Conversion of a large scale orifice measurement station to an ultrasonic measurement station with double capacity

- **Steinar Fosse, Measurement Adviser, Norwegian Petroleum Directorate**
- **Frode Bjelland, Measurement Specialist, Gassco Norway**
- **Gűnter Buss, Supervisor Metering & ICT, Gassco Germany**
- **Dr. Rainer Kramer, Gas metering Specialist, Physikalisch Technische Bundesanstalt (PTB)**

Content

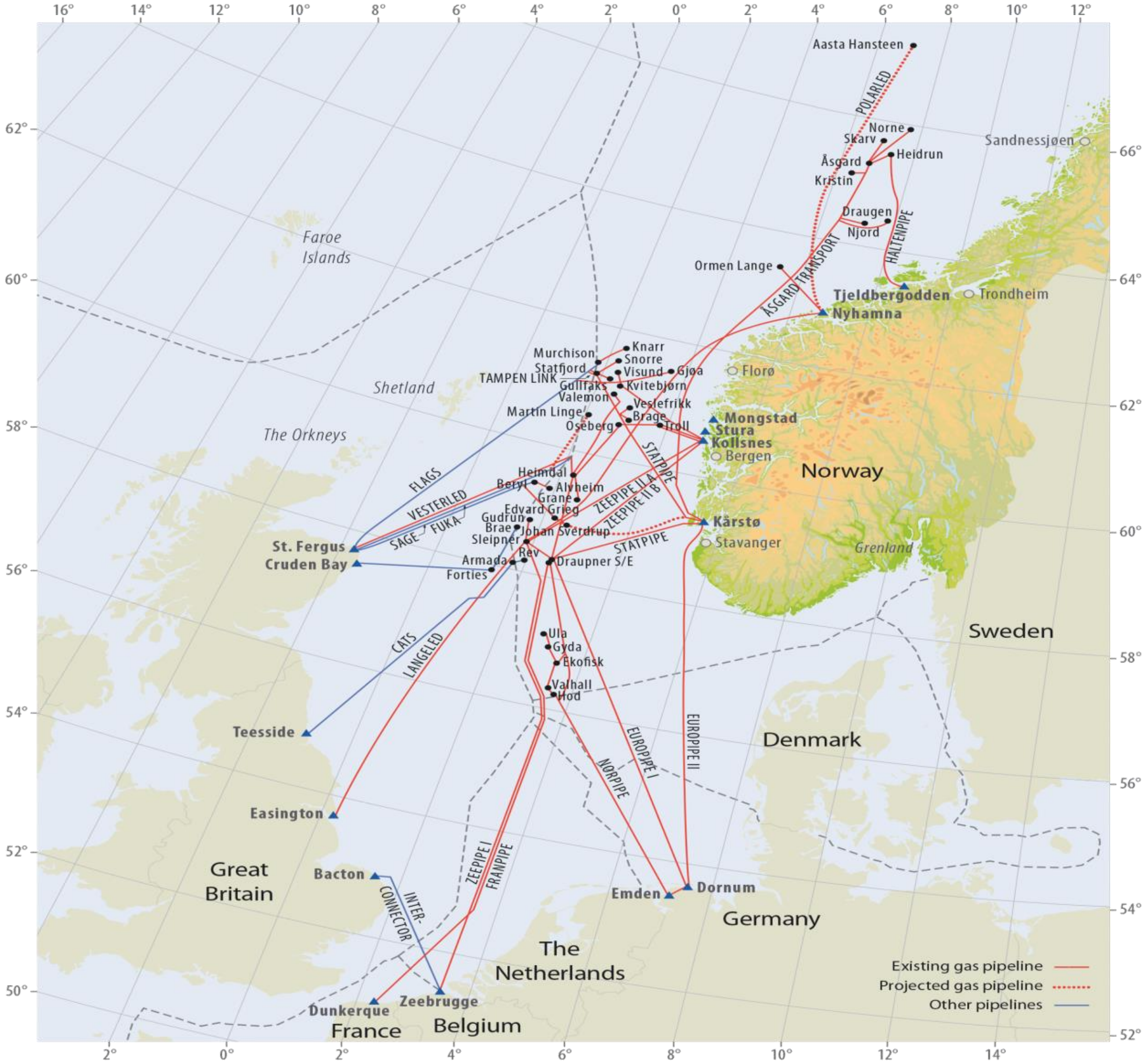
1. Norwegian natural gas deliveries - a historic overview.

The Ekofisk Field was discovered by Phillips Petroleum Company in 1969. It is located offshore in the southern sector of the Norwegian Continental Shelf.

The development of the field started soon after and first oil was tanker loaded on the field in 1971.

The permanent oil pipeline (354 km, 34”) to Teesside in United Kingdom (UK) was ready for operation in 1975.

The permanent gas pipeline (443 km, 36”) to Emden in Germany was ready for operation in 1977. See figure 1. Pipeline infrastructure, underneath.



The terminal facility in Emden Germany (NGT) was fairly simple, but it contained some filters to clean the gas (removal of liquids, particles and H2S). The Measurement station was however huge. Originally the configuration of the 3 customers were Ruhrgas with 9 tubes, Gasunie with 9 tubes and BEB with 3 tubes. All metering tubes were 20” size with Daniel orifice meters and densitometers. The quality measurement was originally done by 2 Calorimeters. They were later replaced by 2 Gas Chromatographs.

Responsible operator for the terminal was Phillips Petroleum/ConocoPhillips and later GasPort (one year) and then Gassco (state company, independent pipeline and terminal operator).

Europipe I was ready for operation in 1995. The landfall and terminal is in Dornum 50 km away from the Emden terminal, but the gas was then sent to Emden EMS (neighbor facility to NGT) where it was metered and sold to the same customers as for NGT. Operator was originally Statoil, but this was transferred to Gasport/Gassco, similar as for ConocoPhillips.

The metering station EMS has the same sizing (20” orifice plates) as the NGT metering station but fewer tubes. 5 for Ruhrgas and Gasunie and 4 for BEB.

Europipe II was ready for operation in 1999. It includes a new metering station located at the landfall in Dornum. This is also an orifice metering station with 6*20” tubes for the customer Ruhrgas.

The customers have now changed names:
Ruhrgas = OGE (Open Grid Europe)
Gasunie = GTS (Gasunie Transportation System)
BEB = GUD (Gasunie Deutschland)

The total maximum gas offtake from the Norwegian Continental Shelf is ca 376 mill Sm3/day. Ca 150 mill Sm3/day can now be delivered through the 2 sales gas metering stations (EMS and ERF) in Germany.

2. Legal framework

When a pipeline involving different nations is planned, then the government in both nations are involved and a treaty is developed. This treaty will normally also include a paragraph which defines both nations rights related to fiscal metering. As the fiscal sales point for these pipeline systems is at the landfall after the terminals in Germany, this is a point of interest for both the authorities in Germany and Norway.

In addition to various authority requirements it is also an Agreement with the Downstream Operators (buyers) (interconnecting agreement). It also leads to additional metering requirements.

Under the treaty a so called Memorandum of Understanding (MoU) is developed. It is a short document which describes some practical ways to cooperate and show the rights for the involved parties. It helps the fiscal authorities in both countries and the Operating company in their communication.

The relevant metering authorities:
Norway: Norwegian Petroleum Directorate

Germany: Pysikalisch Technische Bundesanstalt (PTB) approve equipment and solutions while Mess- Eichwesen Niedersachsen (MEN) do the daily follow up thereafter.

3. The upgrade of the metering station in Emden (EMS)

As the original North Sea Gas Terminal was put in service in 1977, much of the equipment needed to be refurbished. This lead to a large replacement project (Gassco Emden Project – GEP) for the process equipment which included the metering station. The original metering station should be closed and the gas transferred over the fence to the Europipe I metering station where it should be sold through the 3 EMS metering stations, which of only the Gasunie Transportation System (GTS) metering station (see figure 2) required more capacity.

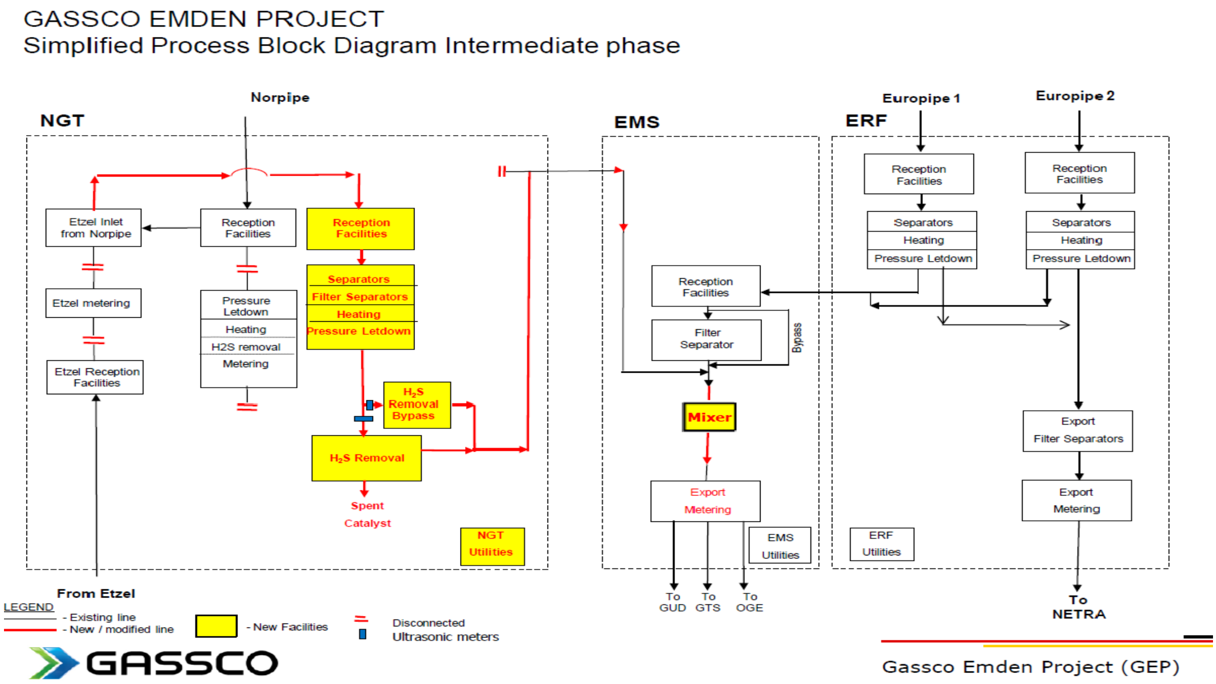


Figure 2

The scope of the project was to increase the capacity of the EMS GTS metering station from the existing 40 mill Sm3/day to 80 mill Sm3/day.
This will be achieved by changing the 4 + 1 orifice meter runs with ultrasonic meter runs. The flow control valves would also have to be replaced. In addition a new mixer as shown on figure 2 and 3 was installed.

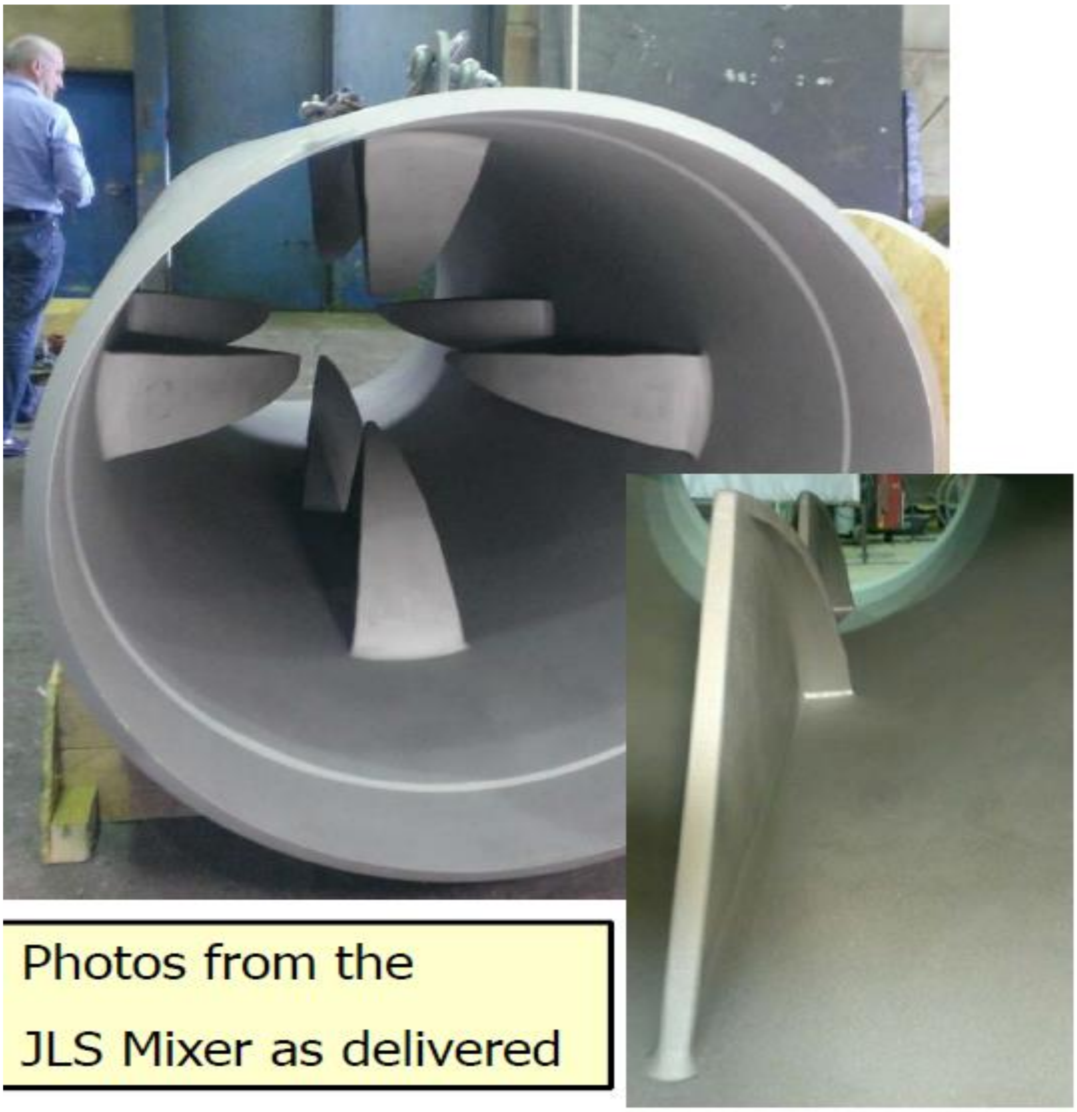


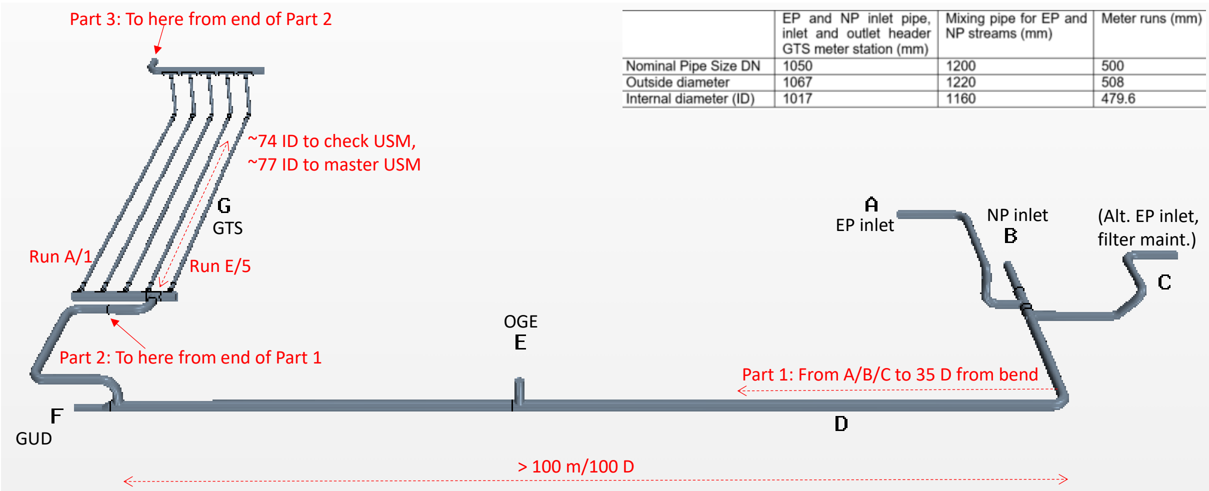
Figure 3

4. Computational Fluid Dynamics (CFD)

The Norwegian research company CMR did a thorough and comprehensive report which included

a) CFD study on the gas mixing at the GC probe shown at point D in figure 4, using STAR CCM+ from CD-adapco
b) CFD study on the flow profiles in the metering runs for some metering run constellations, using a CMR proprietary tool called MUSIC
c) USM measurement results approximately in the area where the master USM is located, using a CMR proprietary tool called USMSIM

In this paper the focus is to show some results of part b) and c) for one flow scenario.



	EP and NP inlet pipe, inlet and outlet header GTS meter station (mm)	Mixing pipe for EP and NP streams (mm)	Meter runs (mm)
Nominal Pipe Size DN	1050	1200	500
Outside diameter	1067	1220	508
Internal diameter (ID)	1017	1160	479.6

Figure 4 Pipe section being CFD simulated

Six different flow scenarios as shown in figure 5 were simulated.

GTS Case	Flow rate (Msm3/d)	Meter run
1	10	A
2	30	A, B
3	40	A, B, C
4	60	A, B, C, D
5	82	A, B, C, D, E
6	10	E

Figure 5 Metering run simulations

In this paper GTS case 4 with meter runs A, B, C and D open are covered.
The flow-split ratio between run A, B, C and D was in the simulations found to be respectively 29, 26.5, 23.5 and 21 % of the total flow rate when the total flow rate was 60 MSm3/day.

A period of fairly stable flow around 59 MSm3/day with the same meter runs in use was found in October 2016. This showed flow-split ratio between run A, B, C and D to be respectively 27, 24, 23 and 26 % of the total flow rate. Hence the flow in meter run D was higher and the flow in meter run A and B were lower in real life compared to the simulations.

Axial flow profiles respectively 2.5 and 78.5 ID (inner diameter) downstream of the valve are shown in Figure 6 for run A, in Figure 7 for run B, in Figure 8 for run C and in Figure 9 for run D. The asymmetry is clearly reduced downstream in the pipe, and the axial flow velocity becomes more symmetric.

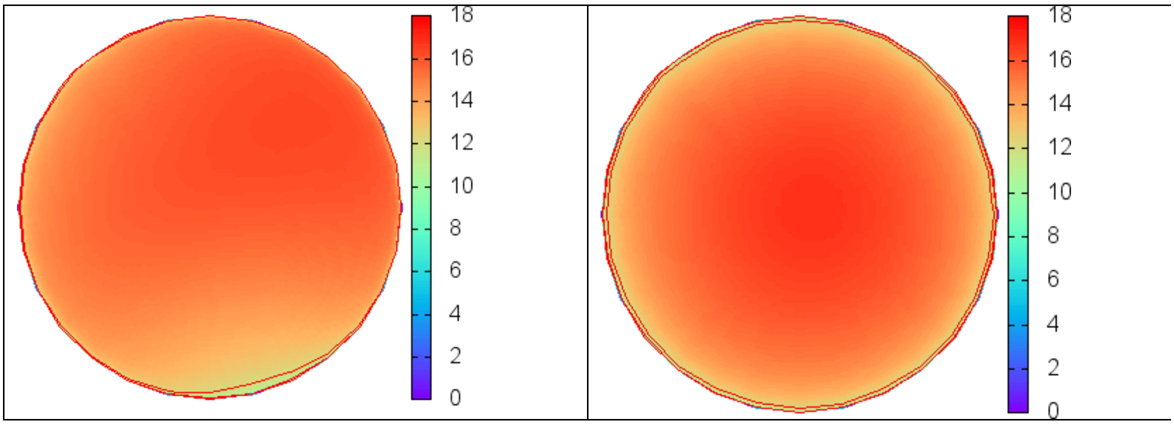


Figure 6 GTS Case 4, Run A: Axial velocity (m/s) in the pipe cross-section in meter run 2.5 ID after the inlet valve to the left and 78.5 ID after the inlet valve to the right. The view direction is upstream towards the inlet header.

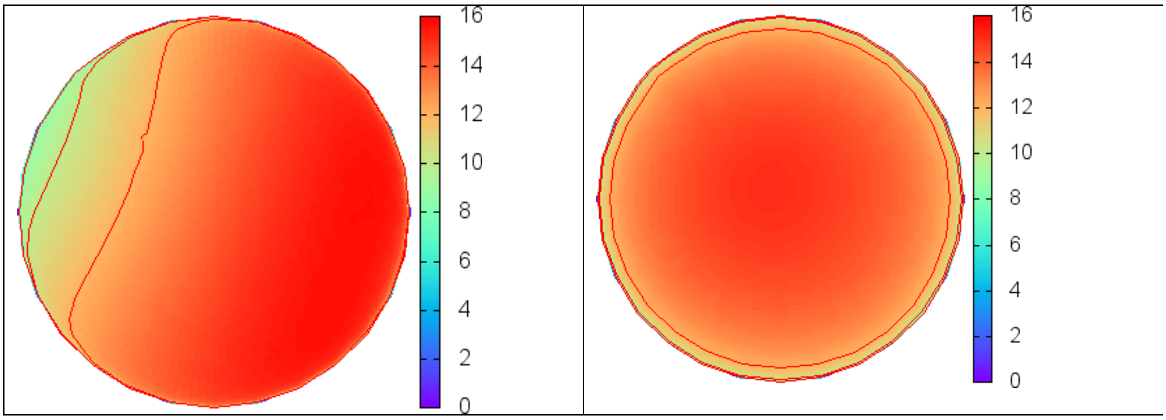


Figure 7 GTS Case 4, Run B: Axial velocity (m/s) in the pipe cross-section in meter run 2.5 ID after the inlet valve to the left and 78.5 ID after the inlet valve to the right. The view direction is upstream towards the inlet header.

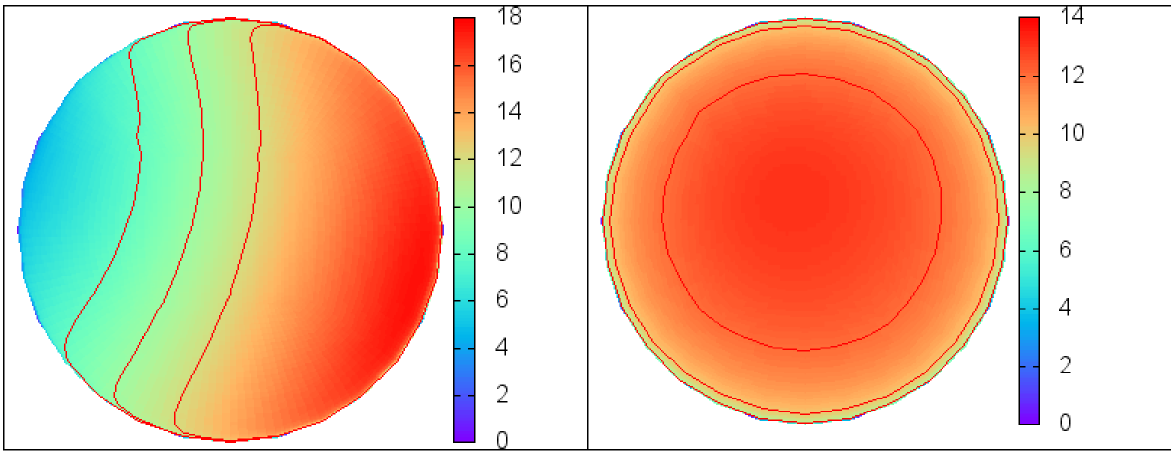


Figure 8 GTS Case 4, Run C: Axial velocity (m/s) in the pipe cross-section in meter run 2.5 ID after the inlet valve to the left and 78.5 ID after the inlet valve to the right. The view direction is upstream towards the inlet header.

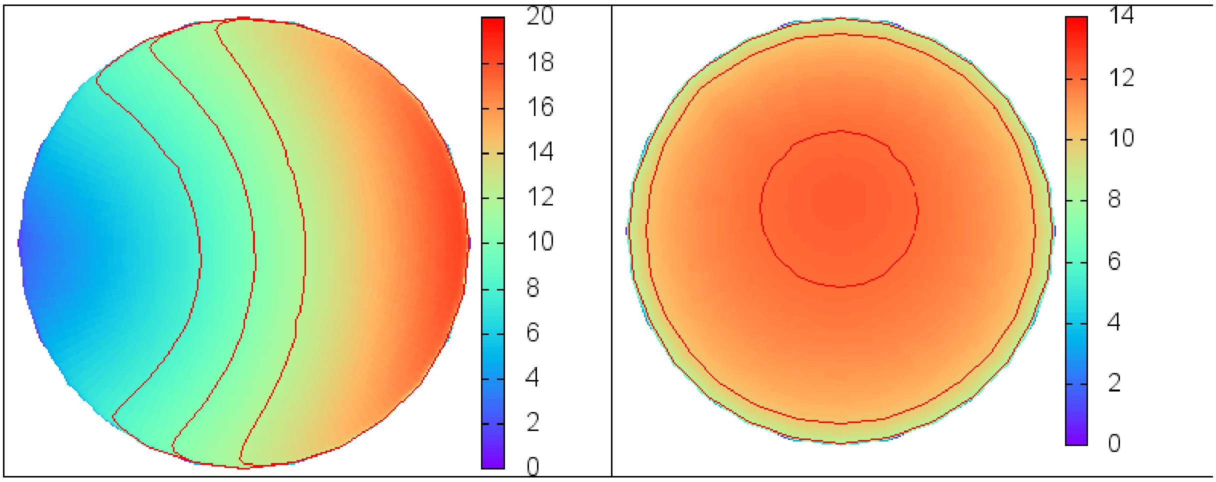


Figure 9 GTS Case 4, Run D: Axial velocity (m/s) in the pipe cross-section in meter run 2.5 ID after the inlet valve to the left and 78.5 ID after the inlet valve to the right. The view direction is upstream towards the inlet header.

When looking at the simulated flow profiles at position 78.5 ID downstream the inlet header in figure 6 to 9, it seems the flow is slightly higher at the top than at the bottom, and this is becoming more evident for every meter run going from run A (small difference) to run D (bigger difference). The flow seems centralized in left to right position.

When looking at the real flows experienced when meter runs A (1) to D (4) were in use from 12th to 14th October 2016, see figure 9.16 page 31 and 9.17 page 32, this behavior is very clear in meter run B and also for run A it is clear, but not for run C and D. For the Sick USMs path A is at the top and path D is at the bottom. For the FMC USMs paths A1 and A2 are at the top (crossed), path B1 and B2 are the top middle chords (crossed), path C is the bottom middle. chord and path D is the bottom chord.

Figure 10 GTS Case 4, meter runs A (1), B (2), C (3) and D (4): Deviation from meter reference along the line

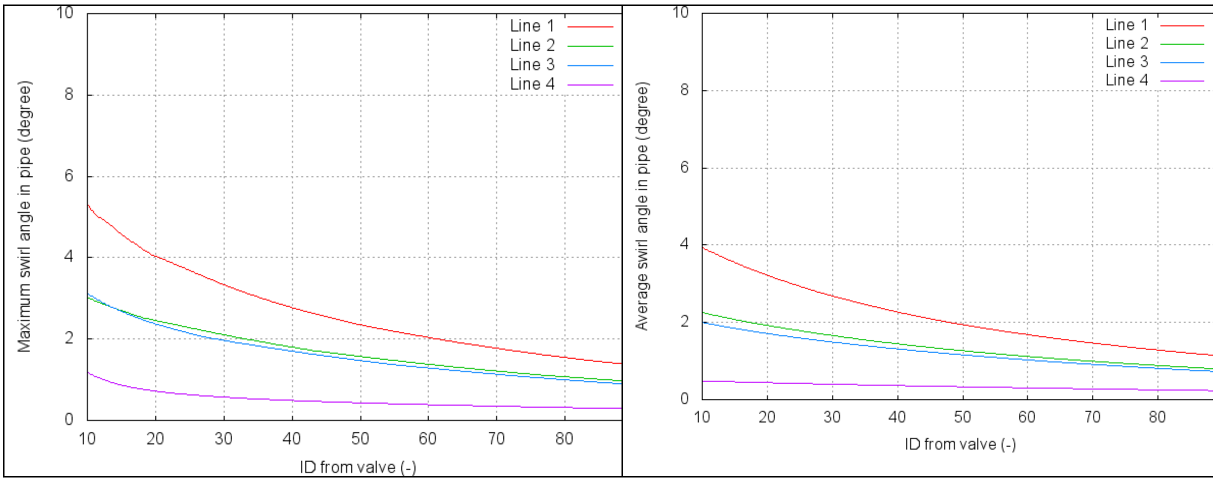


Figure 11 GTS Case 4, run A(1), B(2), C(3) and D(4) active: Maximum swirl angle in cross-section to the left, average swirl angle in the pipe section to the right

5. System overview

- Each metering run contains 2 ultrasonic meters, 2 pressure transmitters and 2 temperature transmitters. Each USM has it dedicated pressure and temperature transmitters.
- The ultrasonic meters are from different brands: 1*SICK and 1*FMC
- Each meter run has 2 separate Sick Flow-X flow computers
- Each ultrasonic meter is connected to a dedicated Flow-X flow computer, using a serial connection for flow data and diagnostic data
- Pressure and temperature transmitters are communicating via the Hart protocol.
- Each Flow computer operates independent from the other flow computers
- All Flow-X flow computers belonging to the Sick pay meters are placed in one rack, all Flow-X flow computers belonging to the FMC check meters are placed in another rack
- All Flow computers have redundant Ethernet connection. Each connection is connected to a different network. Each network has its own IP address range. This dual redundant Ethernet network is the highway for data transmission between the flow computers, GC composition and supervisory computers

- 2 USMs with different path configuration installed in series

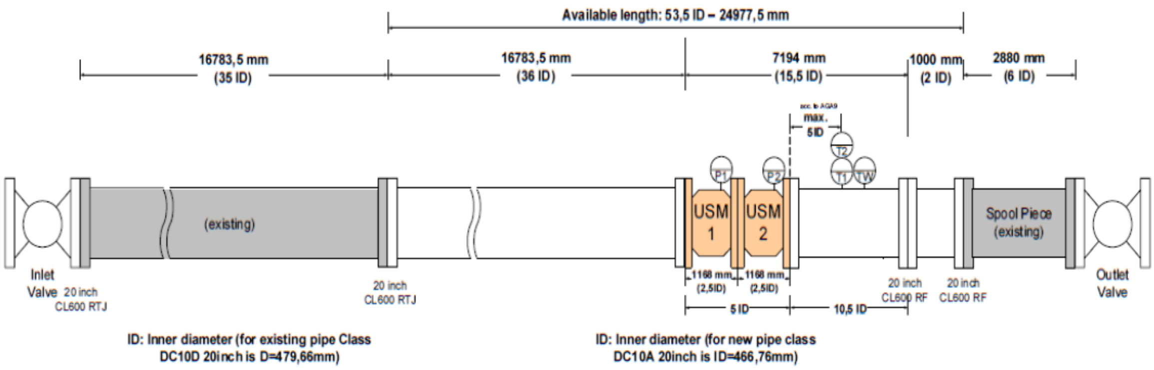
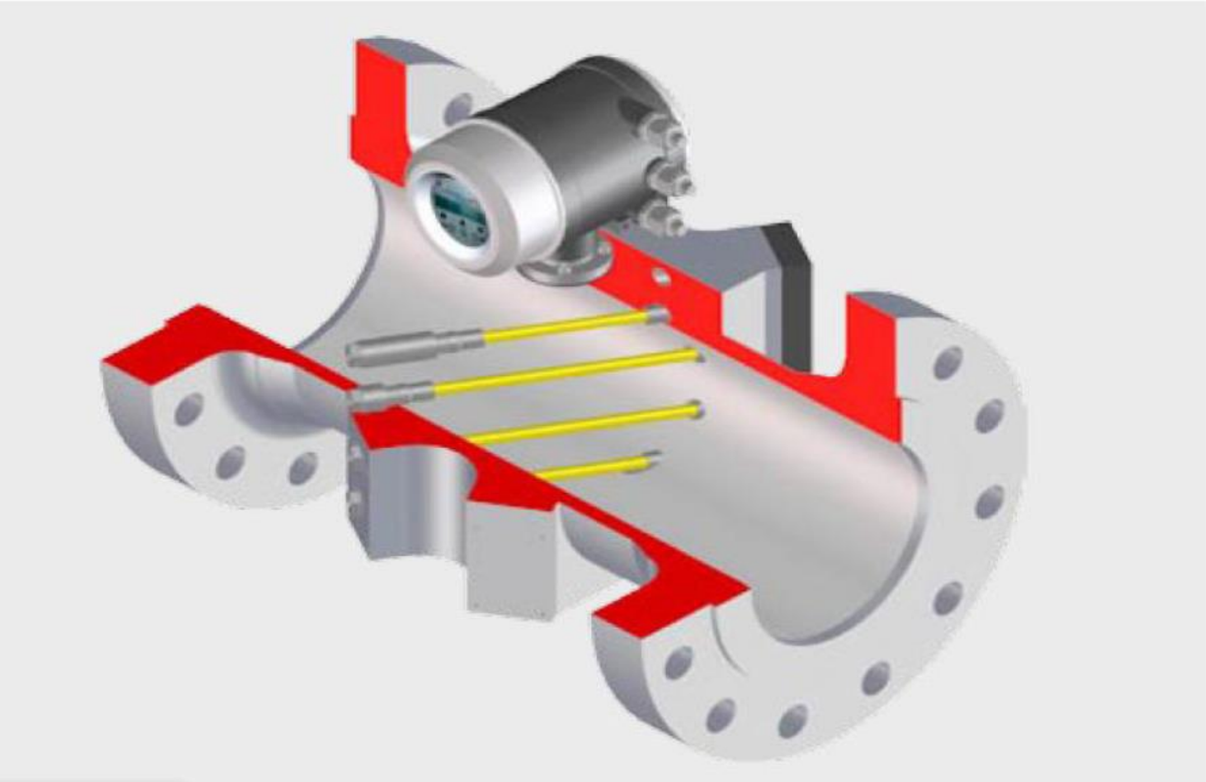


Figure 12

6. USM Meter specifications

SICK Flowsic 600 Figure 13

General specificaties		
Manufacturer		Sick
Model no.		FL600-4PSD20CL0600SC0060RJ2Y-S2-7DC1N1Y
Rating		600#
Type		4-path parallel Ultrasonic gas flow meter
Material of construction / meter body		P355QH1/(S)A350 Grade LF2
Weigth	kg	1025
Maximum gas velocity	m/s	33
Maximum flow range	m3/hr	200-20.000
Transducers Quantity		4 path
Type		Retractable under line pressure / Non-insertion type
Material		Titan 3,7165
Output values		Volumetric flow rate (actual), volume (actual), 4 digit LCD indication
Accuracy	%	±0,5% of MV0,1 ....1 Qmax
Typical calibrated measurement uncertainy	%	±0,1% of reading with good piping conditions
Measurement uncertainy		(Qt....Qmax)
Repeatability	%	< 0,1%
Communication with flow computer		RS485 serial link, SICK MODBUS ASCII
Signal processing unit		
Housing		Stainless steel
Front panel		LCD, language: English, metric units
Cable glands		3x, ATEX: M20 x 1,5 (1x power, 2x communication RS485)
Power supply		12 - 28,8 VDC
Typical power consumption		< 1W
Potection class		IP66/67
Ex-Protection approvals		II 1/2G Ex de ib [ia] IIC T4



FMC MPU 1200 Figure 14

General specificaties		
Manufacturer		FMC
Model no.		MPU 12A20R-0D0X0
Rating		600#
Type		6-path parallel Ultrasonic gas flow meter
Material of construction / meter body		(S)A350 Grade LF2
Weigth	kg	864
Design		Acc. AGA-9
Maximum gas velocity	m/s	0,3-26
Maximum flow range	m3/hr	270-17000
Transducers Quantity		6 path
Type		Retractable under line pressure
Material		Titanium
Output values		Volumetric flow rate (actual), volume (actual), 4 digit LCD indication
Typical calibrated measurement uncertainy	%	±0,1% of reading with good piping conditions
Measurement uncertainy		(Qt....Qmax)
Repeatability / Turn down ratio	%	< 0,05% of measured value/ 100:1 or better
Communication with flow computer		RS485 serial link, MODBUS RTU
Maintenance link		Ethernet
Signal processing unit		
Housing		Stainless steel
Front panel		LCD, language: English, metric units
Cable glands		M25 x 1,5
Power supply		24 VDC
Typical power consumption		< 1W
Potection class		IP65 or higher
Ex-Protection approvals		Eex d IIB T5 PTB 07ATEX1018

7. USM Flow meter testing

The meter runs (see figure 4 & 12/13) were tested at Euroloop test facilities in Rotterdam, Netherland.

- On top of the actual 7 points calibration with 2 verification points, additional tests were performed (on first metering run only):
- Transducer swapping
- Cross talk test
- Chord failure test

Transducer swapping test at 25% and 75% flow rates. This test give experience in the meter tolerance if we later have to exchange transducers for service purposes.

Cross talk test:

- Start at 120% with only USM A active and USM B switched off. Then 120% with USM B active and USM A switched off
- Then a normal 7 point calibration is performed with both meters active, starting with 120% flow and ending up with 5% flow
- The cross talk test is then repeated at 5% flow

Chord failure test at 25% and 75% flow rates.

- Disconnect the transducer cables at the field terminals in electronic enclosures to simulate failing path
- The test shall give experience in the effect on measurement uncertainty when a path fails

All tests passed the relevant API/ISO/PTB/NPD requirements and the additional tests as mentioned above. Logging of basic data (foot print) was done for the various parameters. It is, however, fair to say that both from the vendor side and from the operating company it is valuable and in some cases critical to have experienced engineers on the test site to do quality control and solve eventual discussion topics which might come up.

8. Operating philosophy

The Sick meter is the master meter or pay meter. The FMC meter is the check meter.

The operational mode of the system can be set to manual or automatic.

Automatic mode:

- Line is a part of the automatic valve control and can only be opened if the inlet valve is open
- If any equipment fails in one metering line, independent of this being associated with the Sick meter or the FMC meter, the supervisory computer will initiate to open a closed line
- After the new line is opened, the supervisory computer will send a request to close the failing line
- If any parts (PT, TT, USM or flow computer) related to the pay meter are failing, and the check meter is still ok, then the supervisory computer will search for a line where the pay meter is ok

- If no spare line exist, the check meter in the line can give the fiscal figures – as an ultimate back up.

When it comes to recalibration of USM`s the Norwegian Petroleum Directorate would normally rely on Condition Based Monitoring (CBM) for such a purpose.

The German Physikalisch Technische Bundesanstalt (PTB) was requiring this concept with 2 USM`s in series with different path configuration. The PTB Technische Richtlinien G 18 (Messgeräte für gas) gives an annual baseline check as a requirement. Based on the results of this, an eventual recalibration shall be performed. The maximum allowed deviation from the determined baseline is 0,5% (half of the "Eichfehlergrenze) and 0,3% deviation for the ratio of the VOS of each chord compared to the average VOS value.

9. Condition based monitoring

At the terminal, alarms provide on-line monitoring of deviations between the two USM`s in series in each line on parameters like:

- Flow rates
- Velocity of sound, and towards AGA 10 calculated VoS
- Pressure
- Temperature
- Line density (AGA 8), and for FMC also DECA density

In addition to this on-line monitoring, regular on-site checks and routines are performed by qualified Gassco technicians. Daily alarm and report verification. Weekly GC checks. Two monthly instrument checks. And on annual basis system verification together with German authorities.

Condition Based Monitoring (CBM) is performed to detect any drift or deterioration of the meter performance in a long term perspective. When doing this, care should be taken not to mix deterioration or drift with natural causes for parameter changes, like a change of meter lines in operation.

The CBM is done on the basis of hourly data received in a daily xml file produced by the metering system. This file contains quantities and mass weighted hourly values of all parameters of interest from the pay and the check meters in each line, in addition to GC and quantity data on station level. This includes parameters like mass, actual line volume, reference volume, energy, pressure, temperature, AGA 8 density and USM specific parameters like velocity of sound per chord and per USM, calculated velocity of sound, gas velocity per chord and per USM, AGC, SNR, symmetry, turbulence etc.
This file is automatically sent to Gassco Norway and loaded into a database. The next step is to manually run an excel macro to fetch the data into a monthly excel file containing one sheet per gas day. The parameters are sorted in some sheets, and deviations between the instruments and meters are calculated. At the end of the file, all the graphs of the different parameters are shown to enable trending. In this way, all parameters in a new month can be compared with the situation at start-up, or any other month. As already mentioned, care should be taken to compare periods with the same metering lines in use, and preferably comparable flow rates.

Typical pressure in the metering station is 55 Bara, temperature is 6 degree Celsius, line density is 50 kg/m^3 and a typical composition is shown here:

C1 [Mole%]	C2 [Mole%]	C3 [Mole%]	iC4 [Mole%]	nC4 [Mole%]	iC5 [Mole%]	nC5 [Mole%]	neoC5 [Mole%]	C6+ [Mole%]	CO2 [Mole%]	N2 [Mole%]
90.558	5.584	1.018	0.159	0.161	0.040	0.033	0.001	0.043	1.597	0.808

Figure 9.1 Typical composition

This gives Standard density of 0.757 kg/Sm^3 and GCV of 39.422 MJ/Sm^3.

The attached figures shown in the rest of this chapter are mainly taken from metering line 2 and 4. Metering line 2 exhibits the poorest flow profile, without doubt. Metering line 3 and 4 exhibit the best flow profile. Metering line 1 and 5 show something in between, but normally closer to line 3 and 4 than to line 2.

The excel file contains one sheet of hourly data per calendar day in the month.

	A	B	C	D	E	
1	TERMINA	STREAM_NAME	PRODTYPE	HOUR	QUANTITY	UN
2	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 06:00	10296.996	
3	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 07:00	10516.048	
4	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 08:00	10302.616	
5	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 09:00	10293.845	
6	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 10:00	10344.29	
7	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 11:00	10309.251	
8	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 12:00	8756.679	
9	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 13:00	8541.801	
10	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 14:00	8630.877	
11	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 15:00	8668.444	
12	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 16:00	8744.824	
13	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 17:00	8768.021	

1508	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	VOS USM AVERAGE	02.10.2016 00:00	387.3737889
1509	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	VOS USM AVERAGE	02.10.2016 01:00	387.4729714
1510	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	VOS USM AVERAGE	02.10.2016 02:00	387.7094107
1511	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	VOS USM AVERAGE	02.10.2016 03:00	387.6847186
1512	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	VOS USM AVERAGE	02.10.2016 04:00	387.8396813
1513	EMS-GTS	LINE-1-CHECK-INSTRUMENTS	VOS USM AVERAGE	02.10.2016 05:00	387.4581969
1514	EMS-GTS	LINE-1-MASTER-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 06:00	10310
1515	EMS-GTS	LINE-1-MASTER-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 07:00	10509
1516	EMS-GTS	LINE-1-MASTER-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 08:00	10312
1517	EMS-GTS	LINE-1-MASTER-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 09:00	10302
1518	EMS-GTS	LINE-1-MASTER-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 10:00	10341
1519	EMS-GTS	LINE-1-MASTER-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 11:00	10323

2684	EMS-GTS	LINE-1-MASTER-INSTRUMENTS	VOS USM AVERAGE	02.10.2016 00:00	387.0155031
2685	EMS-GTS	LINE-1-MASTER-INSTRUMENTS	VOS USM AVERAGE	02.10.2016 01:00	387.1250075
2686	EMS-GTS	LINE-1-MASTER-INSTRUMENTS	VOS USM AVERAGE	02.10.2016 02:00	387.3557215
2687	EMS-GTS	LINE-1-MASTER-INSTRUMENTS	VOS USM AVERAGE	02.10.2016 03:00	387.3426809
2688	EMS-GTS	LINE-1-MASTER-INSTRUMENTS	VOS USM AVERAGE	02.10.2016 04:00	387.4973209
2689	EMS-GTS	LINE-1-MASTER-INSTRUMENTS	VOS USM AVERAGE	02.10.2016 05:00	387.1057792
2690	EMS-GTS	LINE-2-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 06:00	0
2691	EMS-GTS	LINE-2-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 07:00	0
2692	EMS-GTS	LINE-2-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 08:00	0
2693	EMS-GTS	LINE-2-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 09:00	0
2694	EMS-GTS	LINE-2-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 10:00	0
2695	EMS-GTS	LINE-2-CHECK-INSTRUMENTS	ACTUALVOLUME-HOURLY-ACC	01.10.2016 11:00	0

14396	EMS-GTS	STATION	WOBBEINDEX-HOURLY-AVG	02.10.2016 00:00	53.40324912
14397	EMS-GTS	STATION	WOBBEINDEX-HOURLY-AVG	02.10.2016 01:00	53.47742584
14398	EMS-GTS	STATION	WOBBEINDEX-HOURLY-AVG	02.10.2016 02:00	53.59042429
14399	EMS-GTS	STATION	WOBBEINDEX-HOURLY-AVG	02.10.2016 03:00	53.63185002
14400	EMS-GTS	STATION	WOBBEINDEX-HOURLY-AVG	02.10.2016 04:00	53.63104763
14401	EMS-GTS	STATION	WOBBEINDEX-HOURLY-AVG	02.10.2016 05:00	53.60479513
14402					

Admin | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 2

Figure 9.2 Hourly data loaded into the monthly excel file

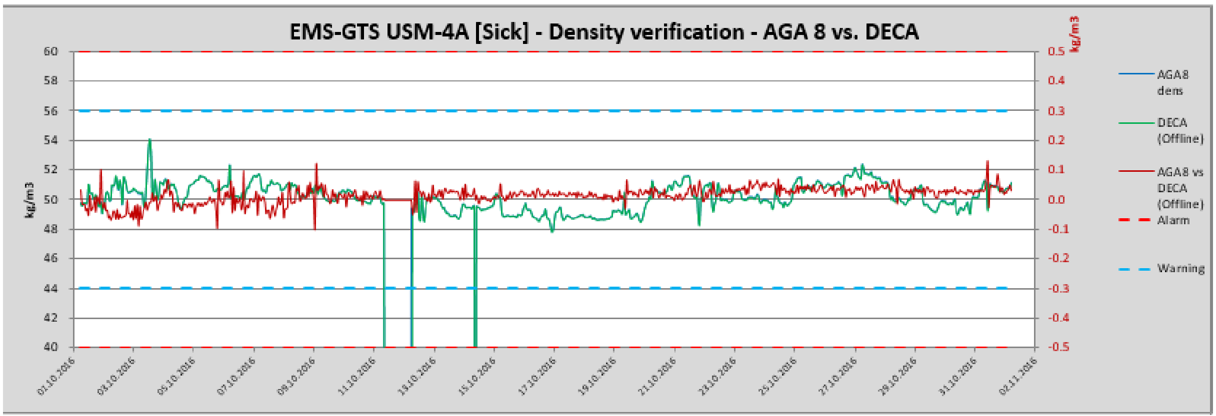
One sheet shows the daily quantities of both USMs and the deviation between them, both per line and for the station totals.

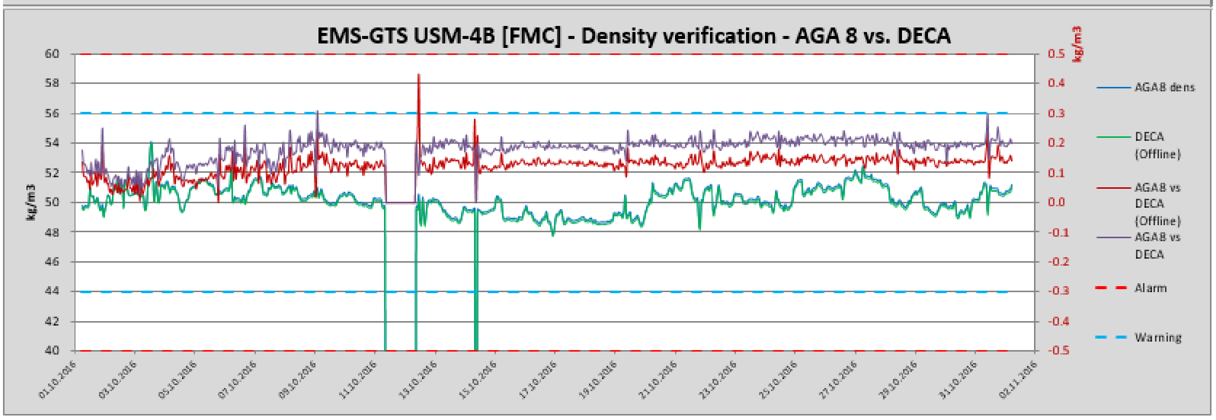
	Station Total Sick Quantities				Station Total FMC Quantities			
Day	Sick Mass kg	Sick ActVol m³	Sick Volume Nm³	Sick Energy MJ	FMC Mass kg	FMC ActVol m³	FMC Volume Nm³	FMC Energy MJ
16	42 905 341	880 047	54 245 643	2 236 106 858	42 932 647	880 259	54 280 161	2 237 529 945
17	43 657 810	894 917	55 213 365	2 276 773 343	43 685 918	895 163	55 248 915	2 278 239 356
18	42 808 837	877 348	54 113 996	2 233 351 196	42 837 844	877 603	54 150 658	2 234 864 460
19	42 768 056	870 215	53 950 639	2 224 688 260	42 792 496	870 378	53 981 469	2 225 959 620
20	45 323 128	893 563	57 087 353	2 355 211 532	45 343 388	893 644	57 112 880	2 356 264 446
21	40 041 458	790 858	50 349 681	2 079 554 596	40 061 944	790 960	50 375 433	2 080 618 494
22	40 334 447	805 086	50 411 335	2 093 214 097	40 346 487	805 019	50 426 392	2 093 839 099
23	42 231 634	844 637	52 803 274	2 191 240 027	42 244 633	844 578	52 819 530	2 191 914 601
24	41 775 258	832 585	52 335 282	2 167 792 809	41 788 591	832 541	52 351 989	2 168 485 074
25	44 563 701	876 219	55 778 791	2 311 438 023	44 573 195	876 083	55 790 675	2 311 930 487
26	44 753 041	871 924	55 969 313	2 323 859 639	44 765 673	871 849	55 985 111	2 324 515 338
27	40 354 160	785 725	50 455 433	2 096 722 066	40 367 352	785 682	50 471 928	2 097 407 580
28	43 331 360	864 199	54 361 441	2 259 902 096	43 346 784	864 176	54 380 792	2 260 706 894
29	46 923 461	911 130	58 850 230	2 446 420 598	46 937 051	911 057	58 867 276	2 447 129 021
30	45 134 836	908 373	56 666 189	2 354 707 609	45 148 281	908 305	56 683 066	2 355 409 126
31	43 250 115	852 315	54 287 213	2 252 012 126	43 265 921	852 313	54 307 060	2 252 835 188
Sum:	1236 799 526.098	24 674 023	1548 636 511	64 372 833 780	1237 315 633.187	24 675 388	1549 283 535	64 399 702 549

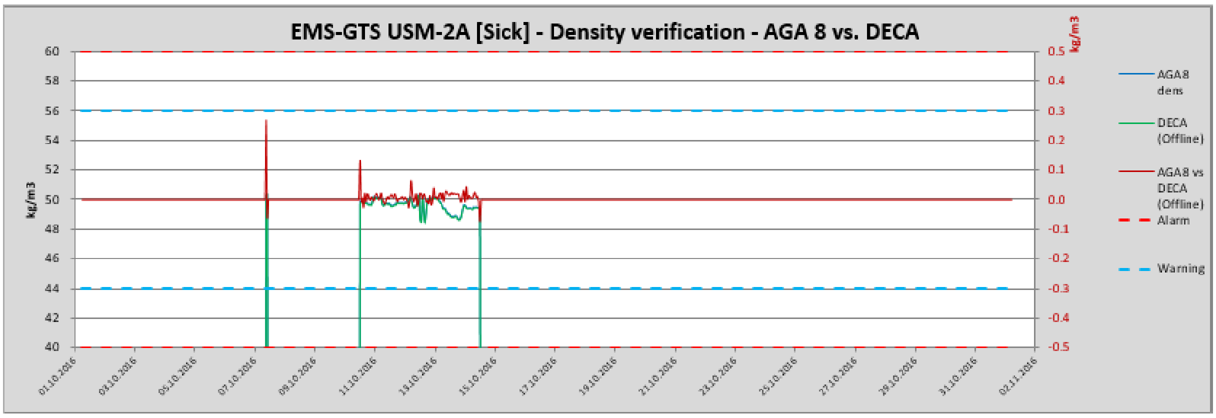
	Deviation: FMC-Sick				% Deviation: (FMC-Sick) / Sick			
Day	AbsDiffMass kg	AbsDiffVol m3	AbsDiffVol Nm3	AbsDiffEnergy MJ	%DiffMass %	%DiffActVol %	%DiffVol %	%DiffEnergy %
1	13 704	(54)	17 094	717 604	0.04 %	-0.01 %	0.04 %	0.04 %
2	8 635	(79)	10 723	455 618	0.03 %	-0.01 %	0.03 %	0.03 %
3	8 062	(65)	10 036	421 591	0.03 %	-0.01 %	0.03 %	0.03 %
4	12 290	(12)	15 264	641 547	0.04 %	0.00 %	0.04 %	0.04 %
5	8 968	(70)	11 112	466 314	0.03 %	-0.01 %	0.03 %	0.03 %
6	14 973	(40)	18 538	779 675	0.04 %	-0.01 %	0.04 %	0.04 %
7	17 443	(20)	21 568	910 637	0.04 %	0.00 %	0.04 %	0.04 %
8	13 846	(50)	17 142	717 477	0.04 %	-0.01 %	0.04 %	0.04 %
9	11 595	(106)	14 404	601 056	0.03 %	-0.01 %	0.03 %	0.03 %
10	24 758	207	30 914	1 285 083	0.07 %	0.03 %	0.07 %	0.07 %
11	23 611	460	29 525	1 226 043	0.06 %	0.05 %	0.06 %	0.06 %
12	3 136	(28)	3 928	162 058	0.01 %	0.00 %	0.01 %	0.01 %
13	27 192	444	34 194	1 413 558	0.06 %	0.05 %	0.06 %	0.06 %
14	25 161	228	31 711	1 312 974	0.06 %	0.03 %	0.06 %	0.06 %
15	21 170	81	26 714	1 103 682	0.05 %	0.01 %	0.05 %	0.05 %
16	27 306	212	34 518	1 423 086	0.06 %	0.02 %	0.06 %	0.06 %
17	28 108	246	35 550	1 466 013	0.06 %	0.03 %	0.06 %	0.06 %
18	29 007	255	36 662	1 513 264	0.07 %	0.03 %	0.07 %	0.07 %
19	24 440	163	30 830	1 271 360	0.06 %	0.02 %	0.06 %	0.06 %
20	20 260	81	25 527	1 052 914	0.04 %	0.01 %	0.04 %	0.04 %
21	20 485	102	25 752	1 063 898	0.05 %	0.01 %	0.05 %	0.05 %
22	12 039	(67)	15 057	625 002	0.03 %	-0.01 %	0.03 %	0.03 %
23	12 999	(59)	16 256	674 574	0.03 %	-0.01 %	0.03 %	0.03 %
24	13 333	(44)	16 707	692 265	0.03 %	-0.01 %	0.03 %	0.03 %
25	9 494	(136)	11 884	492 464	0.02 %	-0.02 %	0.02 %	0.02 %
26	12 632	(75)	15 797	655 699	0.03 %	-0.01 %	0.03 %	0.03 %
27	13 192	(43)	16 495	685 514	0.03 %	-0.01 %	0.03 %	0.03 %
28	15 425	(23)	19 351	804 798	0.04 %	0.00 %	0.04 %	0.04 %
29	13 590	(73)	17 046	708 423	0.03 %	-0.01 %	0.03 %	0.03 %
30	13 446	(68)	16 878	701 517	0.03 %	-0.01 %	0.03 %	0.03 %
31	15 806	(2)	19 847	823 063	0.04 %	0.00 %	0.04 %	0.04 %
Sum:	516 107.089	1365	647 023	26 868 769	0.04 %	0.01 %	0.04 %	0.04 %

Figure 9.3 Daily station totals of the two USM brands and the deviations

The line density is calculated both by using AGA 8 and DECA. The AGA 8 algorithm uses all the GC components, pressure and temperature as input. The DECA algorithm uses the measured VoS from the USM, pressure, temperature, N2 and CO2, and it is developed by CMR which is a Norwegian research institute.
The blue AGA 8 line density and the green DECA density match well and sit on top of each other, and they are connected to the left Y-axis. The deviation between them in red (for FMC USM also the purple) is shown on the right Y-axis. Monitoring that the deviation is around zero gives a confidence that both the USM and the GC are working properly. See figure 9.4.







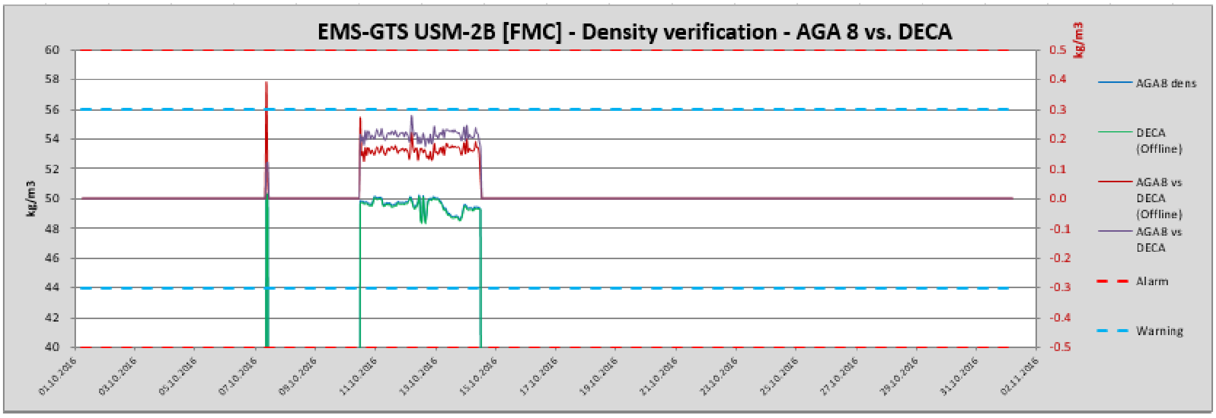
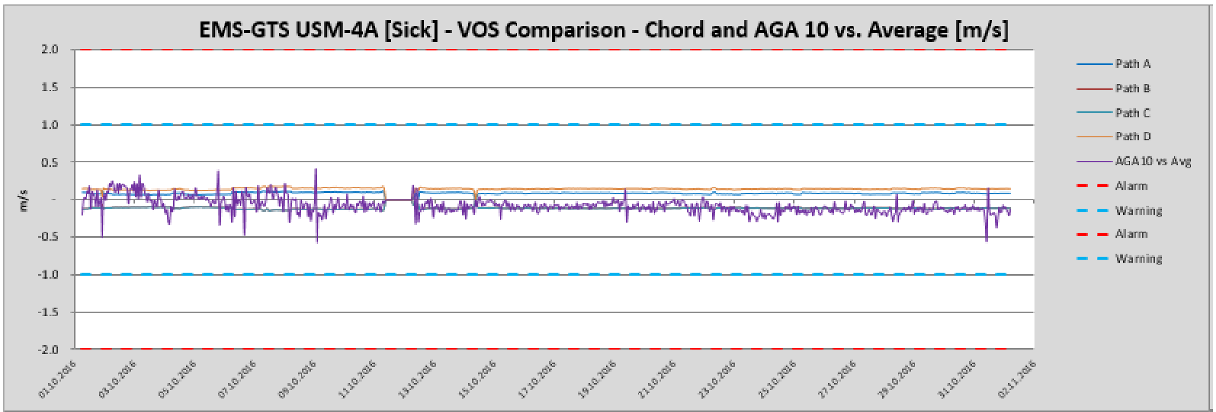
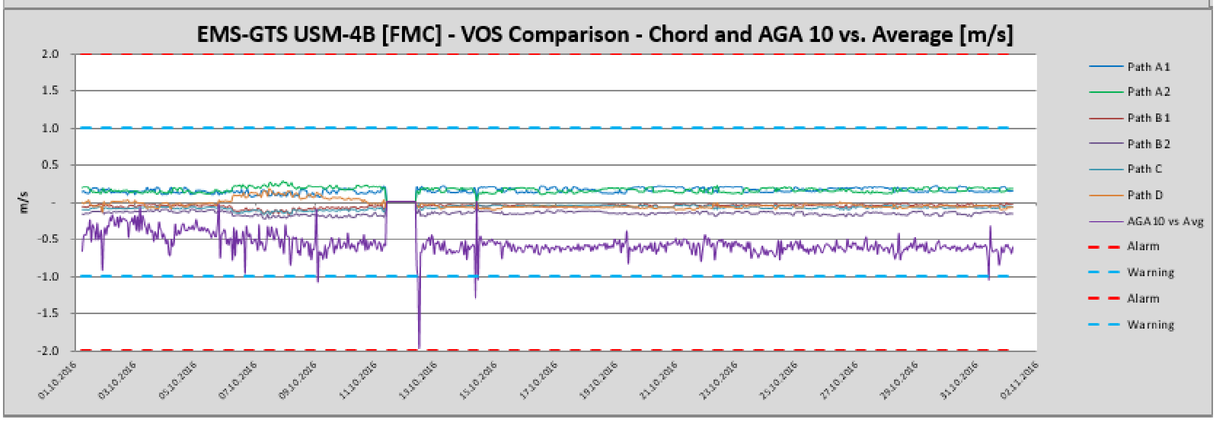


Figure 9.4 AGA 8 vs DECA density

The velocity of sound is trended in several graphs, and below the absolute difference in m/s towards the measured USM average value is shown, both per chord and for the AGA 10 calculated value. This trending involves several instruments and this gives a cross-check of the USM and the GC. See fig 9.5.





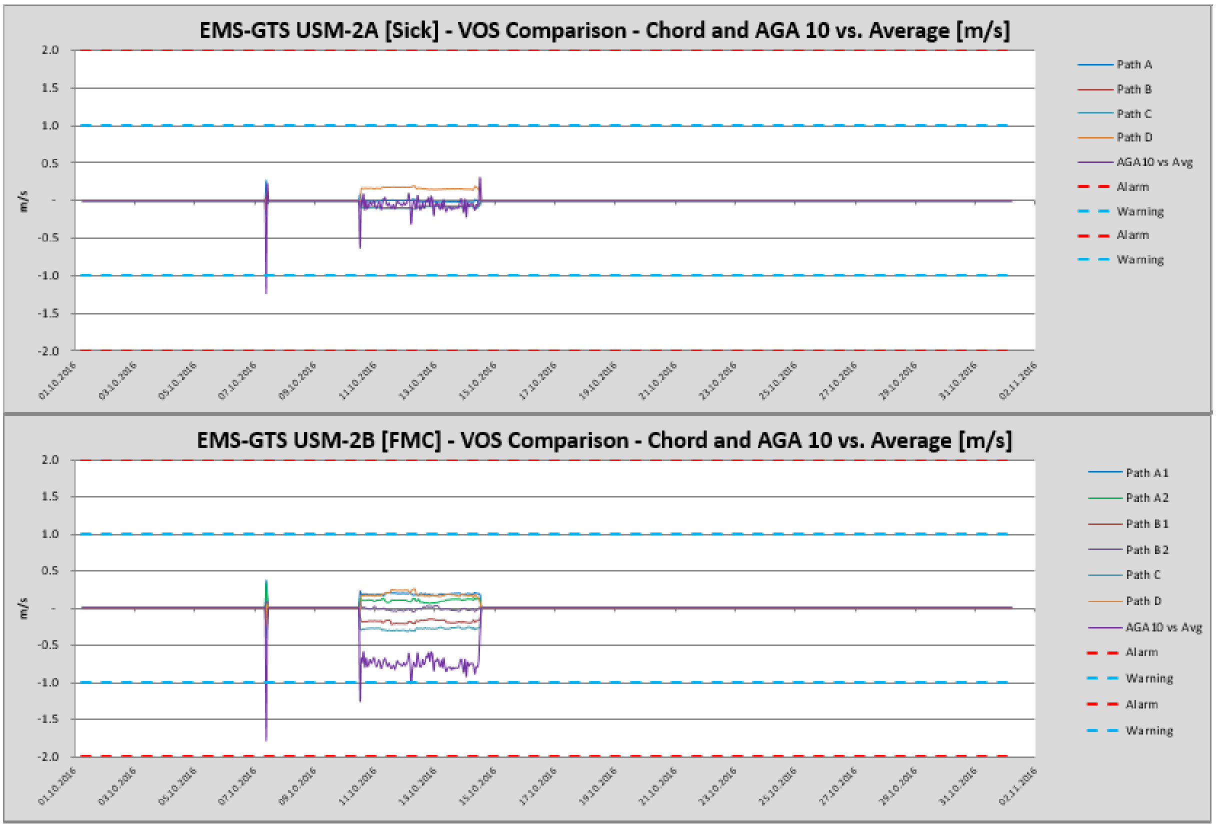
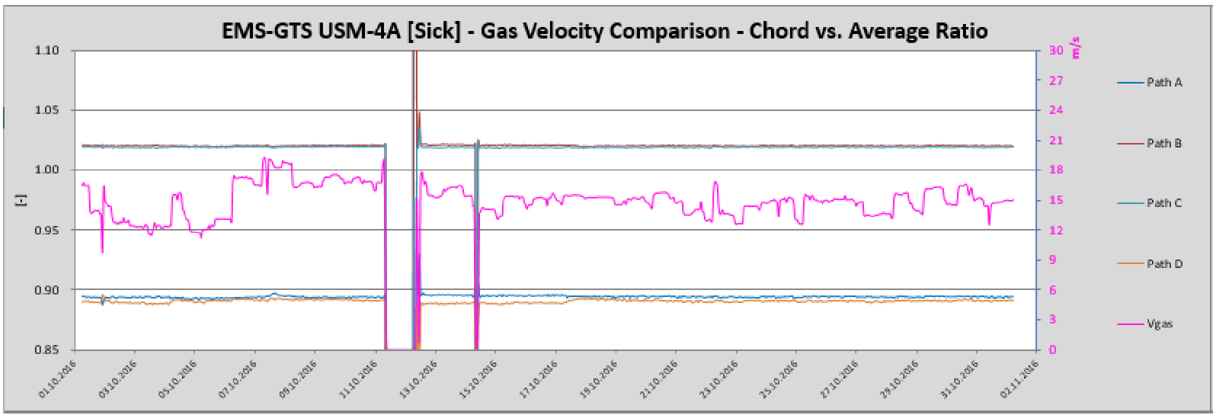


Figure 9.5 Velocity of sound per chord and AGA 10 vs the average

The gas velocity is also trended in several graphs. Below the ratio of the chords to the weighted average are shown. The outer chords should have similar values and the inner chords should have similar values if the flow profile is fully developed. The flow profile of line 2 varies with the lines in use. See fig 9.6.



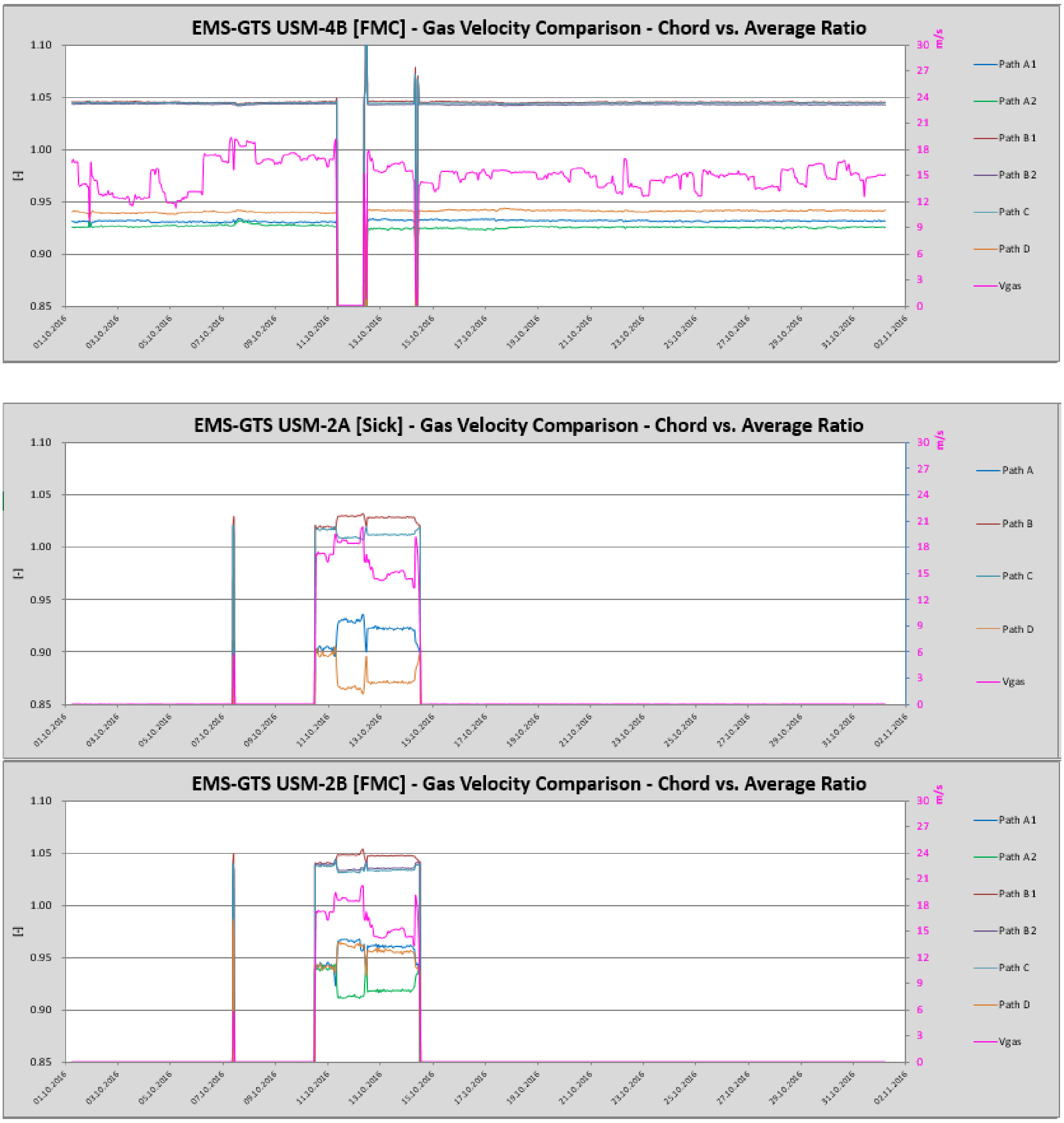


Figure 9.6 Gas velocity ratio per chord

The flow profile flatness gives a relationship between inner and outer chords and gives some information of upstream piping geometry. This should be stable and within limits specified by the vendor. When installation has long and straight upstream length, they normally are around 1.14 for Sick and 89 % for FMC. See figure 9.7.

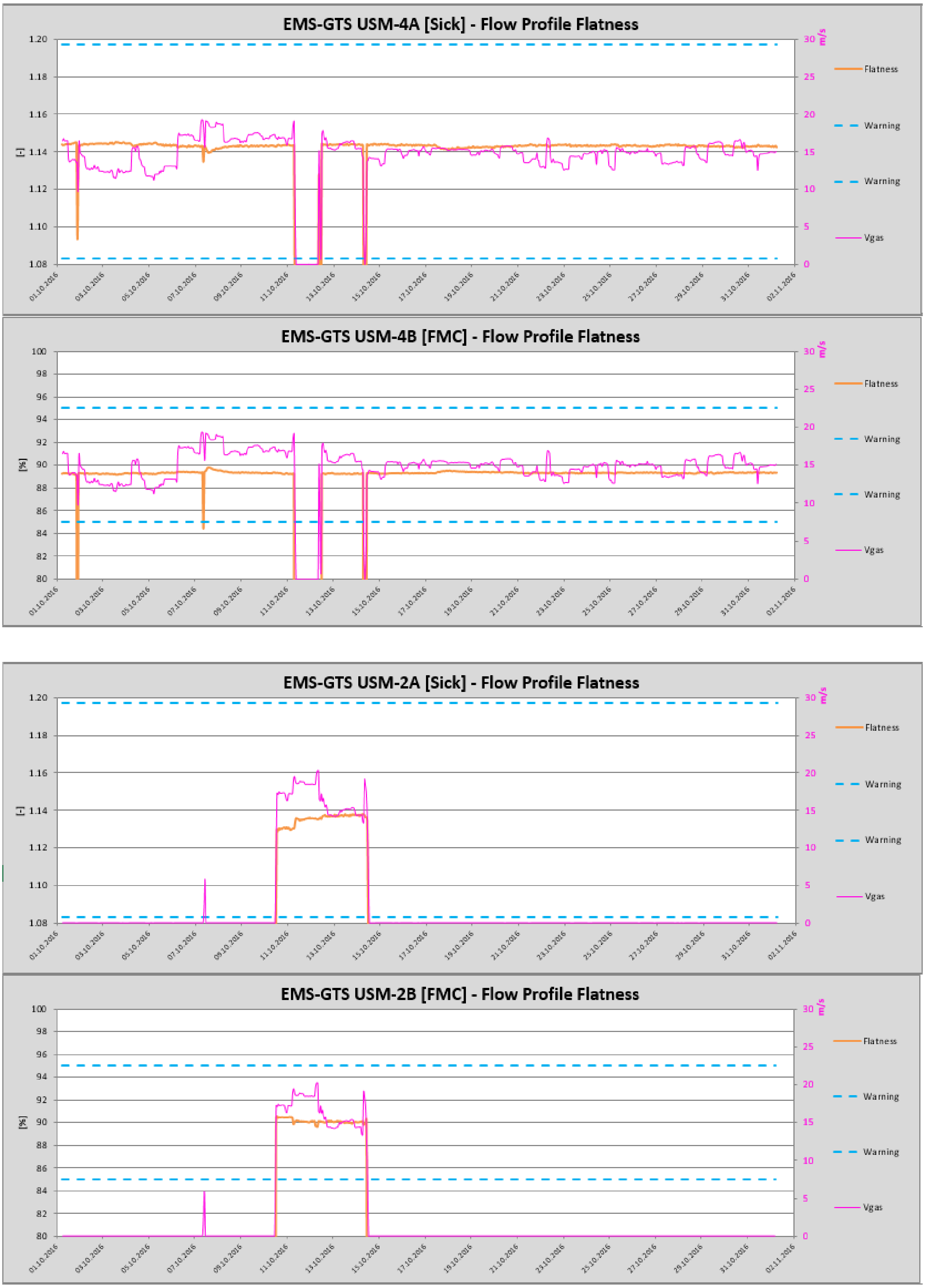
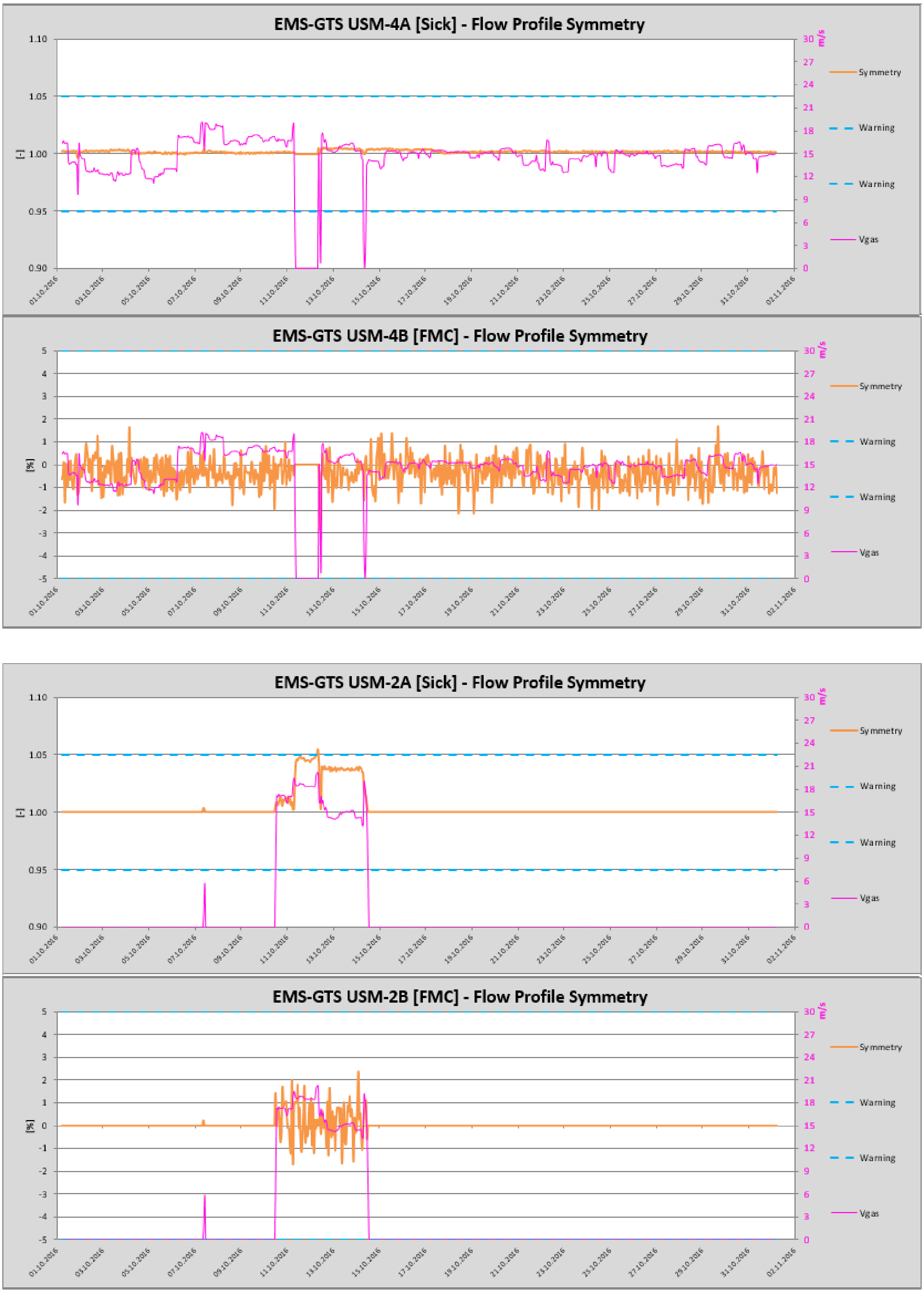
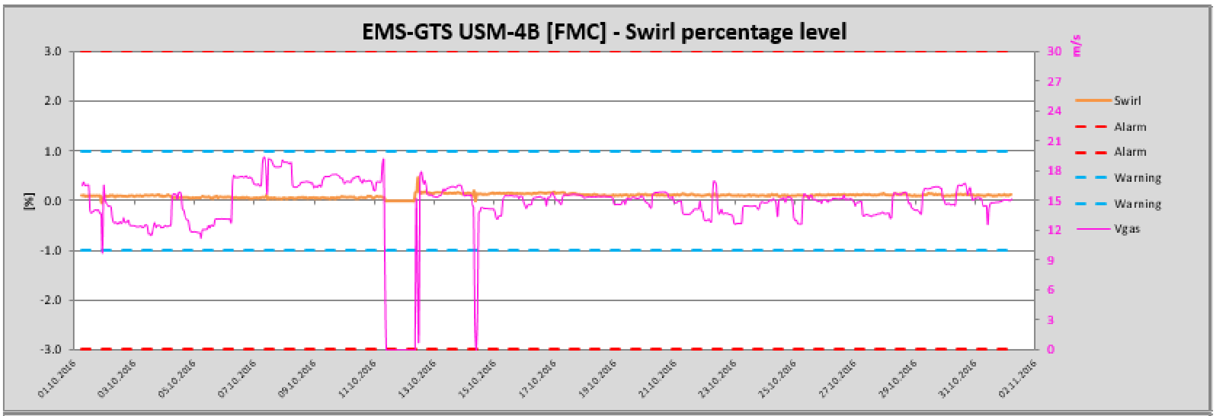


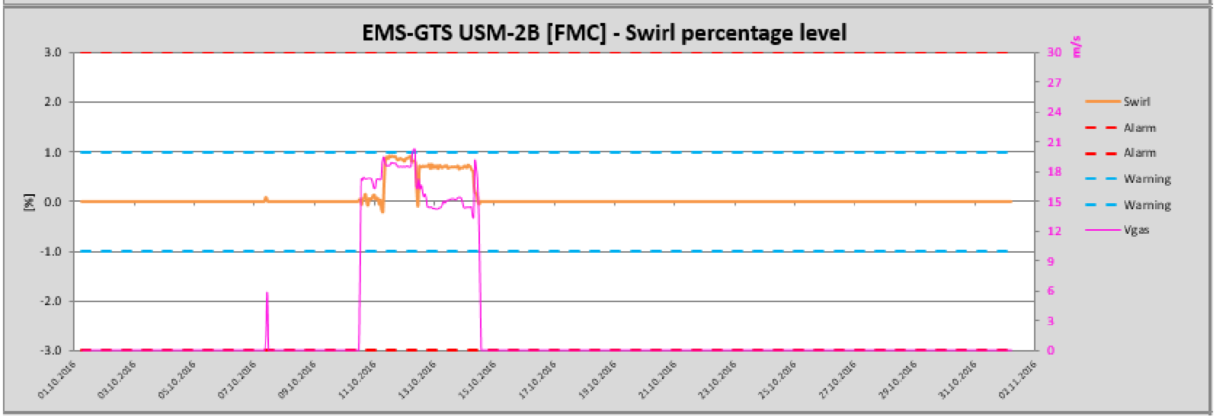
Figure 9.7 Flow profile flatness

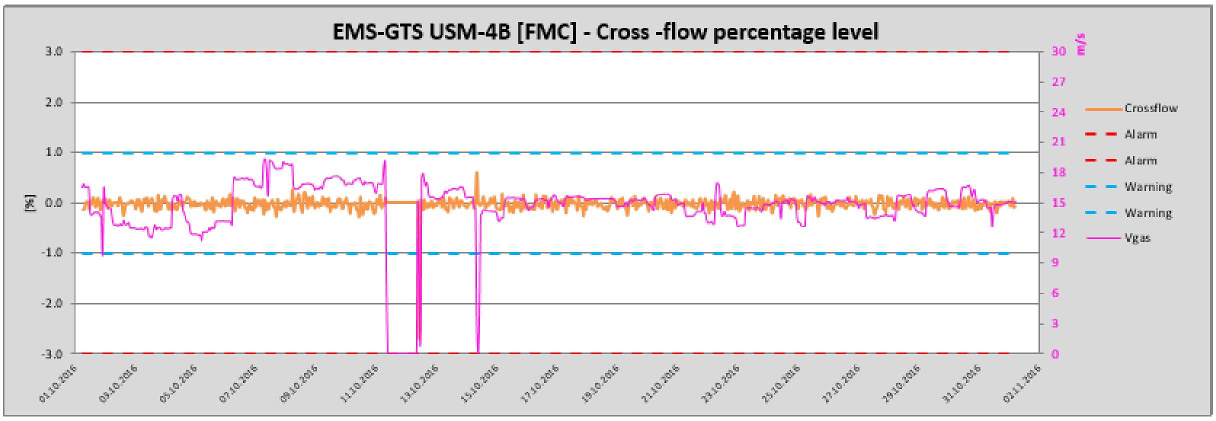
The flow profile symmetry gives a relationship between upper and lower chords and gives some information of upstream piping geometry. This should be stable and within limits specified by the vendor, ideally around 1 for Sick and 0 for FMC. See figure 9.8 underneath.



The swirl percentage gives amount of (clockwise) flow rotation, and cross flow percentage gives amount of dual vortex rotation. Both parameters give some information of upstream piping geometry. They only exist for the FMC meters and these should ideally be stable around 0, and at least within limits specified by the vendor. See figure 9.9, underneath.







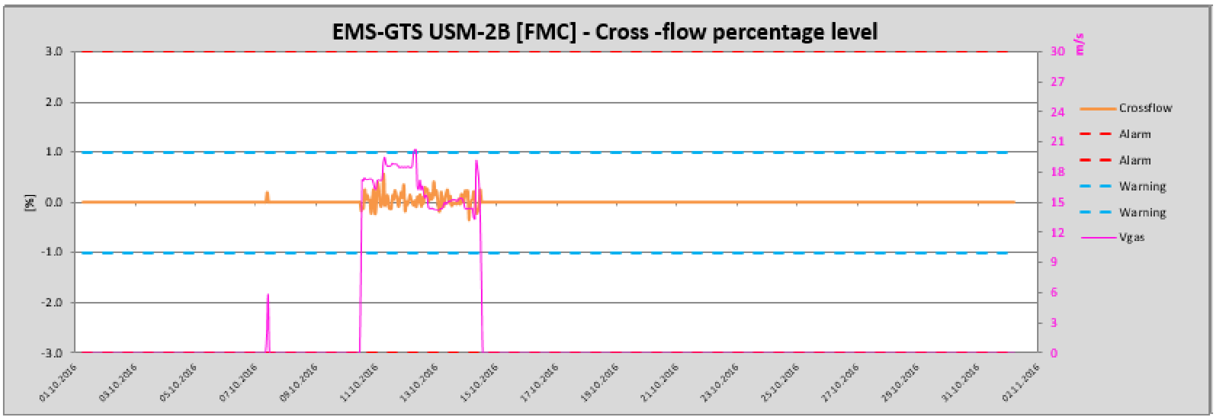
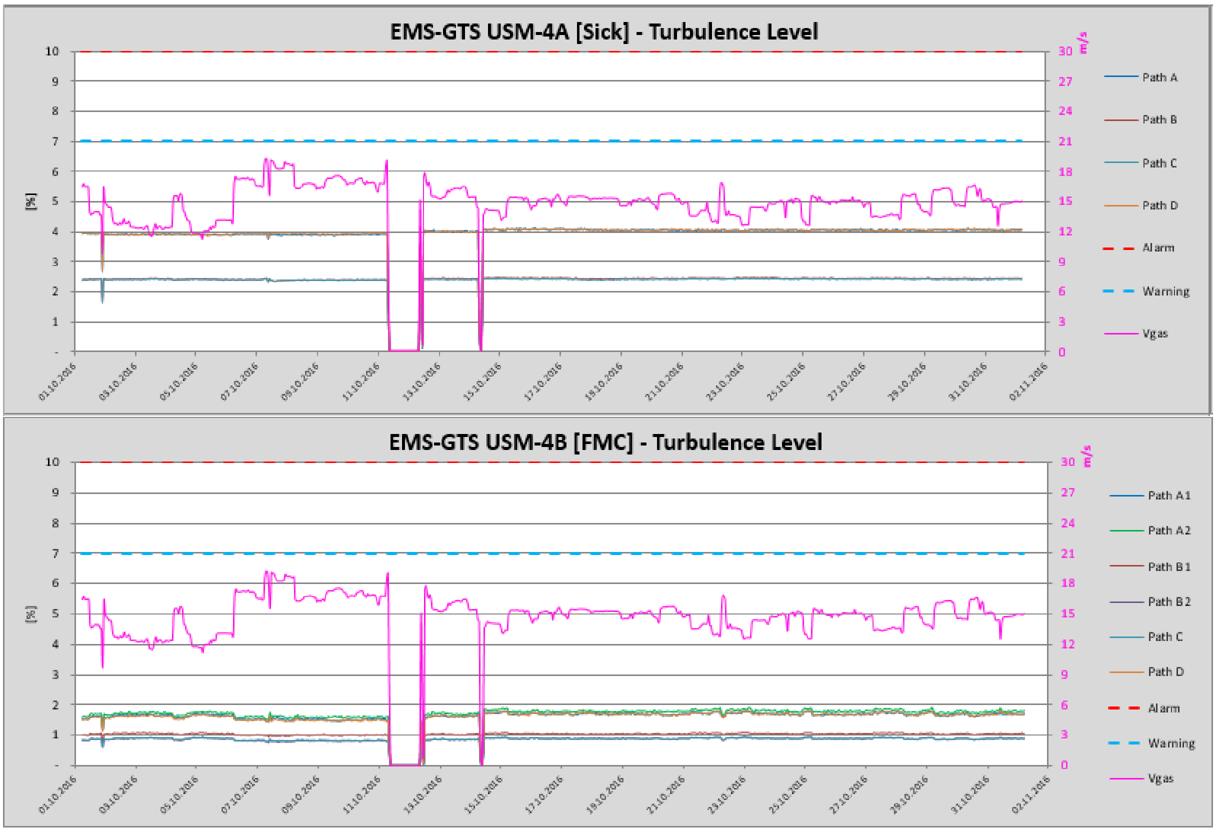


Figure 9.9 Swirl percentage and cross flow percentage

The turbulence level indicates variation in gas velocity (e.g. standard deviation of gas velocity over a certain time period) and may give some information of upstream piping geometry, but higher values can also be caused by equipment like compressors. This parameter should preferably be as low as possible, but higher values do not necessarily indicate faulty readings of the meter. However, if the sampling rate of the USM does not match with the gas flow variations, the uncertainty of the meter will increase. The outer chords will have higher values than the inner chords. See figure 9.10.



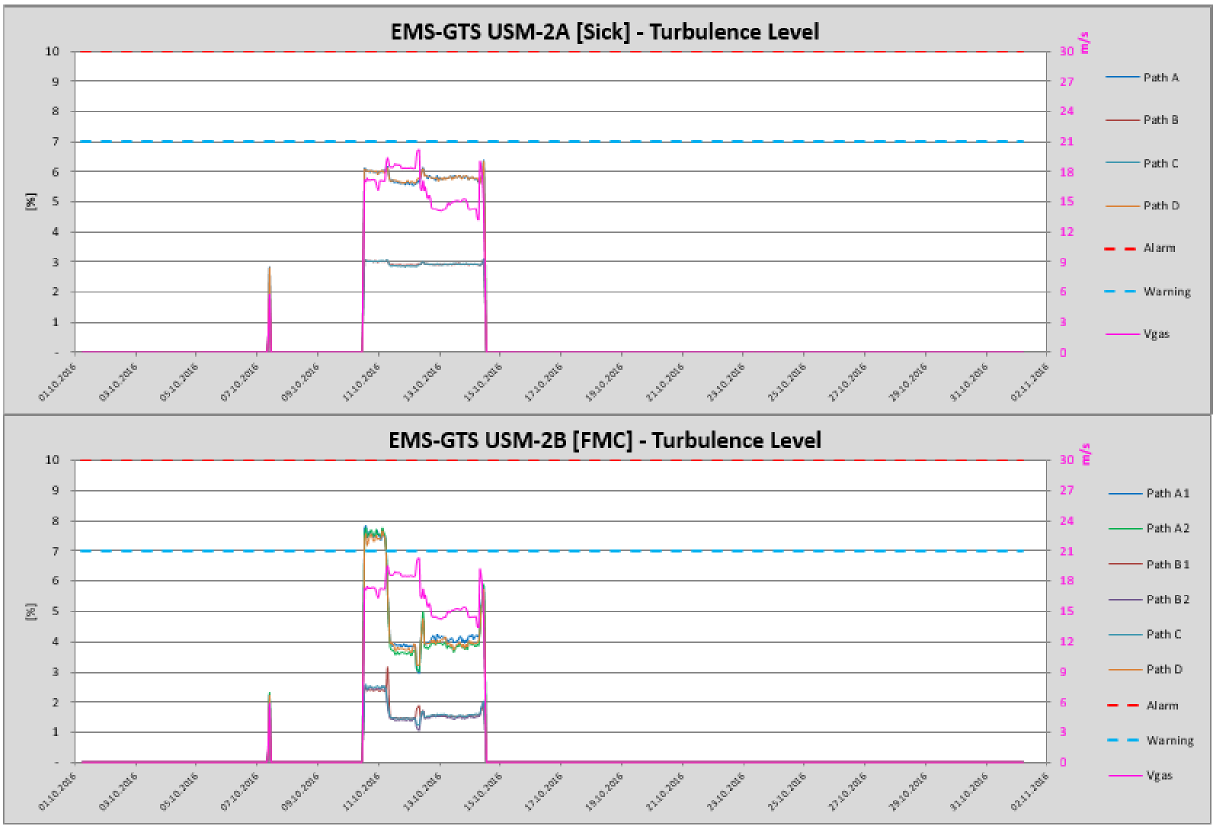
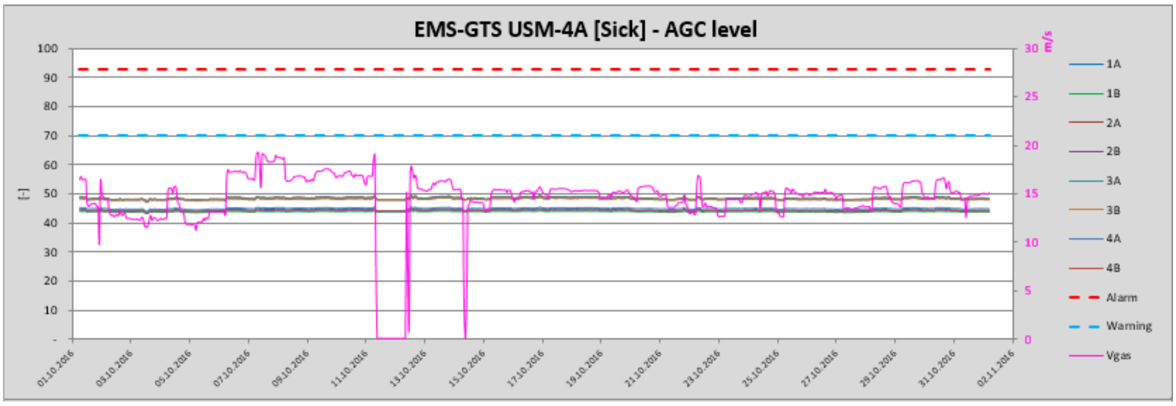


Figure 9.10 Turbulence

As seen on figure 9.10 the turbulence of metering line 2 FMC USM is high in the first period (ca 11 October 2016) but still the gas velocity ratio of the chords show good correspondence, see figure 9.6.

The AGC level is mainly dependent on pressure and path length and should be stable and below limit specified by the vendor, as too high values will result in distorted signal.



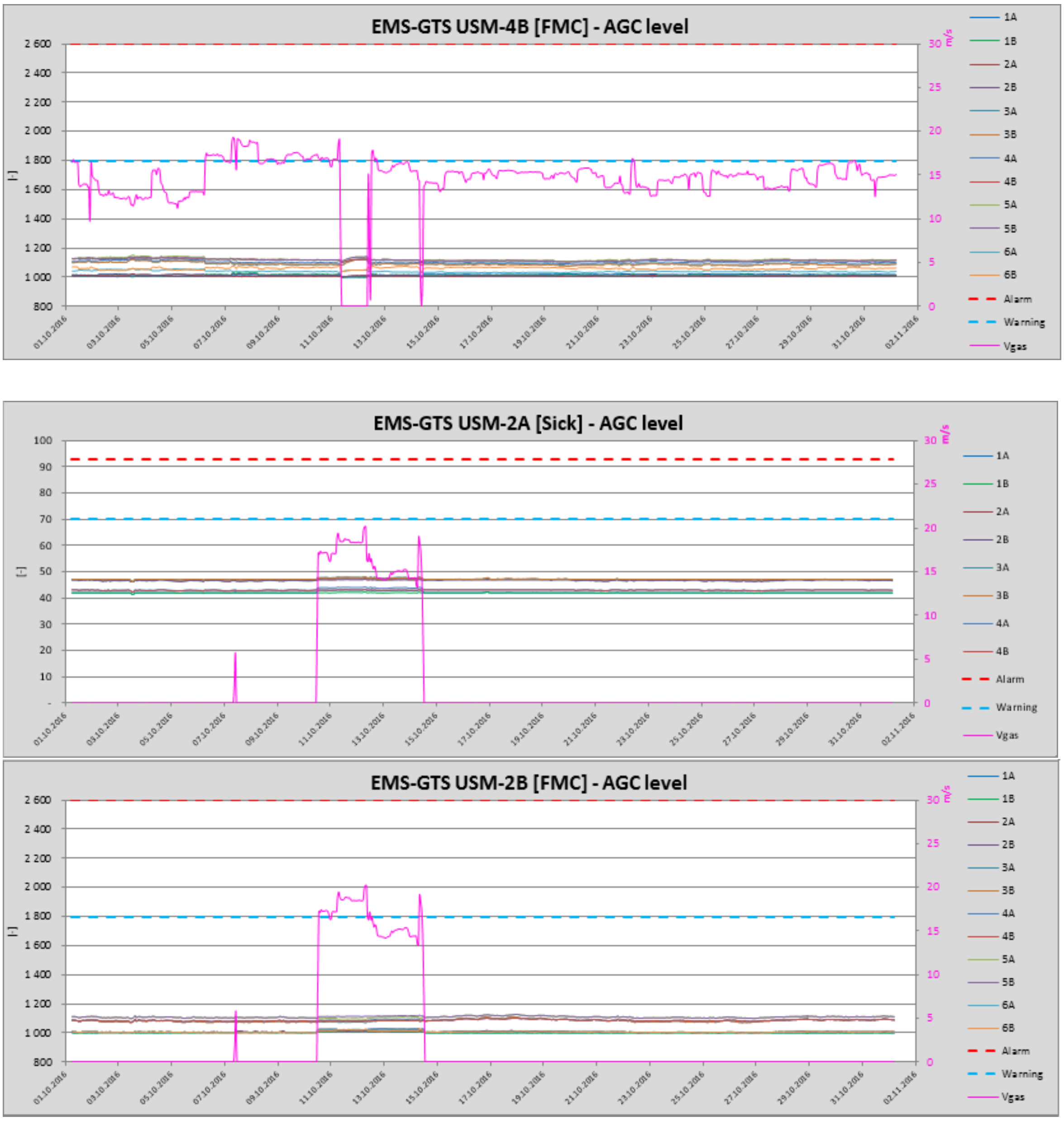
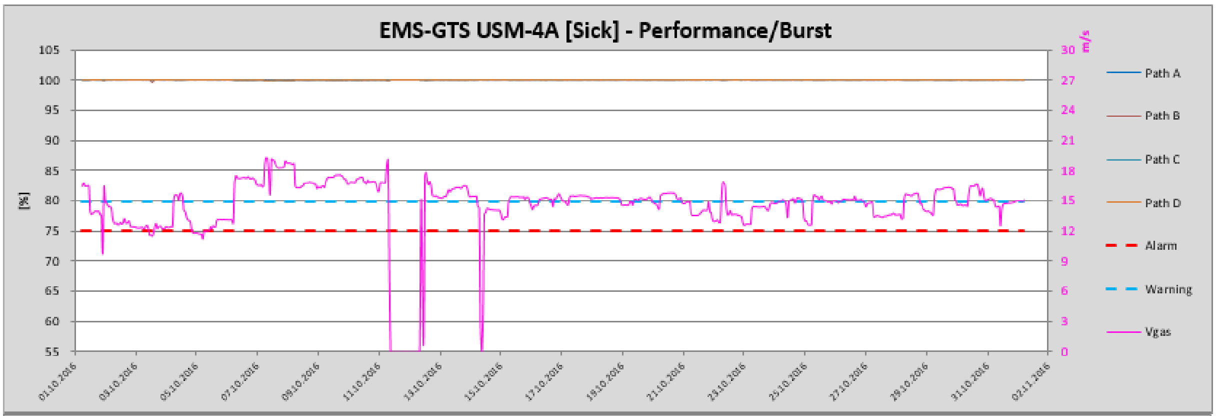


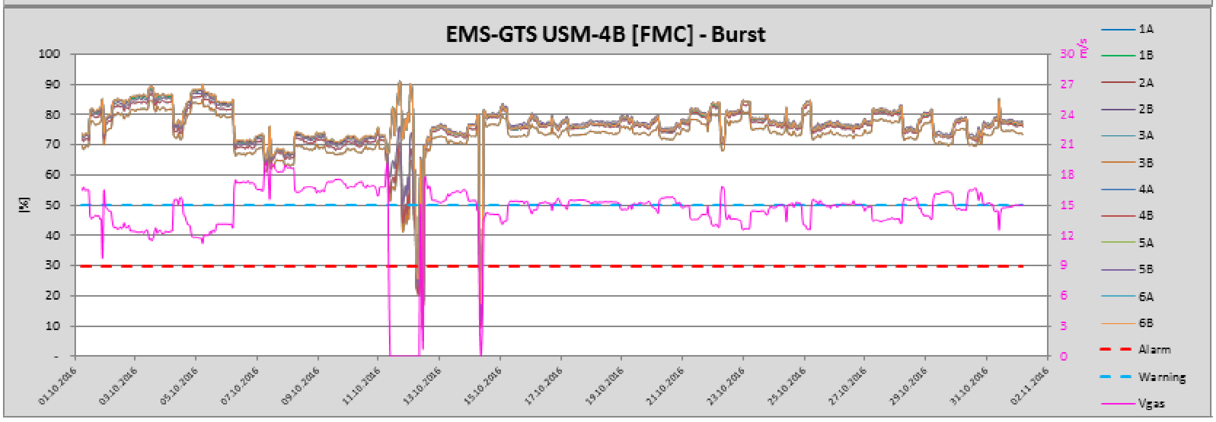
Figure 9.11 AGC level

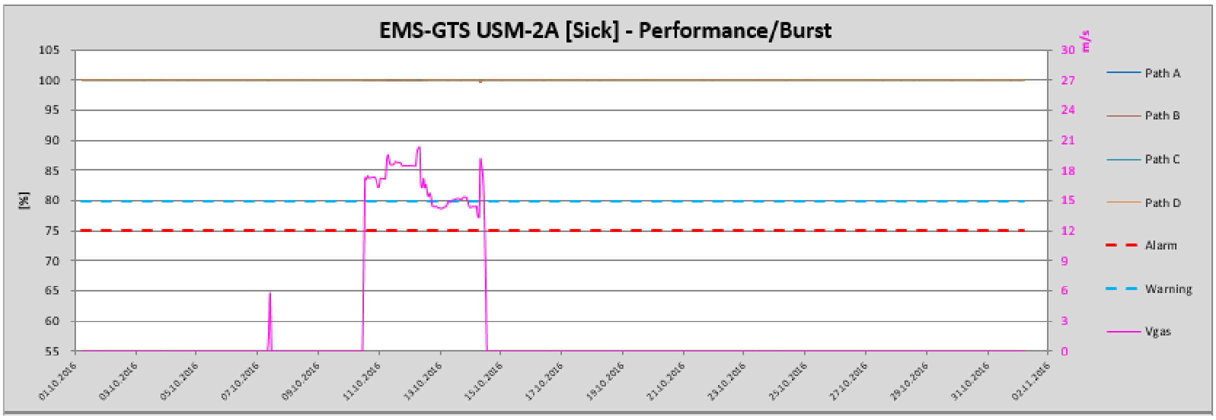
The signal to noise ratio indicates the strength of the signal compared to the noise, and this should be higher than the minimum specified by the vendor.

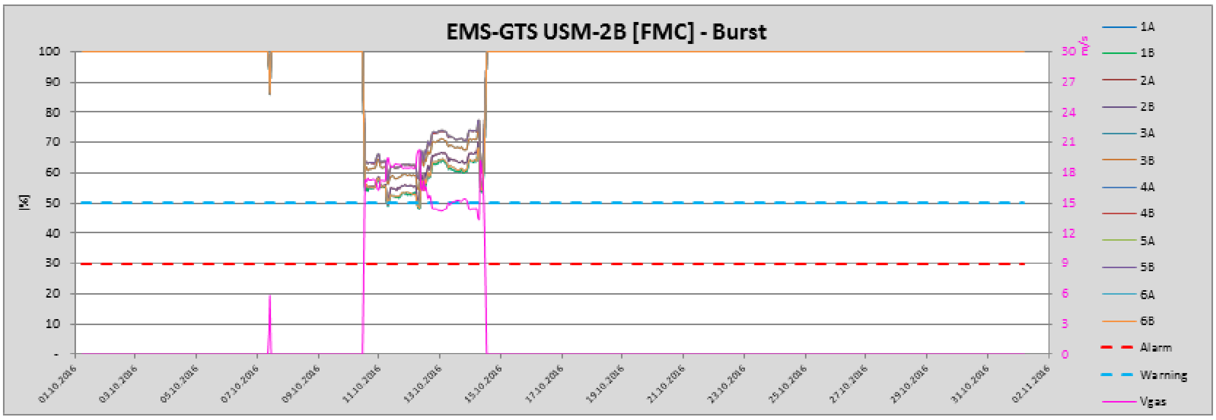
Figure 9.12 Signal to noise ratio

The burst/signal percentage/performance level should ideally be 100 % and preferably above limit specified by the vendor. The number of transmitted signals of the FMC USM is configurable, here 30-35/sec, which is considerable higher than for the Sick USM, here 10/sec. Hence, a lower value of FMC USMs do not influence the accuracy of the measurements in a great deal. Even going below the vendor alarm limit should not harm too much. See fig 9.13. Burst & performance level underneath.









The deviation in actual volume (m^3) of the FMC USM to the Sick USM given as a percentage of the Sick USM figure should preferably be zero.

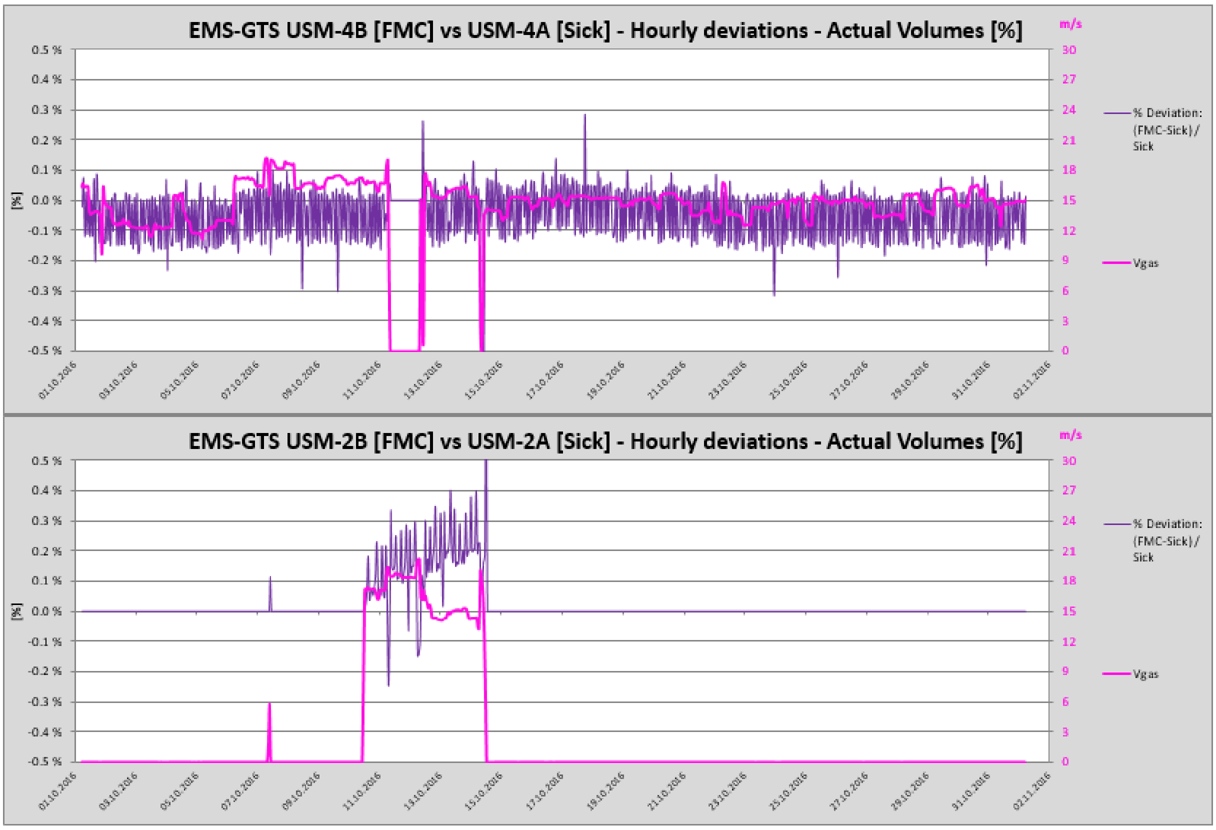


Figure 9.14 Line volume percentage deviation between the USMs

The rest of the figures show data from all lines. The numbers in red shown on metering line 1 indicate which metering lines are in use.

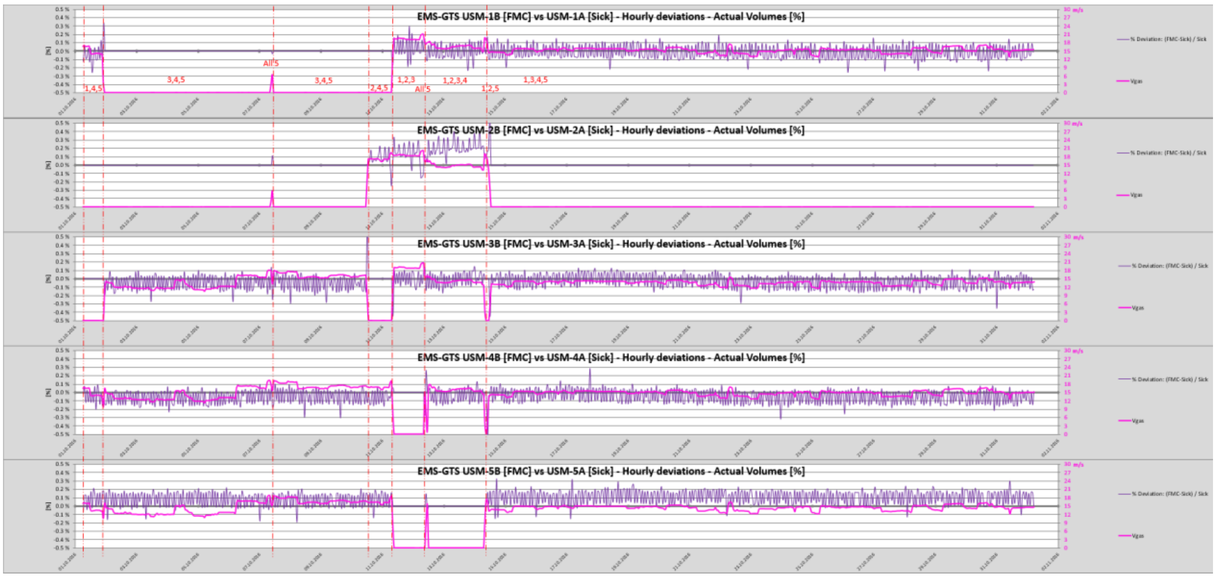


Figure 9.15 Line volume percentage deviation between the USMs, all lines

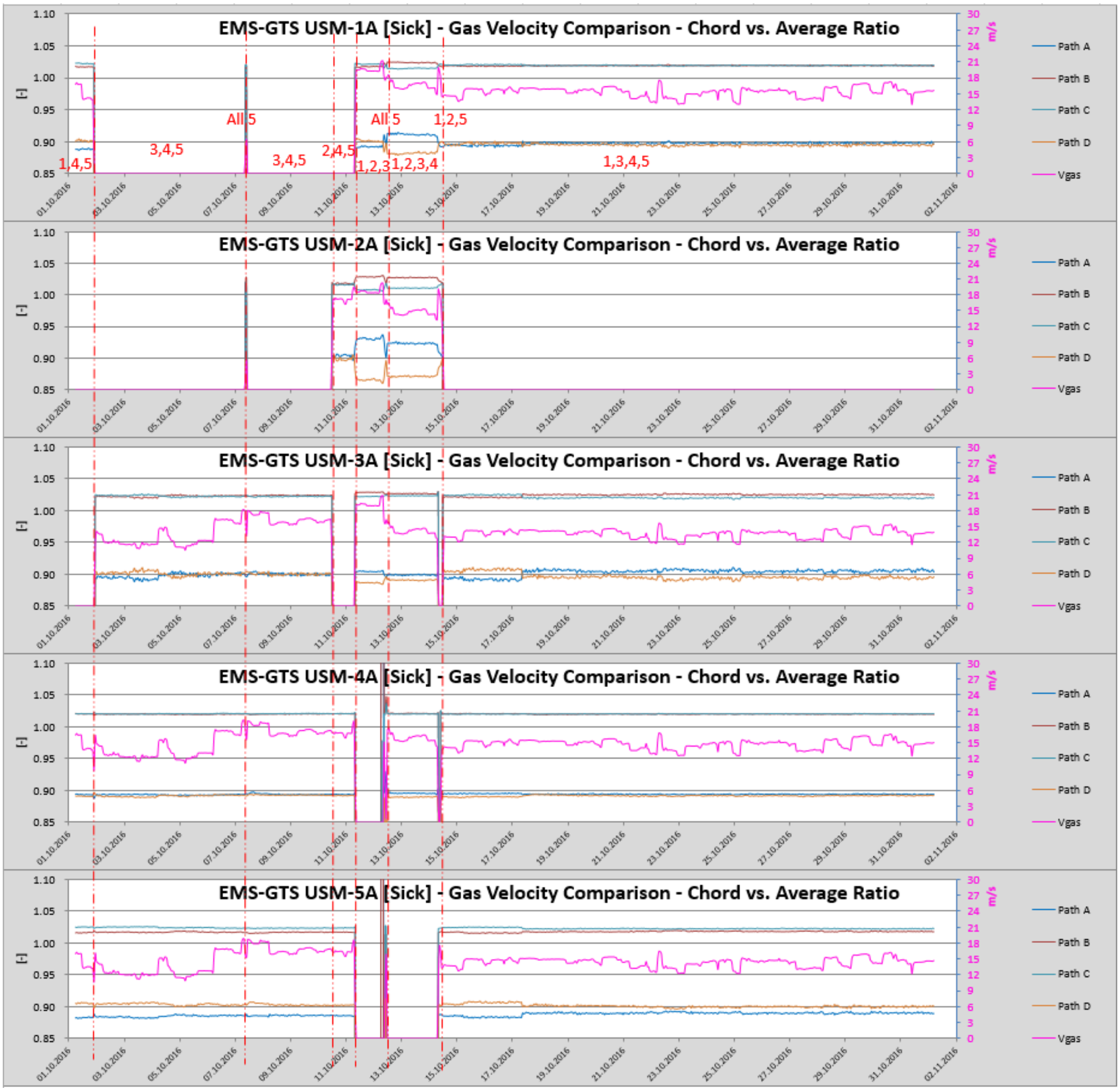


Figure 9.16 Gas velocity ratios of Sick USMs

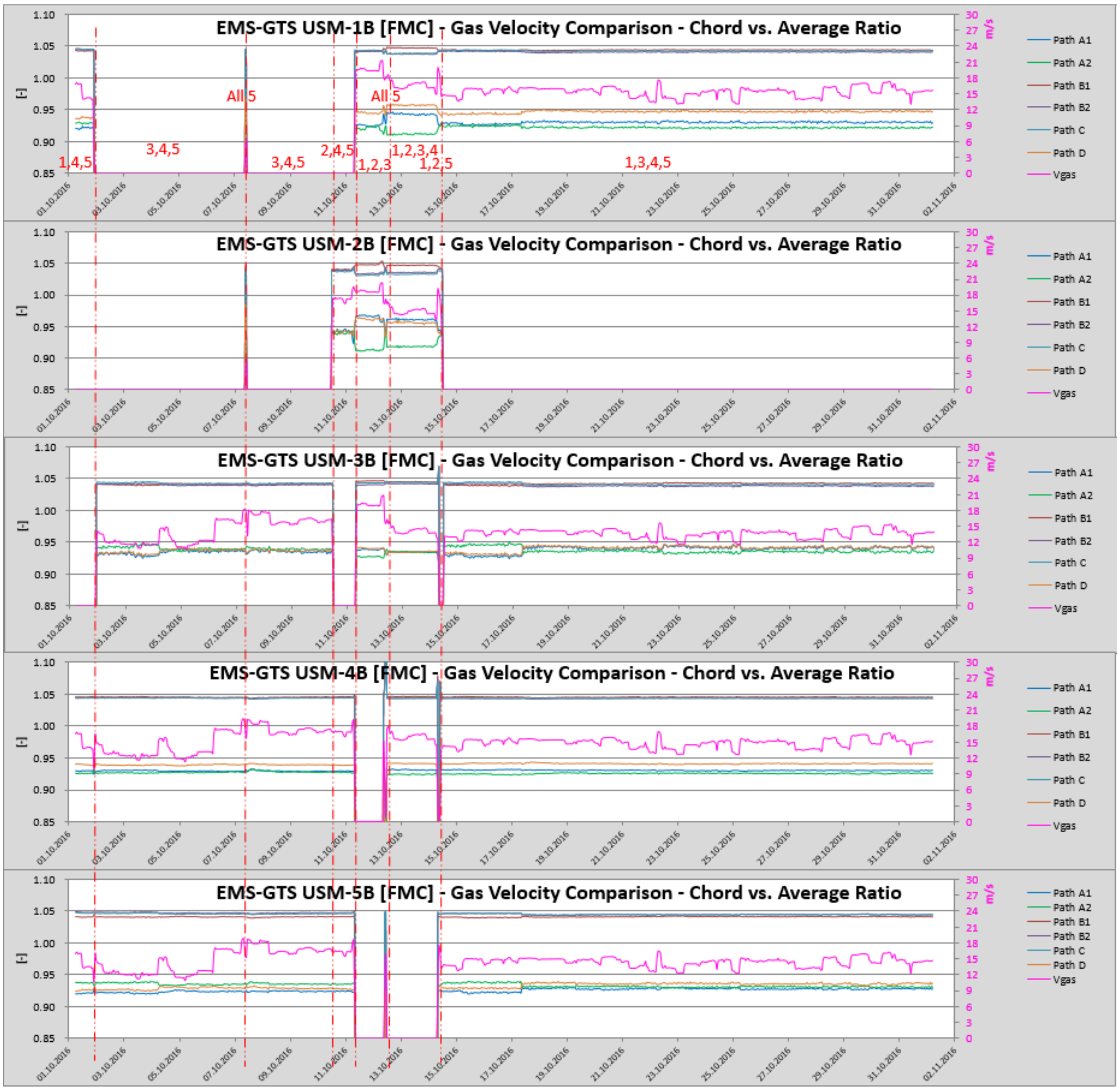


Figure 9.17 Gas velocity ratios of FMC USMs

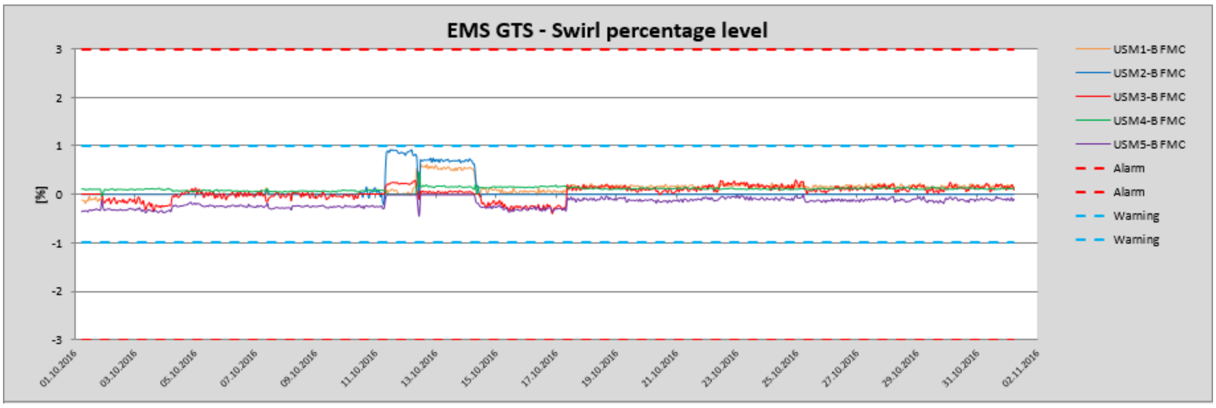


Figure 9.18 Swirl percentage level of FMC USMs

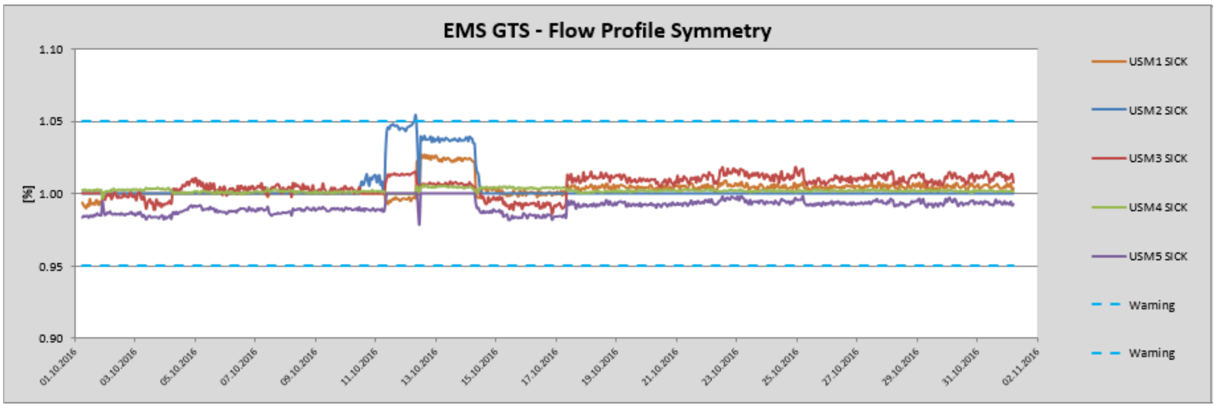


Figure 9.19 Flow profile symmetry of Sick USMs

As seen on figure 9.18 the swirl of the FMC USMand on figure 9.19 the symmetry of the Sick USM have higher values in metering line 2. Also minor increase in line 1. Situation with discrepancy between gas velocity ratios of the chords.

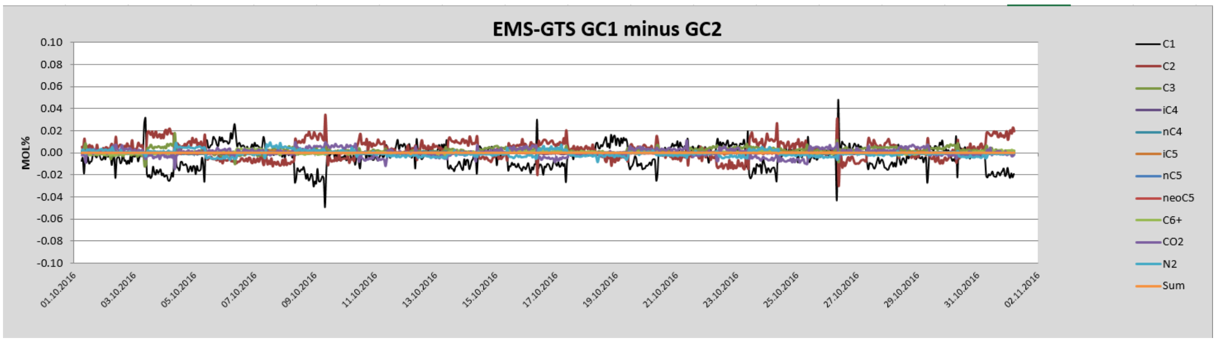


Figure 9.20 GC1 minus GC2 gas components

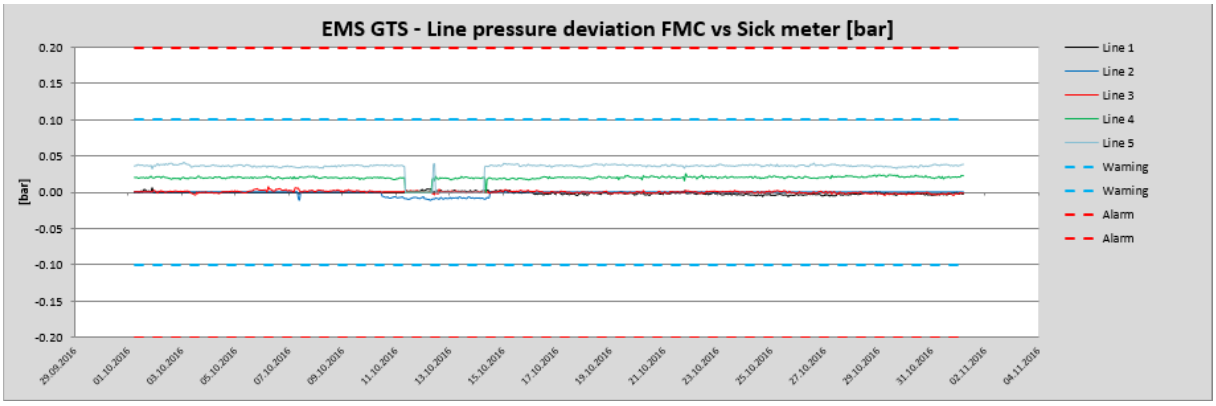


Figure 9.21 Line pressure deviations per line

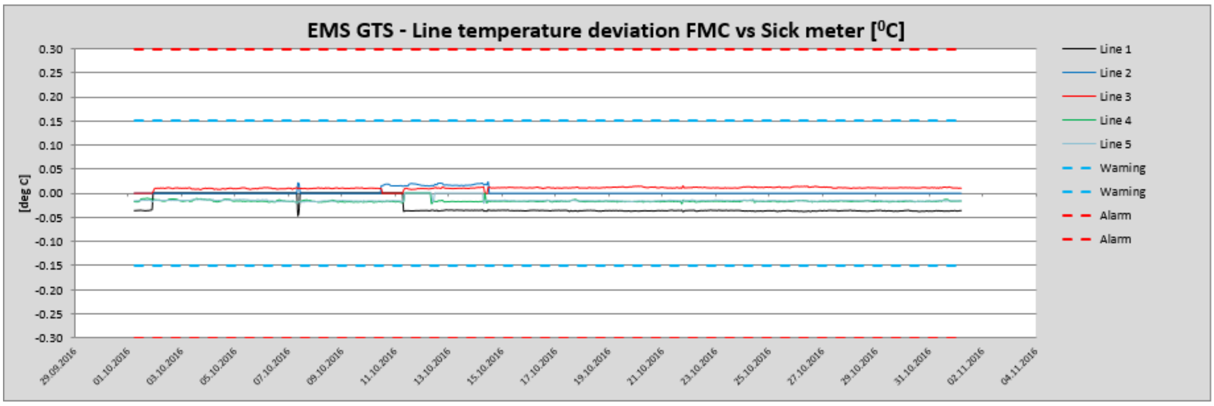


Figure 9.22 Line temperature deviations per line

10. Summary

This was a project with a total value of several millon dollars. It took 4 years to finalize (1 year delayed). All projects are dependent on that all parts are operating synchronized and deliver their parts at expected quality at the right time. The expectation to high quality deliveries would normally increase if critical personnel have been through similar work processes earlier (documented experience). This was not the case for this project and lead to additional effort for the end user. But as in most cases if the people involved are just consistent and dedicated the goal is finally reached.

75 IDs of straight upstream length is not sufficient to prevent disturbed flow profiles if pipe sections upstream metering runs are poorly designed.

CFD analyses are powerful and give impressive detailed and comprehensive results, but they might not always tell the whole truth due to assumptions and limitations set and due to uncertainty in the models.

It seems not to be ideal to have a long header in case of later capacity increase and locate installed meter runs towards one end of it. Unfortunately this was the situation in Emden.

Generally, the USMs show good agreements, but the achieved results varies with metering lines in use. It is useful to log and trend data from the metering station to raise the awareness of how the equipment behaves and to detect drift.

Some of the USM parameters may indicate that the installation is not ideal and they may vary with operational conditions like metering lines in use or flowrate, but this will not be improved by re-calibrating the meters.

Generally the USMs show good agreement.

11.References

1. Memorandum of Understanding between Norway and Germany regarding fiscal metering
2. Norwegian regulations regarding fiscal measurements
3. German regulations regarding fiscal measurements
4. AGA 9
5. ISO 17089 part 1
6. Christian Michelsen Research (CMR) Computational Flow Design (CFD)
7. GEP project project documentation
8. SICK product information
9. FMC product information
10. Euroloop calibration documents
11. Gassco operating documents and operating data