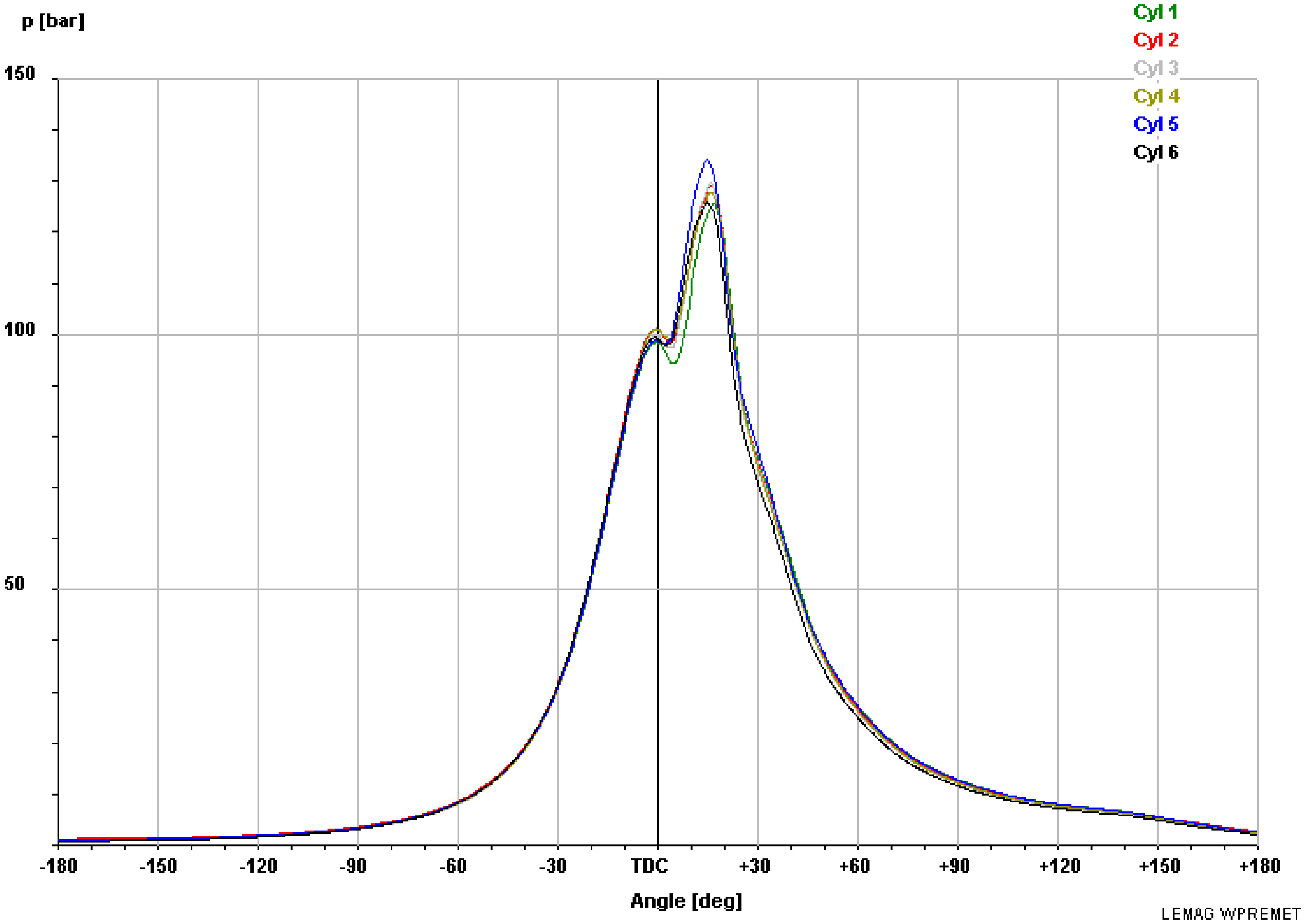
CYL	pTDC [bar]	pmax mean [bar]	apmax [deg]	pexp [bar]	pscav [bar]	rpm [1/min]	MIP [bar]	Pind [kW]	Texh [°C]	Frack	VIT
1	170.5	186.0	13.8	112.7	0.10	750	29.5	518	463	50.0	0.0
2	0.0	0.0	13.8	0.0	0.10	0.0	0.0	0	448	50.0	0.0
3	172.0	190.0	12.3	110.5	0.10	749	28.6	503	465	49.0	0.0
4	172.8	190.0	13.3	109.4	0.10	750	28.4	500	442	50.0	0.0
5	173.9	193.0	11.8	111.7	0.10	749	29.4	517	462	50.0	0.0
6	173.5	190.0	12.3	108.2	0.10	749	27.8	488	453	49.5	0.0
Mean	143.8	158.2	12.8	92.1	0.10	624.5	23.9	421	455.5	49.8	0.0
Psum								2526	Load = 100.0 %		

75 %



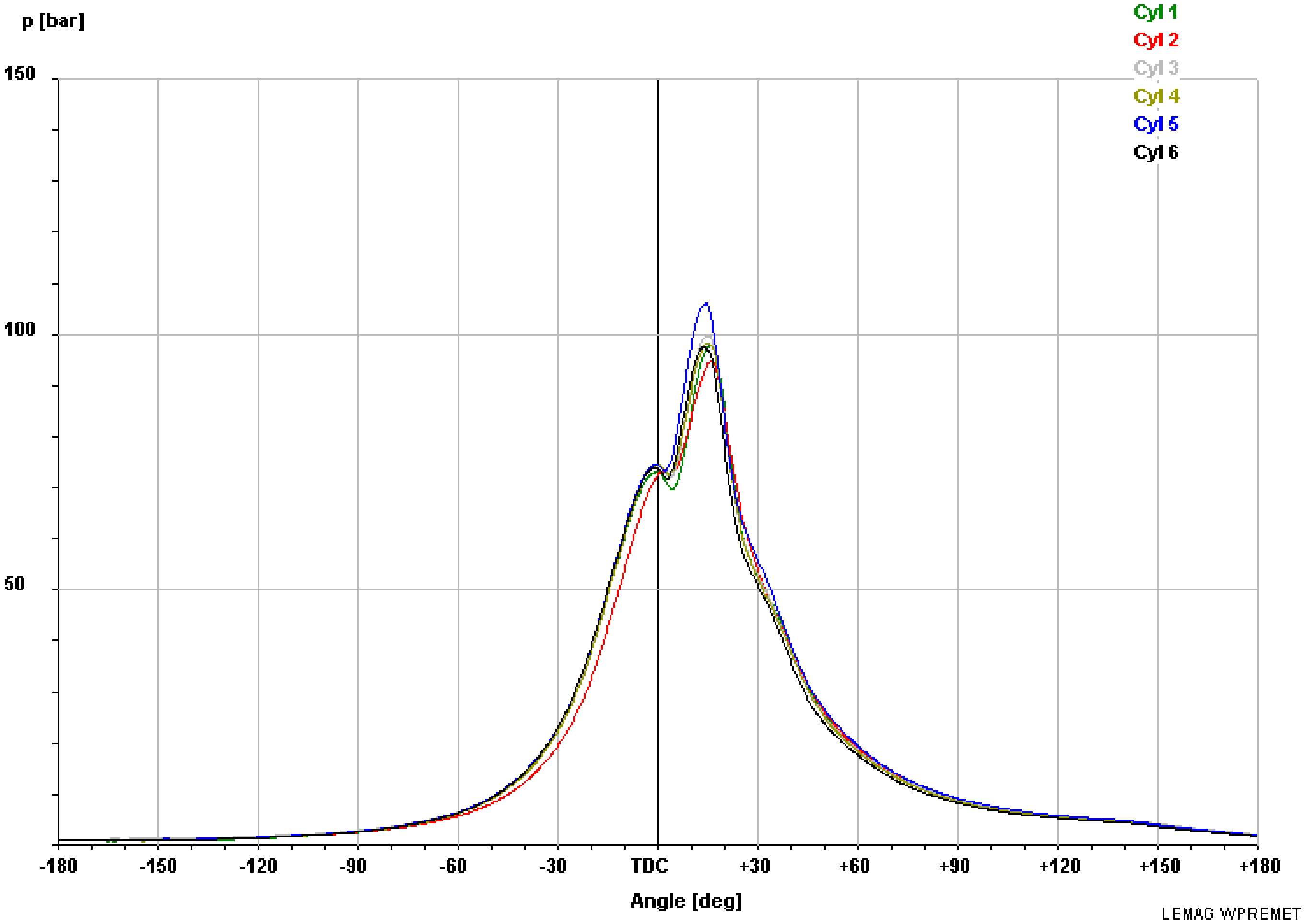
CYL	pTDC [bar]	pmax mean [bar]	apmax [deg]	pexp [bar]	pscav [bar]	rpm [1/min]	MIP [bar]	Pind [kW]	Texh [°C]	Frack	VIT
1	116.9	141.0	16.5	75.5	0.10	750	19.6	345	410	35.0	0.0
2	0.0	0.0	16.5	0.0	0.10	0.0	0.0	0	401	33.5	0.0
3	118.3	147.0	15.8	74.3	0.10	749	19.4	340	407	33.5	0.0
4	118.7	144.0	15.8	73.1	0.10	750	19.1	336	392	35.5	0.0
5	118.2	153.0	15.3	76.5	0.10	749	20.1	354	410	34.0	0.0
6	118.3	143.0	14.8	71.4	0.10	749	18.1	319	396	33.5	0.0
Mean	98.4	121.3	15.8	61.8	0.10	624.5	16.0	282	402.7	34.2	0.0
Psum								1694	Load = 75.0 %		

50 %



CYL	pTDC [bar]	pmax mean [bar]	apmax [deg]	pexp [bar]	pscav [bar]	rpm [1/min]	MIP [bar]	Pind [kW]	Texh [°C]	Frack	VIT
1	98.3	126.0	17.3	64.0	0.10	750	16.6	292	403	28.5	0.0
2	101.0	130.0	16.3	63.0	0.10	749	16.0	282	388	28.5	0.0
3	99.8	130.0	16.3	62.5	0.10	749	16.1	283	388	28.0	0.0
4	101.0	128.0	16.3	62.0	0.10	749	16.1	283	382	30.0	0.0
5	98.8	135.0	15.3	63.8	0.10	749	16.8	295	400	28.5	0.0
6	99.1	126.0	15.3	59.1	0.10	750	14.8	260	386	28.0	0.0
Mean	99.7	129.2	16.1	62.4	0.10	749.3	16.1	282	391.2	28.6	0.0
Psum								1695	Load = 50.0 %		

25 %



CYL	pTDC [bar]	pmax mean [bar]	apmax [deg]	pexp [bar]	pscav [bar]	rpm [1/min]	MIP [bar]	Pind [kW]	Texh [°C]	Frack	VIT
1	73.0	98.0	16.3	45.0	0.10	750	11.4	201	367	21.0	0.0
2	72.6	95.0	16.3	44.4	0.10	750	12.2	215	353	21.0	0.0
3	74.4	100.0	15.3	44.4	0.10	749	11.1	196	344	20.5	0.0
4	74.6	99.0	14.5	43.8	0.10	750	11.1	195	350	22.0	0.0
5	74.5	106.0	15.0	46.1	0.10	749	11.8	208	369	21.0	0.0
6	73.8	98.0	13.8	42.6	0.10	750	10.2	180	349	20.5	0.0
Mean	73.8	99.3	15.2	44.4	0.10	749.7	11.3	199	355.3	21.0	0.0
Psum								1195	Load = 25.0 %		

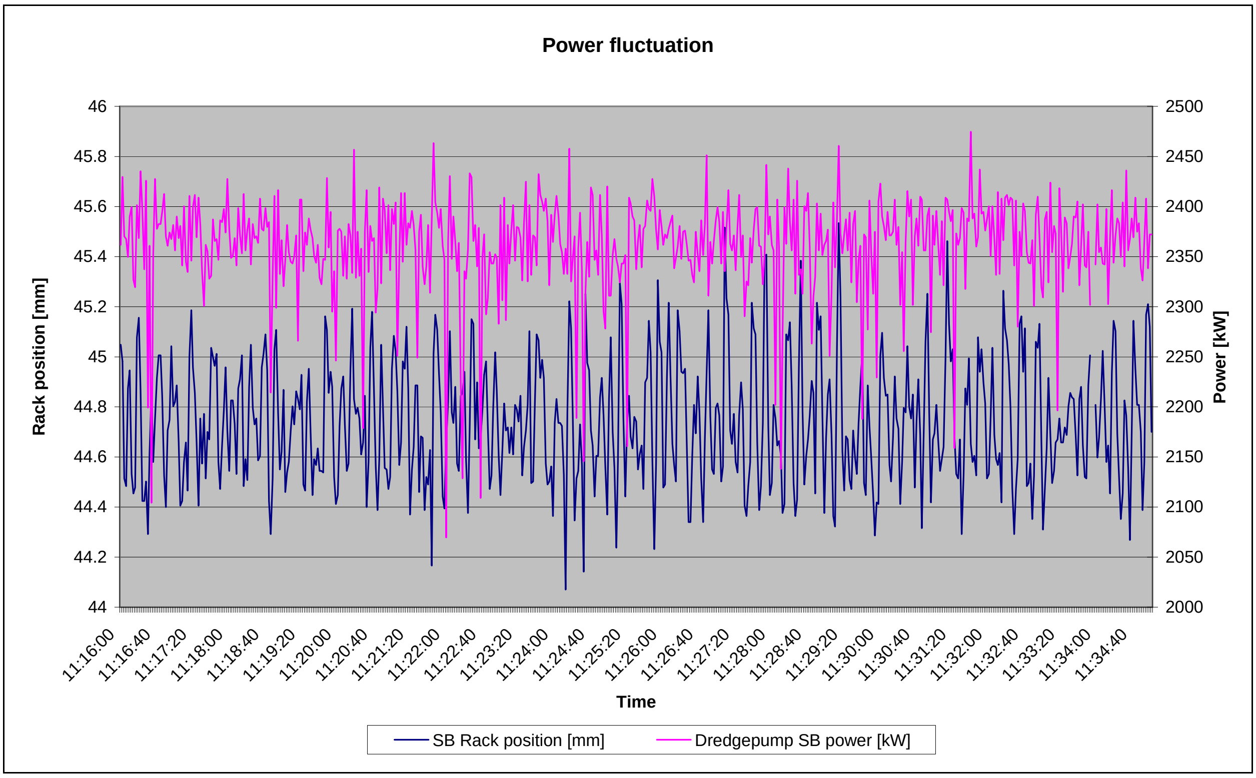
Remarks

Cylinder 2 has not been measured during the 75 % and 100 % load, due to possible damage on the sampling point. However, as can be seen from the 25 % and 50 % load, this cylinder performs the same as cylinder 3, thus the power of cylinder 3 has been added twice.

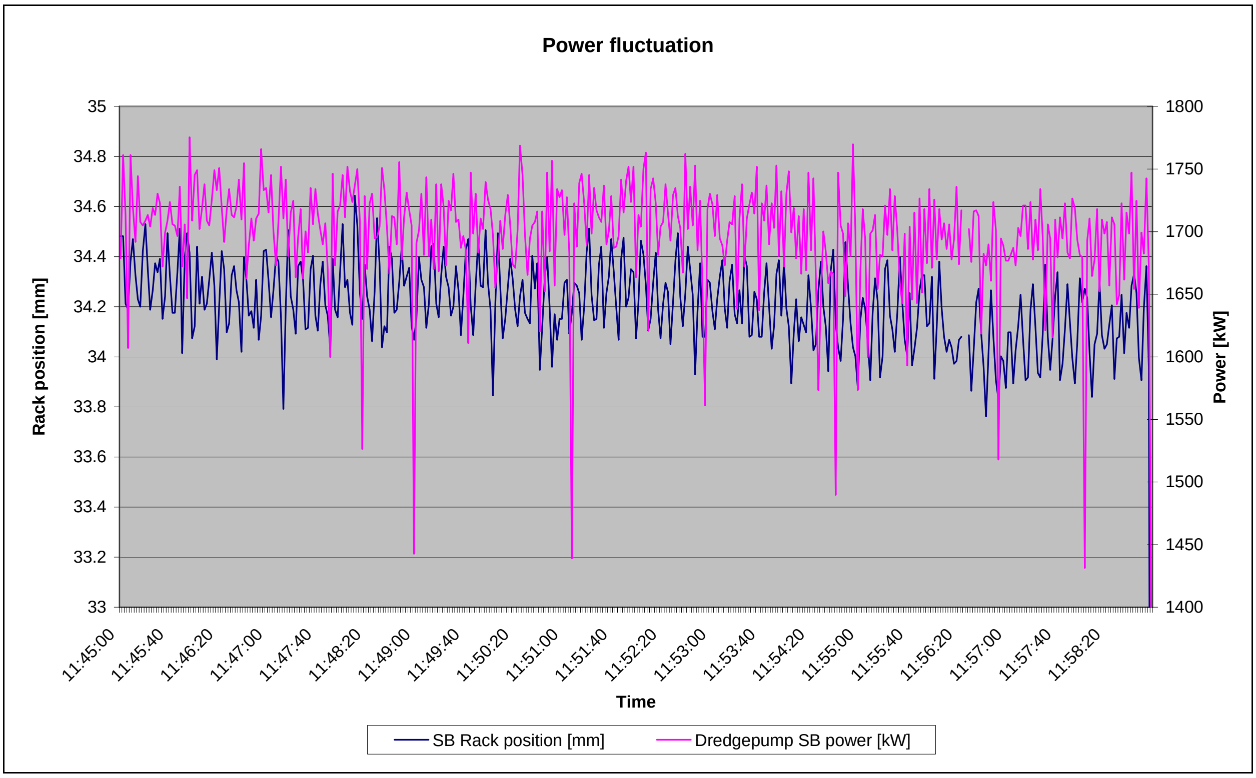
Result of the logging of fuelrack and dredgepump power

Reference test

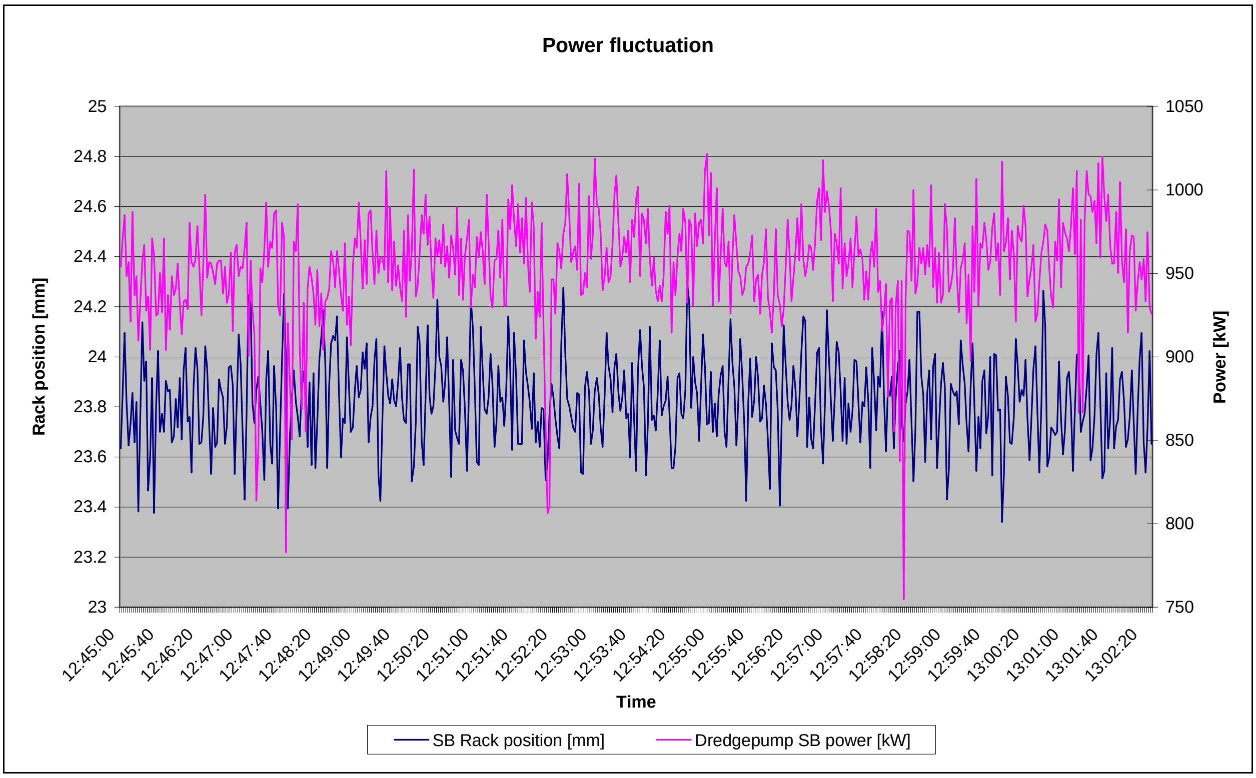
100 %



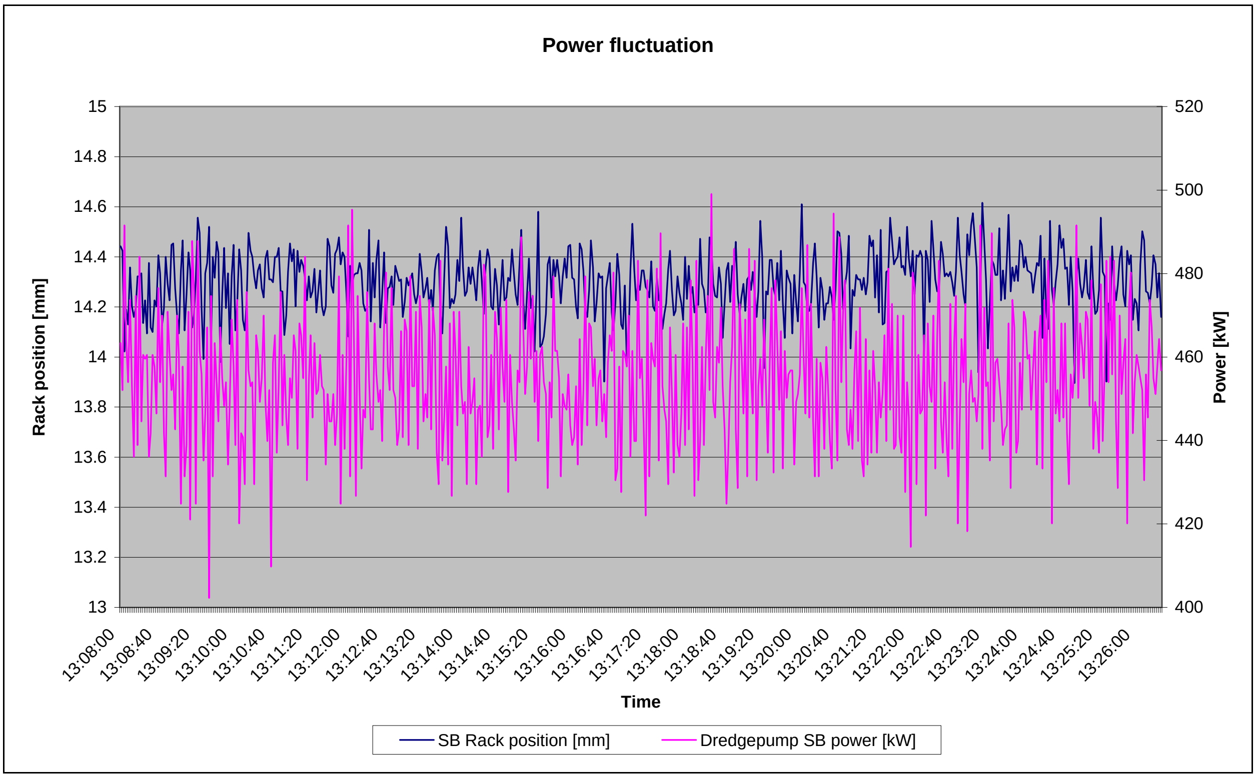
75 %



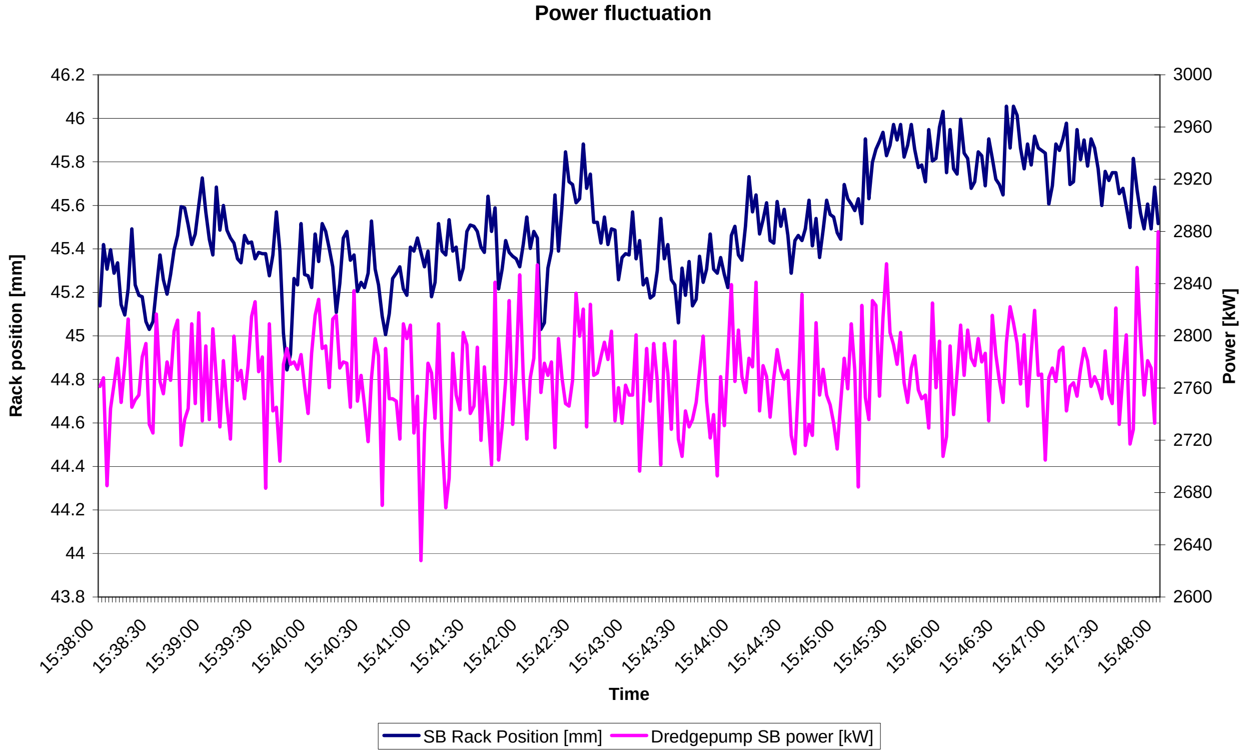
50 %


Power fluctuation
Rack position [mm]
Power [kW]
25
24.8
24.6
24.4
24.2
24
23.8
23.6
23.4
23.2
23
1050
1000
950
900
850
800
750
12:45:00
12:45:40
12:46:20
12:47:00
12:47:40
12:48:20
12:49:00
12:49:40
12:50:20
12:51:00
12:51:40
12:52:20
12:53:00
12:53:40
12:54:20
12:55:00
12:55:40
12:56:20
12:57:00
12:57:40
12:58:20
12:59:00
12:59:40
13:00:20
13:01:00
13:01:40
13:02:20
Time
SB Rack position [mm]
Dredgepump SB power [kW]

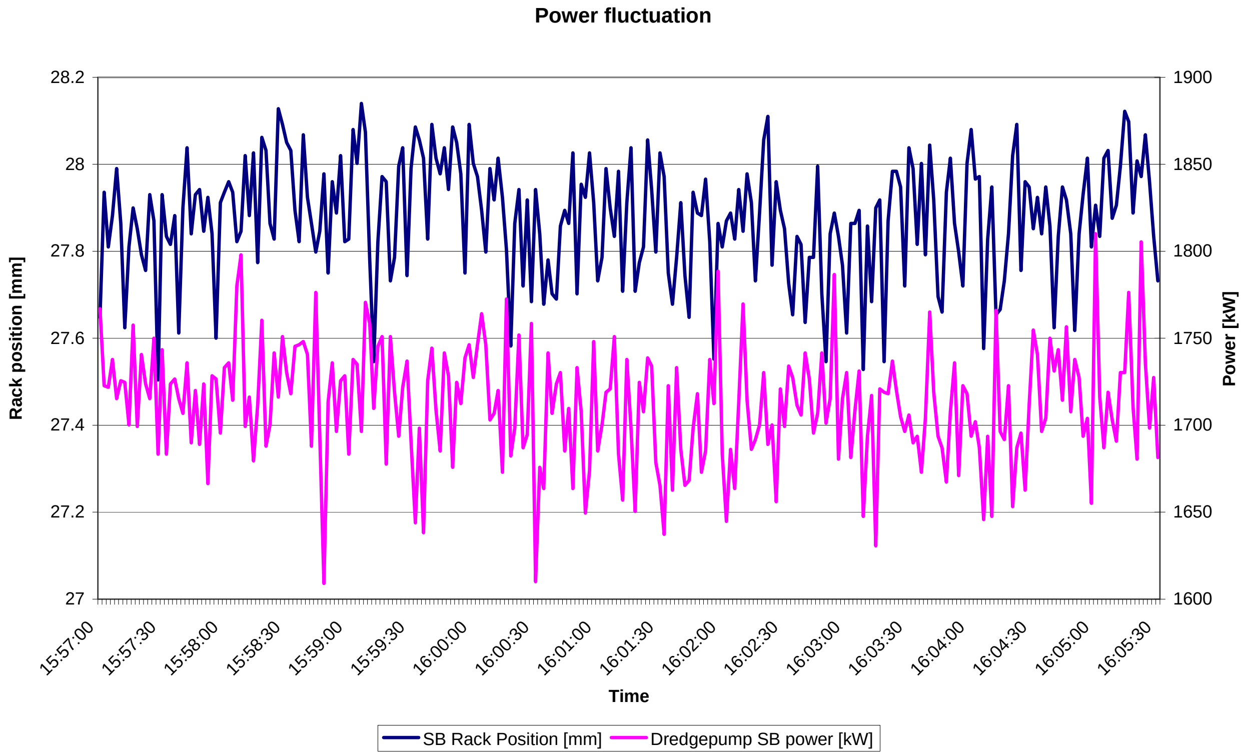
25 %


Power fluctuation
Rack position [mm]
Power [kW]
15
14.8
14.6
14.4
14.2
14
13.8
13.6
13.4
13.2
13
520
500
480
460
440
420
400
13:08:00
13:08:40
13:09:20
13:10:00
13:10:40
13:11:20
13:12:00
13:12:40
13:13:20
13:14:00
13:14:40
13:15:20
13:16:00
13:16:40
13:17:20
13:18:00
13:18:40
13:19:20
13:20:00
13:20:40
13:21:20
13:22:00
13:22:40
13:23:20
13:24:00
13:24:40
13:25:20
13:26:00
Time
SB Rack position [mm]
Dredgepump SB power [kW]

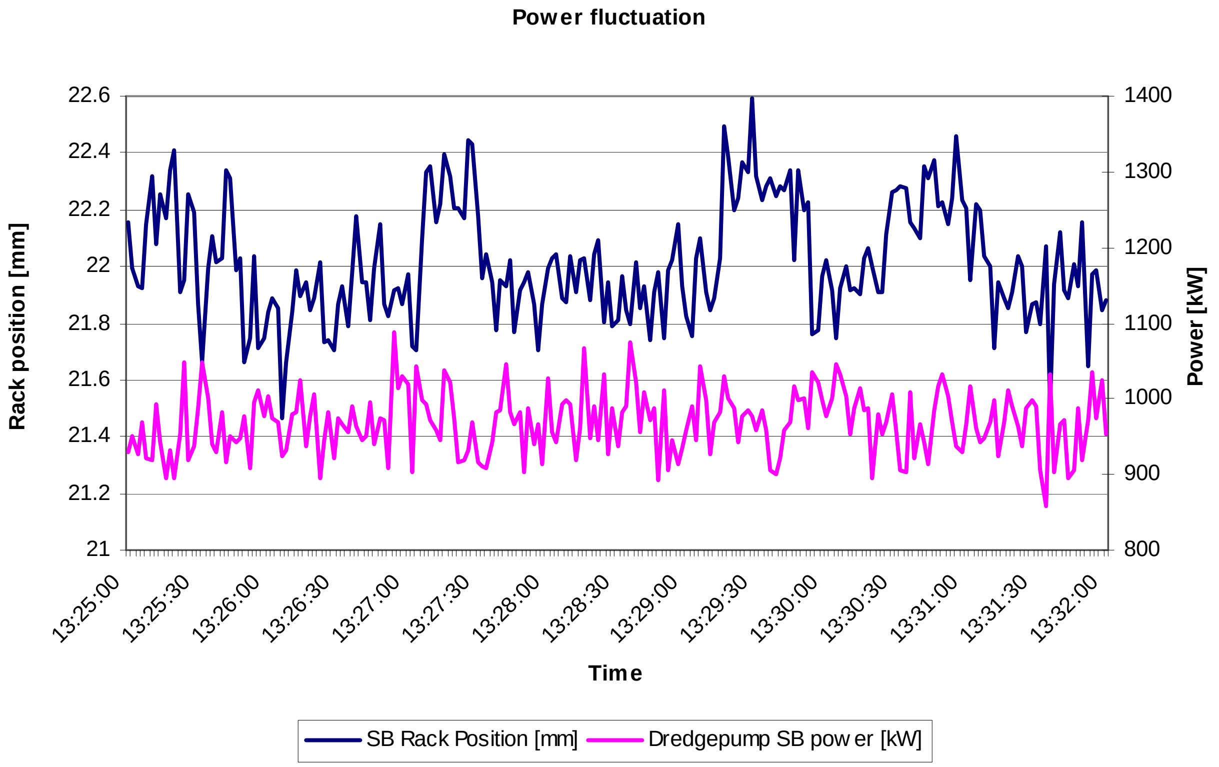
Verification test
100 %



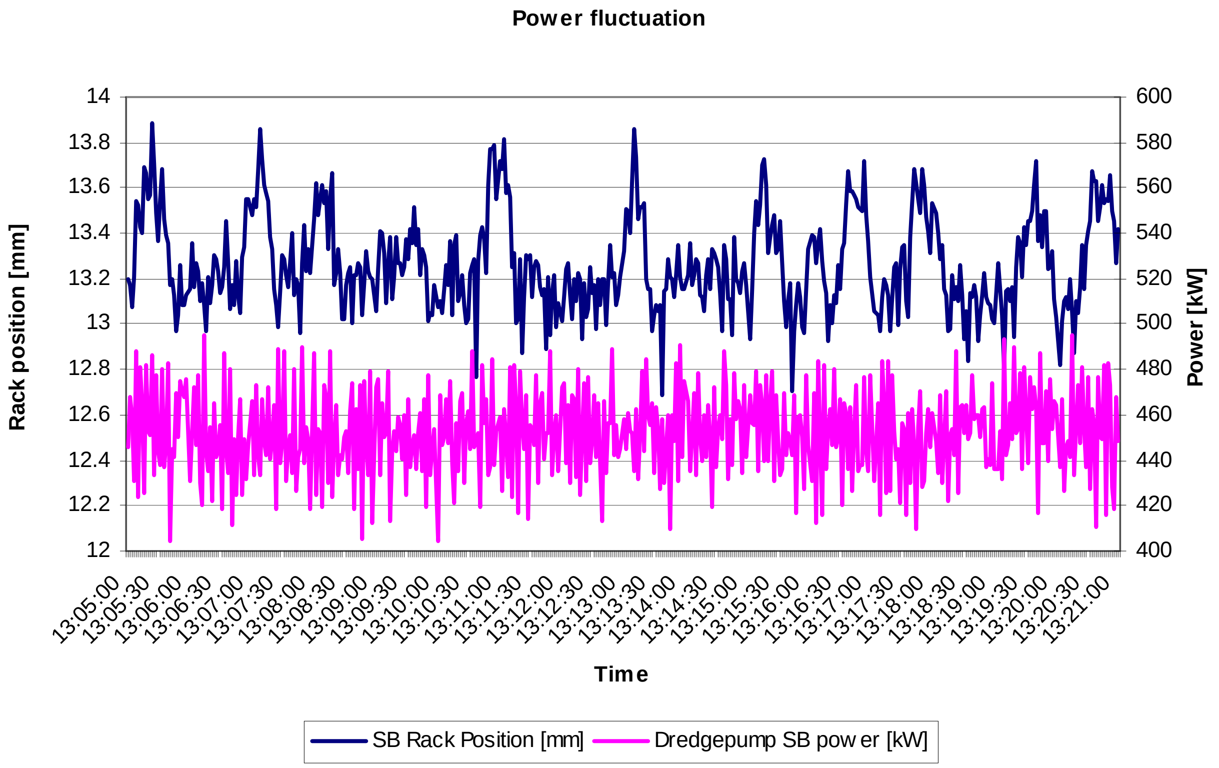
75 %



50 %


Power fluctuation
22.6
22.4
22.2
22
21.8
21.6
21.4
21.2
21
Rack position [mm]
1400
1300
1200
1100
1000
900
800
Power [kW]
13:25:00
13:25:30
13:26:00
13:26:30
13:27:00
13:27:30
13:28:00
13:28:30
13:29:00
13:29:30
13:30:00
13:30:30
13:31:00
13:31:30
13:32:00
Time
SB Rack Position [mm]
Dredgepump SB power [kW]

25 %


Power fluctuation
14
13.8
13.6
13.4
13.2
13
12.8
12.6
12.4
12.2
12
Rack position [mm]
600
580
560
540
520
500
480
460
440
420
400
Power [kW]
13:05:00
13:05:30
13:06:00
13:06:30
13:07:00
13:07:30
13:08:00
13:08:30
13:09:00
13:09:30
13:10:00
13:10:30
13:11:00
13:11:30
13:12:00
13:12:30
13:13:00
13:13:30
13:14:00
13:14:30
13:15:00
13:15:30
13:16:00
13:16:30
13:17:00
13:17:30
13:18:00
13:18:30
13:19:00
13:19:30
13:20:00
13:20:30
13:21:00
Time
SB Rack Position [mm]
Dredgepump SB power [kW]

Engine parameters
Reference test
100 %

Cylinder	Fuelrack	Average exh. temp.	Cylinder liner temp.	Main bearing temp.
[-]	[mm]	[ºC]	[ºC]	[ºC]
				83
1	44.5	460	140	89
2	45	454	141	90
3	44.5	464	142	91
4	45	436	135	93
5	44.5	449	142	91
6	44	440	143	90
				89
Average	45	451	141	90

Fuel oil temp.	50	[ºC]
Fuel oil pressure	4.9	[bar]

Air intake temp.	41	[ºC]
Charge air temp. after cooler	64	[ºC]
Charge air temp. after compr.	179	[ºC]
Charge air pressure	2.4	[bar]

Exh. gas temp. turbo inlet 1	552	[ºC]
Exh. gas temp. turbo inlet 2	542	[ºC]
Exh. gas temp. turbo outlet	400	[ºC]

Lube oil temp. before cooler	77	[ºC]
Lube oil temp. before engine	66	[ºC]
Lube oil pressure before filter	4.7	[bar]
Lube oil pressure before engine	4.3	[bar]

LT water temp. before engine	46	[ºC]
LT water temp. aft. ch. air cooler	51	[ºC]
LT water pressure before engine	3.0	[bar]

HT water temp. aft. ch. air cooler	97	[ºC]
HT water temp. after engine	91	[ºC]
HT water temp. engine outlet	98	[ºC]
HT water pressure before engine	2.7	[bar]

75 %

Cylinder	Fuelrack	Average exh. temp.	Cylinder liner temp.	Main bearing temp.
[-]	[mm]	[ºC]	[ºC]	[ºC]
				82
1	35	429	123	87
2	36	424	123	88
3	35	431	125	89
4	35	400	122	92
5	34	417	123	89
6	34	407	122	88
				88
Average	35	418	123	88

Fuel oil temp.	50	[ºC]
Fuel oil pressure	5.3	[bar]

Air intake temp.	40	[ºC]
Charge air temp. after cooler	56	[ºC]
Charge air temp. after compr.	145	[ºC]
Charge air pressure	1.65	[bar]

Exh. gas temp. turbo inlet 1	524	[ºC]
Exh. gas temp. turbo inlet 2	513	[ºC]
Exh. gas temp. turbo outlet	409	[ºC]

Lube oil temp. before cooler	76	[ºC]
Lube oil temp. before engine	65	[ºC]
Lube oil pressure before filter	4.7	[bar]
Lube oil pressure before engine	4.4	[bar]

LT water temp. before engine	44	[ºC]
LT water temp. aft. ch. air cooler	49	[ºC]
LT water pressure before engine	3.0	[bar]

HT water temp. aft. ch. air cooler	88	[ºC]
HT water temp. after engine	84	[ºC]
HT water temp. engine outlet	88	[ºC]
HT water pressure before engine	2.6	[bar]

50 %

Cylinder	Fuelrack	Average exh. temp.	Cylinder liner temp.	Main bearing temp.
[-]	[mm]	[ºC]	[ºC]	[ºC]
				80
1	26	391	114	85
2	27	391	114	84
3	25	397	117	85
4	26	360	110	90
5	25	381	115	85
6	24	361	113	83
				85
Average	26	380	114	85

Fuel oil temp.	51	[ºC]
Fuel oil pressure	4.3	[bar]

Air intake temp.	39	[ºC]
Charge air temp. after cooler	49	[ºC]
Charge air temp. after compr.	96	[ºC]
Charge air pressure	0.85	[bar]

Exh. gas temp. turbo inlet 1	488	[ºC]
Exh. gas temp. turbo inlet 2	474	[ºC]
Exh. gas temp. turbo outlet	418	[ºC]

Lube oil temp. before cooler	70	[ºC]
Lube oil temp. before engine	62	[ºC]
Lube oil pressure before filter	4.8	[bar]
Lube oil pressure before engine	4.5	[bar]

LT water temp. before engine	41	[ºC]
LT water temp. aft. ch. air cooler	45	[ºC]
LT water pressure before engine	2.8	[bar]

HT water temp. aft. ch. air cooler	93	[ºC]
HT water temp. after engine	93	[ºC]
HT water temp. engine outlet	93	[ºC]
HT water pressure before engine	2.7	[bar]

25 %

Cylinder	Fuelrack	Average exh. temp.	Cylinder liner temp.	Main bearing temp.
[-]	[mm]	[ºC]	[ºC]	[ºC]
				80
1	17	348	105	84
2	18	349	105	82
3	17.5	351	107	83
4	17.5	306	103	89
5	17	327	105	84
6	16	307	104	81
				85
Average	17	331	105	84

Fuel oil temp.	50	[ºC]
Fuel oil pressure	5.1	[bar]

Air intake temp.	39	[ºC]
Charge air temp. after cooler	46	[ºC]
Charge air temp. after compr.	70	[ºC]
Charge air pressure	0.3	[bar]

Exh. gas temp. turbo inlet 1	436	[ºC]
Exh. gas temp. turbo inlet 2	401	[ºC]
Exh. gas temp. turbo outlet	391	[ºC]

Lube oil temp. before cooler	70	[ºC]
Lube oil temp. before engine	62	[ºC]
Lube oil pressure before filter	4.9	[bar]
Lube oil pressure before engine	4.5	[bar]

LT water temp. before engine	41	[ºC]
LT water temp. aft. ch. air cooler	44	[ºC]
LT water pressure before engine	2.8	[bar]

HT water temp. aft. ch. air cooler	93	[ºC]
HT water temp. after engine	94	[ºC]
HT water temp. engine outlet	94	[ºC]
HT water pressure before engine	2.8	[bar]

Verification test
100 %

Cylinder	Fuelrack	Average exh. temp.	Cylinder liner temp.	Main bearing temp.
[-]	[mm]	[ºC]	[ºC]	[ºC]
				81
1	50	463	144	86
2	50	448	144	88
3	49	465	147	89
4	50	442	139	92
5	50	462	148	90
6	49.5	453	146	89
				87
Average	50	456	145	88

Fuel oil temp.	37	[ºC]
Fuel oil pressure	3.5	[bar]

Air intake temp.	28	[ºC]
Charge air temp. after cooler	65	[ºC]
Charge air temp. after compr.	182	[ºC]
Charge air pressure	2.95	[bar]

Exh. gas temp. turbo inlet 1	553	[ºC]
Exh. gas temp. turbo inlet 2	547	[ºC]
Exh. gas temp. turbo outlet	389	[ºC]

Lube oil temp. before cooler	-	[ºC]
Lube oil temp. before engine	63	[ºC]
Lube oil pressure before filter	4.7	[bar]
Lube oil pressure before engine	4.3	[bar]

LT water temp. before engine	39	[ºC]
LT water temp. aft. ch. air cooler	43	[ºC]
LT water pressure before engine	2.7	[bar]

HT water temp. aft. ch. air cooler	93	[ºC]
HT water temp. after engine	84	[ºC]
HT water temp. engine outlet	93	[ºC]
HT water pressure before engine	2.5	[bar]

75 %

Cylinder	Fuelrack	Average exh. temp.	Cylinder liner temp.	Main bearing temp.
[-]	[mm]	[ºC]	[ºC]	[ºC]
				82
1	35	410	126	87
2	33.5	401	122	87
3	33.5	407	123	88
4	35.5	392	123	91
5	34	410	125	89
6	33.5	396	123	87
				88
Average	34	403	124	87

Fuel oil temp.	37	[ºC]
Fuel oil pressure	3.5	[bar]

Air intake temp.	28	[ºC]
Charge air temp. after cooler	56	[ºC]
Charge air temp. after compr.	135	[ºC]
Charge air pressure	1.65	[bar]

Exh. gas temp. turbo inlet 1	498	[ºC]
Exh. gas temp. turbo inlet 2	498	[ºC]
Exh. gas temp. turbo outlet	390	[ºC]

Lube oil temp. before cooler	75	[ºC]
Lube oil temp. before engine	94	[ºC]
Lube oil pressure before filter	-	[bar]
Lube oil pressure before engine	4.3	[bar]

LT water temp. before engine	39	[ºC]
LT water temp. aft. ch. air cooler	41	[ºC]
LT water pressure before engine	2.6	[bar]

HT water temp. aft. ch. air cooler	92	[ºC]
HT water temp. after engine	84	[ºC]
HT water temp. engine outlet	88	[ºC]
HT water pressure before engine	2.9	[bar]

50 %

Cylinder	Fuelrack	Average exh. temp.	Cylinder liner temp.	Main bearing temp.
[-]	[mm]	[ºC]	[ºC]	[ºC]
				80
1	28.5	403	119	85
2	28.5	388	115	85
3	28	388	116	86
4	30	382	116	90
5	28.5	400	118	86
6	28	386	115	85
Average	29	391	117	85

Fuel oil temp.	38	[ºC]
Fuel oil pressure	3.5	[bar]

Air intake temp.	28	[ºC]
Charge air temp. after cooler	51	[ºC]
Charge air temp. after compr.	105	[ºC]
Charge air pressure	1.25	[bar]

Exh. gas temp. turbo inlet 1	479	[ºC]
Exh. gas temp. turbo inlet 2	488	[ºC]
Exh. gas temp. turbo outlet	400	[ºC]

Lube oil temp. before cooler	71	[ºC]
Lube oil temp. before engine	63	[ºC]
Lube oil pressure before filter	4.7	[bar]
Lube oil pressure before engine	4.3	[bar]

LT water temp. before engine	39	[ºC]
LT water temp. aft. ch. air cooler	41	[ºC]
LT water pressure before engine	3.0	[bar]

HT water temp. aft. ch. air cooler	93	[ºC]
HT water temp. after engine	87	[ºC]
HT water temp. engine outlet	94	[ºC]
HT water pressure before engine	2.7	[bar]

25 %

Cylinder	Fuelrack	Average exh. temp.	Cylinder liner temp.	Main bearing temp.
[-]	[mm]	[ºC]	[ºC]	[ºC]
				80
1	21	367	111	84
2	21	353	109	84
3	20.5	344	109	85
4	22	350	107	90
5	21	369	112	85
6	20.5	349	110	83
Average	21	355	110	84

Fuel oil temp.	38	[ºC]
Fuel oil pressure	3.5	[bar]

Air intake temp.	28	[ºC]
Charge air temp. after cooler	48	[ºC]
Charge air temp. after compr.	81	[ºC]
Charge air pressure	0.65	[bar]

Exh. gas temp. turbo inlet 1	448	[ºC]
Exh. gas temp. turbo inlet 2	458	[ºC]
Exh. gas temp. turbo outlet	403	[ºC]

Lube oil temp. before cooler	71	[ºC]
Lube oil temp. before engine	62	[ºC]
Lube oil pressure before filter	4.7	[bar]
Lube oil pressure before engine	4.4	[bar]

LT water temp. before engine	39	[ºC]
LT water temp. aft. ch. air cooler	40	[ºC]
LT water pressure before engine	2.9	[bar]

HT water temp. aft. ch. air cooler	93	[ºC]
HT water temp. after engine	90	[ºC]
HT water temp. engine outlet	3	[ºC]
HT water pressure before engine	2.7	[bar]

Emission readings

Reference test (readings in mg/Nm^3)

ENVIROTECH CONSULTANCY WLL

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KINGDOM OF BAHRAIN

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Fax: +973 17714481
Email: newtech@batelco.com.bh

ENVIRONMENTAL REPORT- STACK EMISSION

July-08

Customer Name		Nature of work	Emission Measurement
Boskalis Westminster Middle East		Location of work	Coastway
P.O. Box 10630		Date of sampling	19th July 2008
Manama		Date of analysis	19th July 2008
Kingdom of Bahrain		Equipment used	Portable Flue Gas Analyser Lancom Series III: Sno: 13550573
Sample Identification		Flue gas from exhaust- SB engine	
Sampling Conditions		Different power output	

Date & Time	Time	Load (%)	Measured Values (Dry Gas and 15% O2 Normalised)								Flue Gas Temp. (°C)
			O_2 (%)	NO_2 (mg/Nm^3)	NO (mg/Nm3)	NO_x (mg/Nm3)	SO_2 (mg/Nm3)	CO (mg/Nm3)	CO_2 (%)	H_2S (mg/Nm3)	
19/07/2008	11:27	100.0	11.72	0.0	757	1158.0	153.0	77.0	5.54	0.0	321
19/07/2008	11:30	100.0	11.80	0.0	757	1158.0	168.0	78.0	5.61	0.0	327
19/07/2008	11:34	100.0	11.80	0.0	761	1164.0	174.0	78.0	5.57	0.0	328
19/07/2008	11:51	75.0	12.30	0.0	638	976.0	157.0	106.0	5.14	0.0	328
19/07/2008	11:54	75.0	12.40	0.0	637	975.0	164.0	108.0	5.11	0.0	328
19/07/2008	11:57	75.0	12.40	0.0	634	970.0	167.0	111.0	5.03	0.0	328
19/07/2008	12:55	50.0	13.90	0.0	564	864.0	143.0	240.0	4.48	0.0	317
19/07/2008	12:58	50.0	14.00	0.0	557	853.0	147.0	240.0	4.42	0.0	319
19/07/2008	13:01	50.0	14.00	0.0	559	856.0	152.0	239.0	4.40	0.0	321
19/07/2008	13:18	25.0	15.20	0.0	559	855.0	157.0	213.0	3.69	0.0	306
19/07/2008	13:21	25.0	15.30	0.0	555	850.0	160.0	219.0	3.62	0.0	305
19/07/2008	13:24	25.0	15.30	0.0	565	865.0	165.0	222.0	3.65	0.0	304

Name of the analyst: A Felix Anbarasan — Authorised for release by: R Krishnasamy

Signature and Date: — Signature and Date: R. Krishnasamy

Note: The measured values are 15% Oxygen corrected

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Verification test (readings in ppm)

NEWTECH/ENVIROTECH CONSULTANCY WLL

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ENVIRONMENTAL REPORT- STACK EMISSION

15-12-08

Customer Name		Nature of work	Emission Measurment
Boskalis Westminster Middle East		Location of work	Coastway
PO Box 10630		Date of sampling	15th December 2008
Manama		Date of analysis	15th December 2008
Kingdom of Bahrain		Equipment used	Portable Flue Gas Analyser Lancom III
Sample Identification		Flue gas from exhaust-SB engine	
Sampling Conditions		Different power output	

Date	Time	Load MW (%)	Measured Values (Dry Gas and 15% O2 Normalised)								Flue Gas Temp. (°C)
			O_2 (%)	NO_2 (mg/Nm^3)	NO (mg/Nm3)	NO_x (mg/Nm3)	SO_2 (mg/Nm3)	CO (mg/Nm3)	CO_2 (%)	H_2S (mg/Nm3)	
15/12/2008	13.06	25.00	14.20	3.4	620.0	623.4	12.6	87.9	5.09	0.0	354
15/12/2008	13.1	25.00	13.10	0.0	576.4	576.4	69.3	119.0	6.02	0.0	371
15/12/2008	13.12	25.00	13.20	0.0	576.2	576.2	76.0	119.8	5.92	0.0	371
15/12/2008	13.18	50.00	12.70	0.0	659.3	659.3	86.1	77.6	6.3	0.0	374
15/12/2008	13.21	50.00	12.80	0.0	668.7	668.7	94.4	73.4	6.33	0.0	374
15/12/2008	13.24	50.00	12.80	0.0	671.2	671.2	102.1	73.4	6.28	0.0	375
15/12/2008	15.34	100.00	12.2	0.0	797.8	797.8	3.8	64.1	6.78	0.0	364
15/12/2008	15.37	100.00	12.2	0.0	795.0	795.0	5.2	62.6	6.76	0.0	368
15/12/2008	15.4	100.00	12.2	0.0	800.7	800.7	18.6	63.6	6.83	0.0	371
15/12/2008	15.57	75.00	12.7	0.0	689.6	689.6	55.3	53.2	6.27	0.0	370
15/12/2008	16	75.00	12.8	0.0	645.8	645.8	61.8	74.5	6.23	0.0	371
15/12/2008	16.03	75.00	12.60	0.0	704.3	704.3	71.7	53.9	6.35	0.0	370
Applicable Air Emission Standards		**None**	**None**	**None**	**None**	**None**	**None**	**None**	**None**	**None**	**None**

Name of the analyst:K.Shanmuga Sundaram — Authorised for release by:A.Ponnuchamy

Signature and Date: — Signature and Date: 17/12/08

Note: The measured values are 15% Oxygen corrected

ENVIROTECH CONSULTANCY W.L.L.
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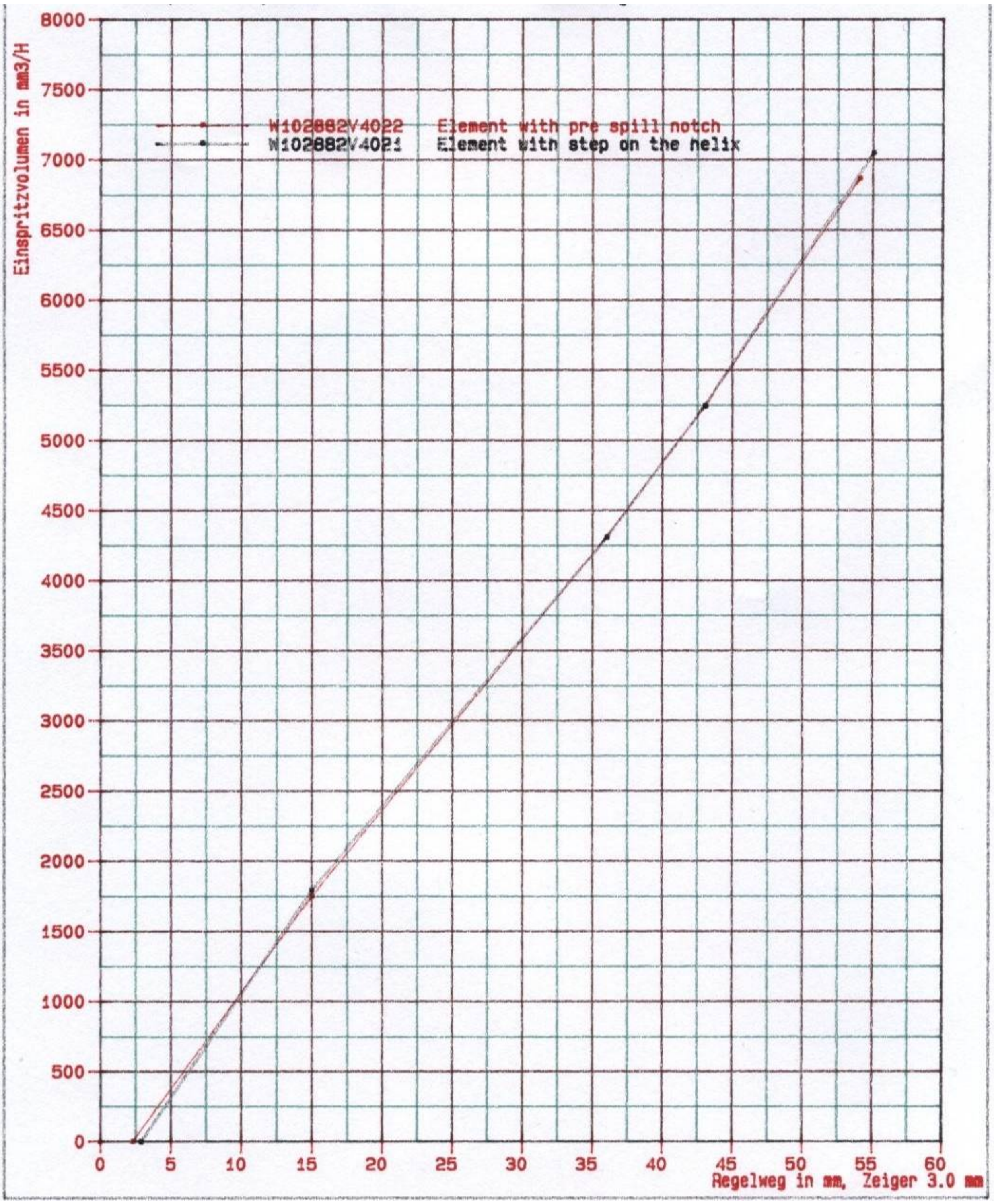
Fuel pump characteristic



Fuel injection per rack position [x] per cylinder

$$V_{inj} = 130 \bullet (x - 2.5) \quad \left[mm^3 / stroke \right]$$

Fuel specification Reference Test

DNV Petroleum Services

		July 19th	Dec 7th	
Sample No		F308016390	F508010759	
Sample Type		(MDO)	(MDO)	
Bunker Port		BAHRAIN	BAHRAIN	
Bunker Date		19-JUL-08	07-DEC-08	
Sent From		DUBAI	BAHRAIN	
Date Sent		27-JUL-08	13-DEC-08	
Arrived at Lab		29-JUL-08	15-DEC-08	
Supplier		BAPCO	BAPCO	
Sampling Point		BEFORE SB MAIN ENGINE	SHIP MANIFOLD	
Sampling Date		19-JUL-08	07-DEC-08	
Seal Data		DNVPS, 3446870 INTACT	DNVPS, 3446567 INTACT	
Tested Results	**Units**			**DMB**
Density @ 15C	kg/m3	833.3	841.5	900.0
Viscosity @ 40C	mm2/s	3.4	3.7	11.0
Water	%V/V	LT 0.1	LT 0.1	0.3
Micro Carbon Residue	%m/m	LT 0.1	LT 0.1	0.30
Sulfur	%m/m	LT 0.05	LT 0.05	2.00
Total Sediment Existent	%m/m	LT 0.01	LT 0.01	0.10
Ash	%m/m	LT 0.01	LT 0.01	0.01
Vanadium	mg/kg	LT 1	LT 1	
Sodium	mg/kg	LT 1	LT 1	
Aluminium	mg/kg	LT 1	LT 1	
Silicon	mg/kg	LT 1	1	
Iron	mg/kg	LT 1	LT 1	
Nickel	mg/kg	LT 1	LT 1	
Calcium	mg/kg	LT 1	LT 1	
Magnesium	mg/kg	LT 1	LT 1	
Lead	mg/kg	LT 1	LT 1	
Zinc	mg/kg	LT 1	LT 1	
Phosphorus	mg/kg	LT 1	LT 1	
Potassium	mg/kg	LT 1	LT 1	
Pour Point	Deg.C	-3	LT 0	0\6
Flash Point	Deg.C	67	GT 70	60
FTIR Analysis	NORMAL		NORMAL	
Gross Heat Combustion	MJ/kg	45.96	-	
Hydrogen	%m/m	13.38	-	
Calculated				
Net Heat Combustion	MJ/kg	43.12	42.83	
Aluminium + Silicon	mg/kg	LT 2	LT 2	
Calculated Cetane Index	-	58	56	35