New Generation Multiphase Flowmeters from Schlumberger and Framo Engineering AS

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Abstract

The cooperation between Schlumberger and Framo Engineering has resulted in a significant step forward in multiphase flow metering. This paper describes a new instrument, called **VenturiX,** which will be implemented in two new products: **PhaseTester**, dedicated to Periodic Testing services, and **PhaseWatcher,** dedicated to Permanent Monitoring applications.

The **VenturiX** is a compact instrument consisting of a venturi and a dual energy composition meter located at the Venturi throat and interrogated at high rate. The meter response is flow regime independent so no upstream flow conditioning is needed. It has been extensively tested over the last three years in several flow loops and in real field conditions. The results of these tests are reviewed.

1 Introduction

At the beginning of 1997, Framo Engineering AS and Schlumberger recognized that, although they were concerned by different applications - permanent monitoring for Framo, periodic testing for Schlumberger - they had reached similar conclusions and were developing similar technologies to meter multiphase flows. They decided to join forces in order to produce innovative solutions in this domain. A joint Technology and Marketing Center, called 3-Phase Measurements AS, was created at Bergen (Norway) where Framo Engineering AS is based, and staffed with personnel seconded by both companies.

This cooperation gave birth to a common three-phase meter called **VenturiX**. Three experimental prototypes have been built so far and extensively tested in several flow loops and against test separators in field conditions. A Pilot Series is being manufactured.

The **VenturiX** design is particularly compact, a mandatory requirement for periodic testing applications: it simply combines a venturi and a dual energy composition meter located at the venturi throat. The key feature is that the composition meter is scanned at high rate. The **VenturiX** response is particularly robust (independent of inlet flow regime), the most challenging requirement for multiphase flow meters, so no upstream flow conditioning is needed.

The **VenturiX** will be implemented in two products dedicated to different applications: **PhaseTester**, for periodic testing services, and **PhaseWatcher**, for permanent monitoring sub sea and topside.

This paper is aimed at explaining why the compact combination of a venturi and a dual energy composition meter is insensitive to flow-regimes, hence especially suitable for multiphase flow metering. It will also review the test campaigns carried out over the last three years covering a wide variety of flow conditions, in order to fine tune, step by step, the **VenturiX** interpretation model and make it flow regime independent.

2 History of the concept

In 1989, Framo Engineering AS started developing a multiphase flowmeter for Permanent Monitoring applications, sub sea and topside. The priority was to overcome what is now recognized as the most difficult challenge in multiphase flow metering to get a robust instrument that could be installed on any well whatever the flow conditions. This is why the meter was built around a straightforward concept backed up by well-proven technologies: a multiphase flow mixer aimed at damping the slugs and homogenizing the flow, a venturi and a dual energy composition meter. Framo commercialized their first meter in 1994. Since that time, 37 meters have been sold.

In 1990, Schlumberger started a program, first at Schlumberger Cambridge Research then at Schlumberger Riboud Product Center, aimed at producing a multiphase flowmeter for periodic testing applications. The objective was to replace the traditional well test separator. The two main motivations were to save costs and to improve data quality. Since the meter is required to travel from well to well, the critical design criterion were a compact design and a robust answer.

Schlumberger's multiphase program met early with failures from which important lessons were drawn.

A first instrument, called GVXM, was designed in 1994. The meter was intended to measure only the liquid and gas rates (the water cut was obtained from a liquid sample). It used a redundant combination of sensors: a Gradio-manometer, a Venturi and a velocity measurement based on Cross-Correlation between differential pressure sensors.

Two prototypes were extensively tested, first at Elf Pecorade and Agip Trecate flow loops, then against a test separator in the Middle East over a period of six months in real periodic testing conditions. Compared with the encouraging flow loop tests, the results of the field test were frustrating: 75 % of the liquid rates were within the 5 % targeted accuracy, but some liquid rates were out by 20 % or more; 80 % of the gas rates were within the 10 % targeted accuracy, but some gas rates were out by 30 % or more.

It was recognized that the GVXM interpretation model is flow regime dependent. It was discovered that the cross-correlation is an ambiguous velocity measurement, not resulting in the same answer in bubbly flows and in slug flows. For similar reasons, the interpretation of the gradio-manometer, in terms of effluent density, is questionable at high Gas Volume Fraction.

The GVXM project was closed at the end of 1996.

3 The VenturiX key concepts

Having spent a lot of time and money, Schlumberger had developed a few strong convictions.

1 Flow rates must be evaluated in terms of mass (which are conservative), not in terms of volumes (which are not)

2 To be compact, a multiphase flowmeter must accommodate any flow regime without the help of any upstream mixing device.

3 To accommodate slug flows, the composition meter needs to be interrogated at high rate.

4 A Venturi is an efficient flow conditioner.

5 The pressure drop across a venturi can be interpreted in terms of total mass flow rate, provided the fluid density is evaluated at the throat.

6 At the throat of a venturi, the slip law is flow regime independent because it is dictated by stringent fluid dynamic equations.

7 Any three phase composition meter must combine two different measurements. In this regard, a dual energy composition meter has a formidable advantage. Both measurements are performed at the same time and at the same place: both sense the same flow.

At this stage, it became clear that Schlumberger and Framo Engineering AS had selected the same well proven technologies - a venturi and a dual energy composition meter - but were using different strategies to deal with unsteady flows. It was acknowledged that Schlumberger's approach was attractive, because it was opening the door to a significantly more compact design. It was also recognized that the robustness of the **VenturiX** had to be checked against a wide variety of flow regimes. The test program needed to include well controlled environments, such as flow loops, where fluid properties and reference rates are indisputable, and also test separators in real field conditions where environmental parameters are usually not controlled.

4 Flow loop tests

Over the last three years, the **VenturiX** underwent six flow loop campaigns in five different sites totaling over 1,400 flow periods with different fluids, different line pressures and variable flow regimes. As summarized in the table below, each campaign was an opportunity to test the model against different environmental parameters and to refine it. Since the **VenturiX** stores raw data, a Schlumberger requirement, each model upgrade has been checked against the whole set of available data.

Date	site	flow periods	Issues
Q1 1997	SRPC (France)	200+	Venturi pressure-drop model and slip-law Quite steady flows. Line pressure up to 4 bars
Q2 1997	NEL (Scotland)	160	Unsteady flows. Line pressure up to 4 bars Fast processing of the Composition Meter
Q4 1997	Framo (Norway)	40	Line pressure up to 10 bars
Q1 1998	IFP (France)	210	Line pressure up to 30 bars Fluid Property Model
Q4 1998	CEPRO (Venezuela)	250	**Oil viscosity up to 2300 cPo**
Q2 1999	NEL (Scotland)	500	Multiflow II JIP. The ultimate qualification

The results of all of these tests using the latest version of the interpretation model are shown in the attached figures.

5 Field Tests against Test Separators

In Q4 1998, two additional prototypes were built and sent to the Field where they were evaluated in series with a test separator in typical Periodic Testing conditions. The results of three campaigns have been analyzed so far. The conditions are summarized in the table below. Two more campaigns were begun in Q3 1999, in Nigeria and in Venezuela.

Campaign	# 1	# 2	# 3	#4	#5	#6
Date	Dec 98	Jan 99	May 99	June 99	Aug 99	Sept 99
# of flow periods	38	38	27	22	10	2
# of wells tested	8	5	7	1	6	1
Line pres. (psia)	260-1200	150-1380	100-140	1000-1200	40-120	190
GVF (%)	60-90	60-98	70-97	92-94	0-90	93
Oil visc. (cPo)	< 15	< 15	**100-2000**		**140-620**	**200**
Liq. rate (blpd)	2500-11000	900-4800	500-1750	2200-6600	1000-6000	500-600
Gas rate (MMscfd)	2-8	0.8-10	0.3-1.5	13-46	0-0.1	0.3-0.5

The main results are shown on the following figures.

On Figure 7, the **VenturiX** liquid flow rate is plotted against the separator.
On Figure 8, the **VenturiX** gas flow rate is plotted against the separator.
On Figure 9, the error on the water/liquid ratio is plotted against the gas volume fraction at line conditions. (Note that the targeted accuracy is 5% absolute up to 90% GVF).

6 Design Specifications

The following specifications apply to a 4” **PhaseTester** (skid-mounted, portable module for periodic testing).

Design Specifications	
Weight	1,500 kg
Size	1.5 x 1.6 x 1.7 m
Power consumption	50 W
Chemical source activity	100 mCi
Hazardous area	Zone 1
Ingress protection	IP67
Line pressure rating	5,000 psi
Line temperature rating	-20 +150°C
Ambient temperature	-20 +85°C

	Maximum Design uncertainty (up to 90% GVF)		
	Liquid Rate	Gas Rate	Water/Liquid Ratio
Max. of	5% of reading 2.5% of full scale	10% of reading 5% of full scale	5% absolute
Full scale	155 m^3/h	800 m^3/h	100%

6 Conclusions

The **VenturiX** is an innovative multiphase flow meter designed initially by Schlumberger to replace conventional test separators in periodic testing operations. It has been jointly industrialized by Schlumberger and Framo Engineering AS, benefiting from Framo’s expertise in fluid process and sub sea installations, as well as from Schlumberger’s expertise in instrumentation and well testing.

The **VenturiX** is based on reliable and well-proven technologies. Venturi’s and nuclear densitometers have been used by the oil industry for a long time. It is compact because it does not require the help of any upstream flow-conditioning device. It accommodates unsteady flows because the Composition Meter is scanned at high rate. Its response is flow regime independent because gas/liquid flows are severely constrained while passing through a convergence.

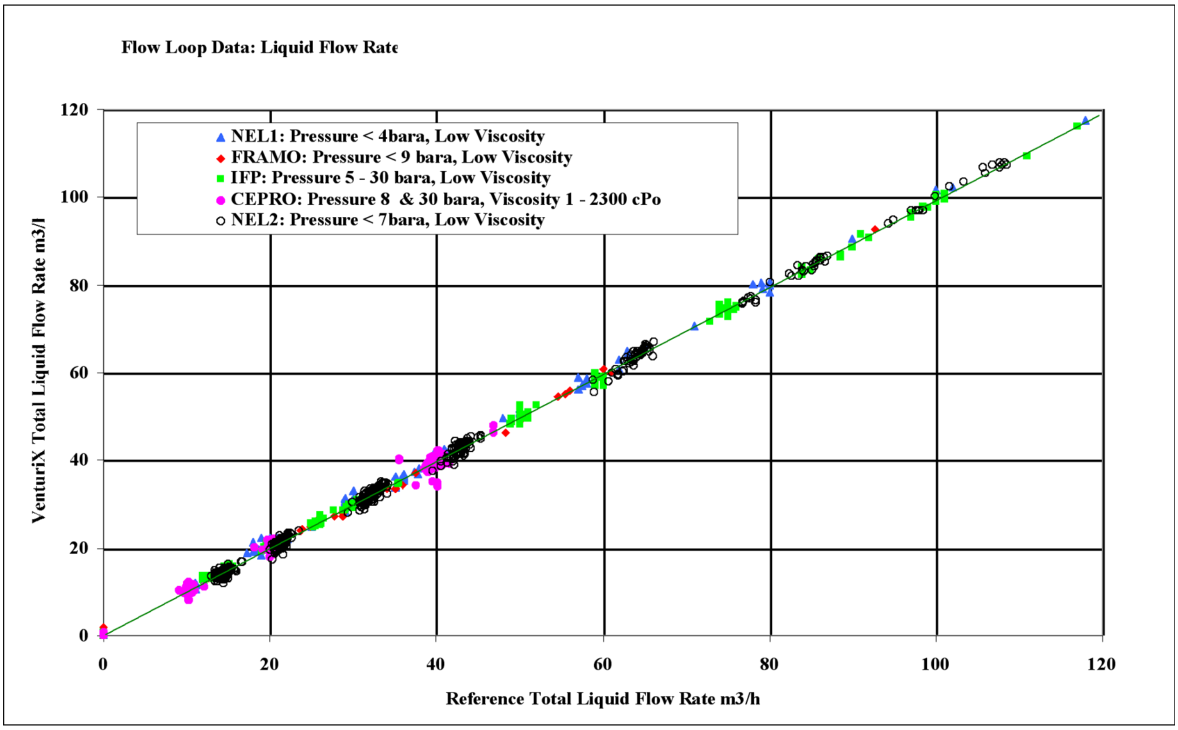
The robustness of the **VenturiX** interpretation model has been carefully checked over the last three years in a large variety of flow conditions in several flow loops and in real field conditions.

The **VenturiX** technology is being currently implemented in two products that will be available to the oil industry in a near future:

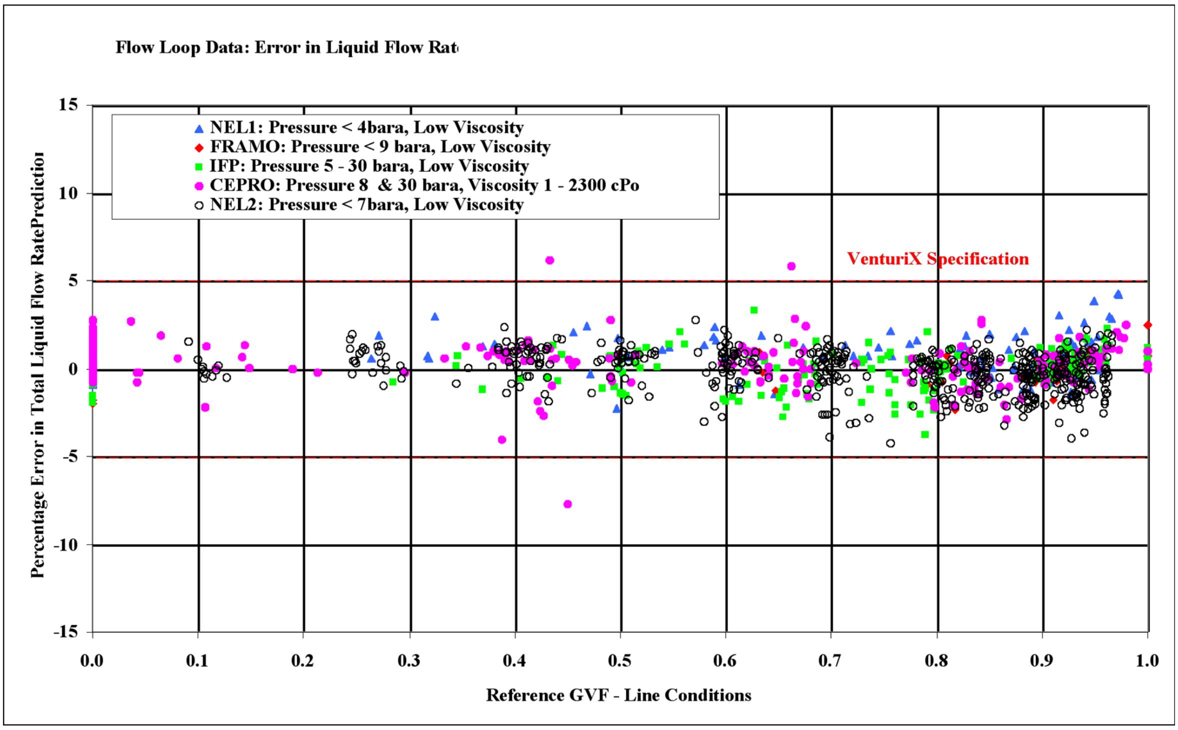
PhaseTester for Periodic testing applications

PhaseWatcher for Permanent monitoring applications

VenturiX Flow-loop data

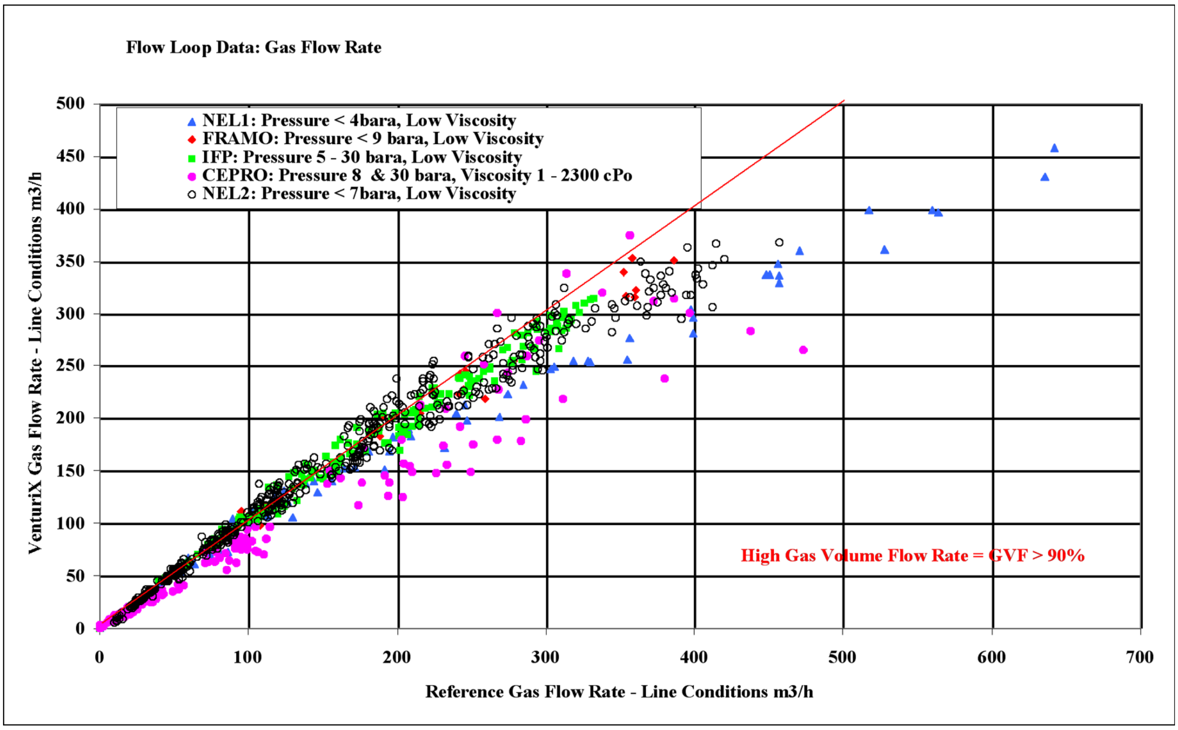


Predicted Liquid versus reference liquid (at line conditions) Fig. 1

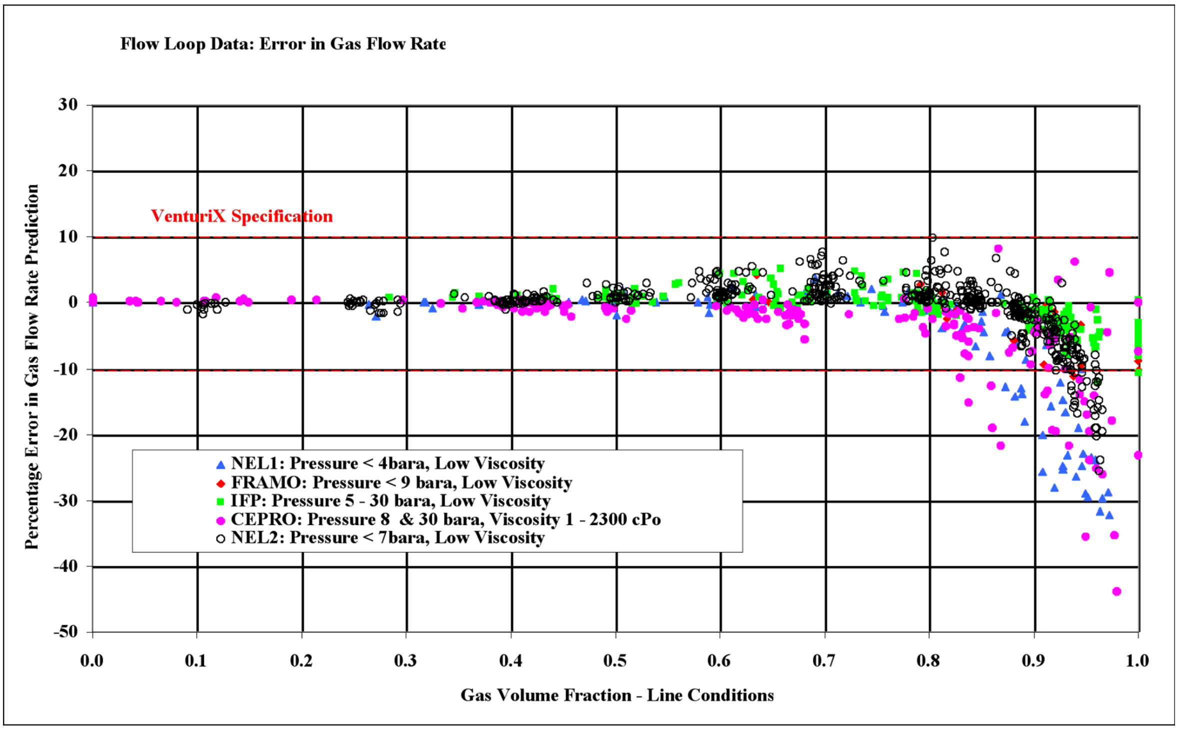


Liquid percentage error (at line conditions) Fig. 2

VenturiX Flow-loop data

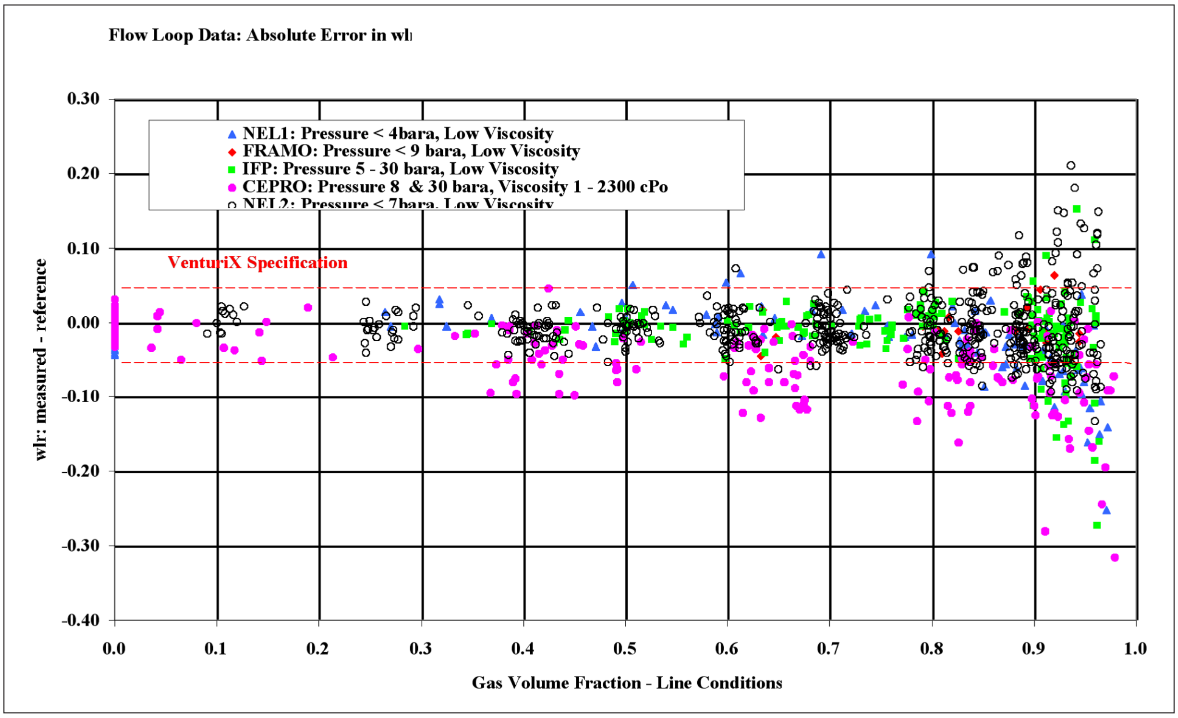


Predicted Gas versus reference gas (at line conditions) Fig. 3

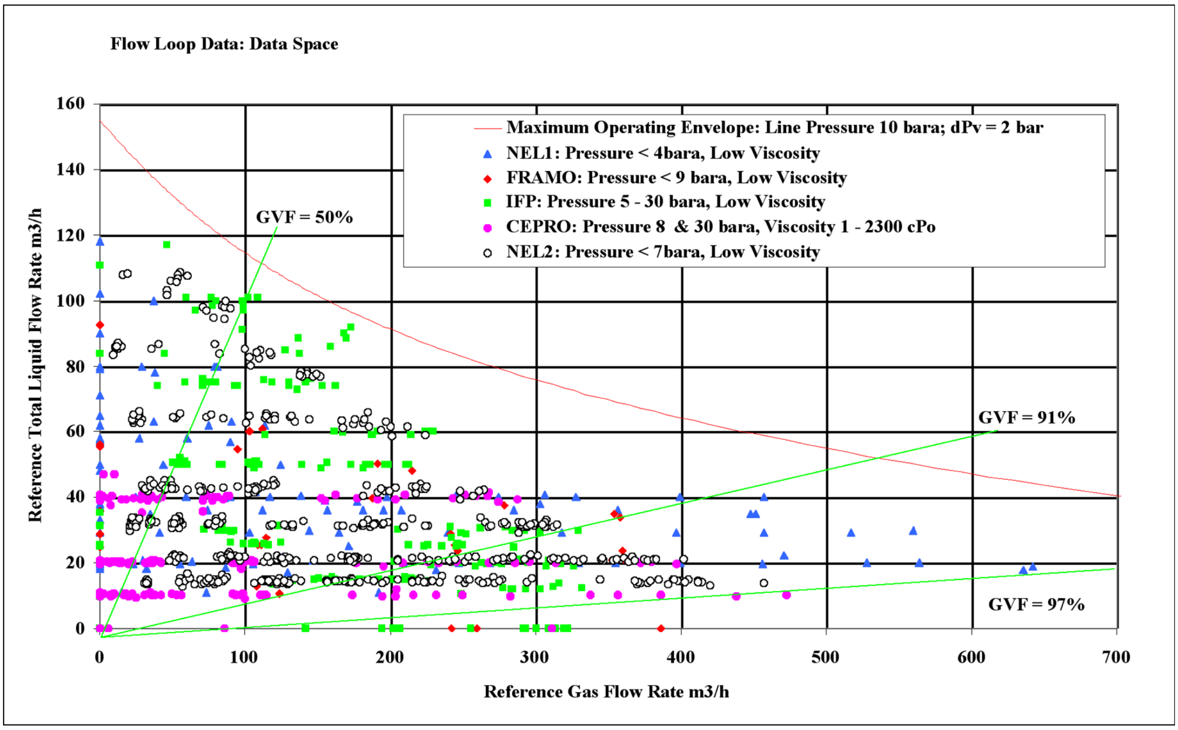


Gas percentage error (at line conditions) Fig. 4

VenturiX Flow-loop data

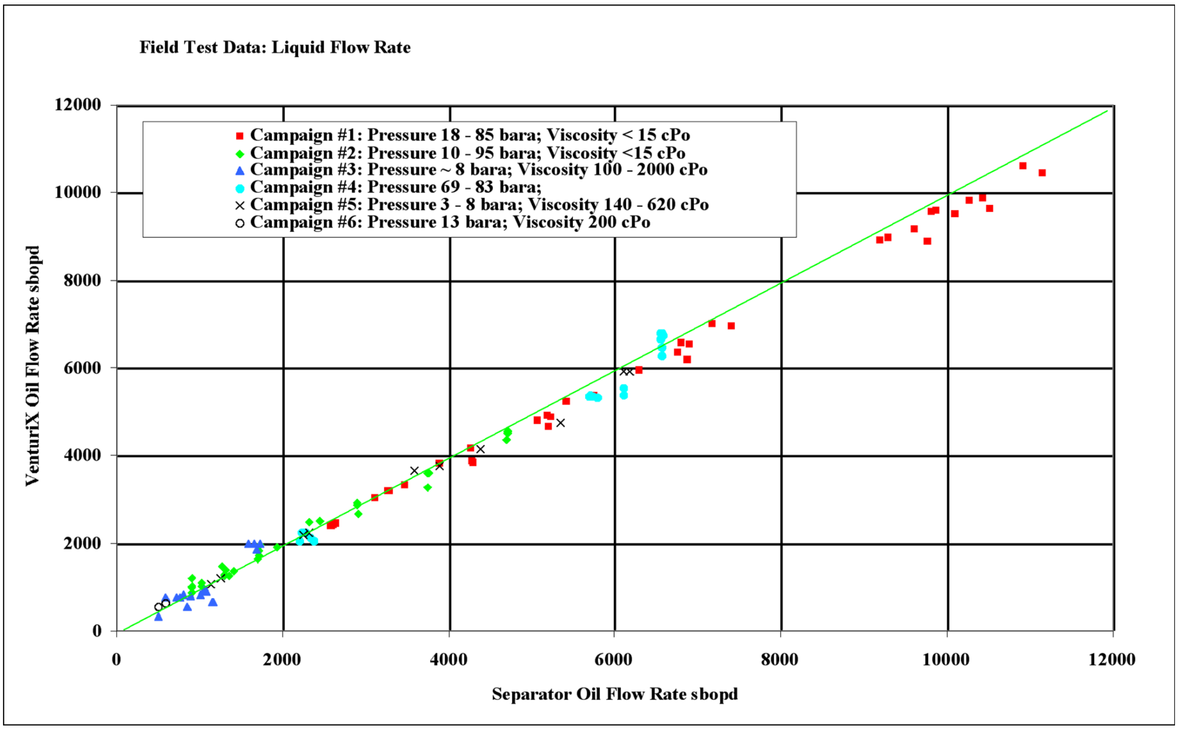


Water Liquid Ratio absolute error Fig. 5

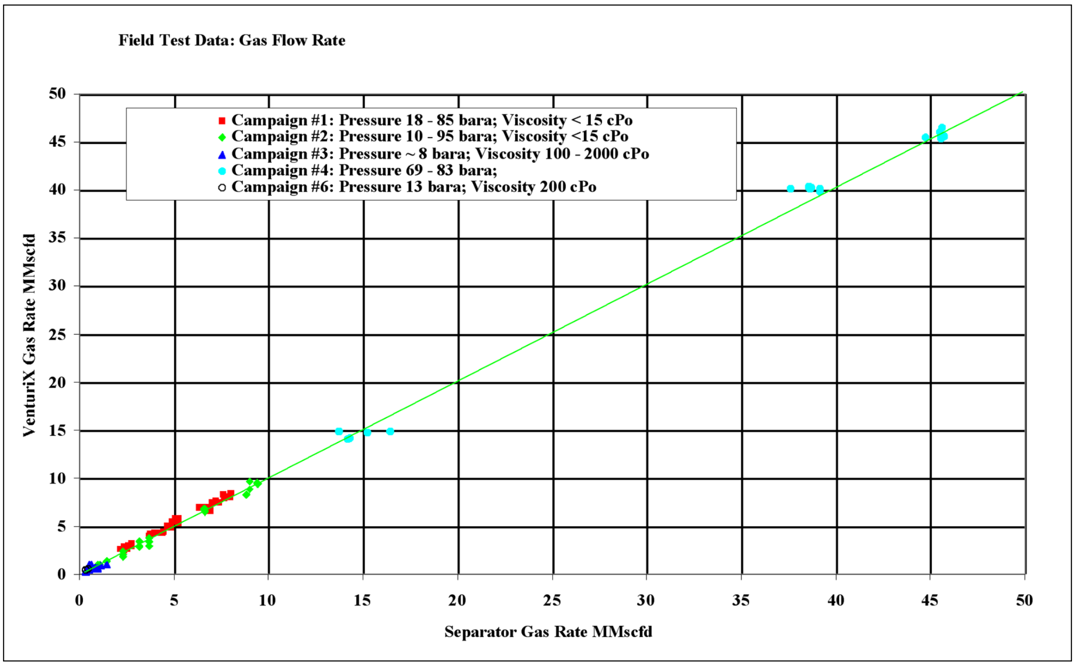


Gas-Liquid test matrix (at line conditions) Fig. 6

Field Tests against Test Separators

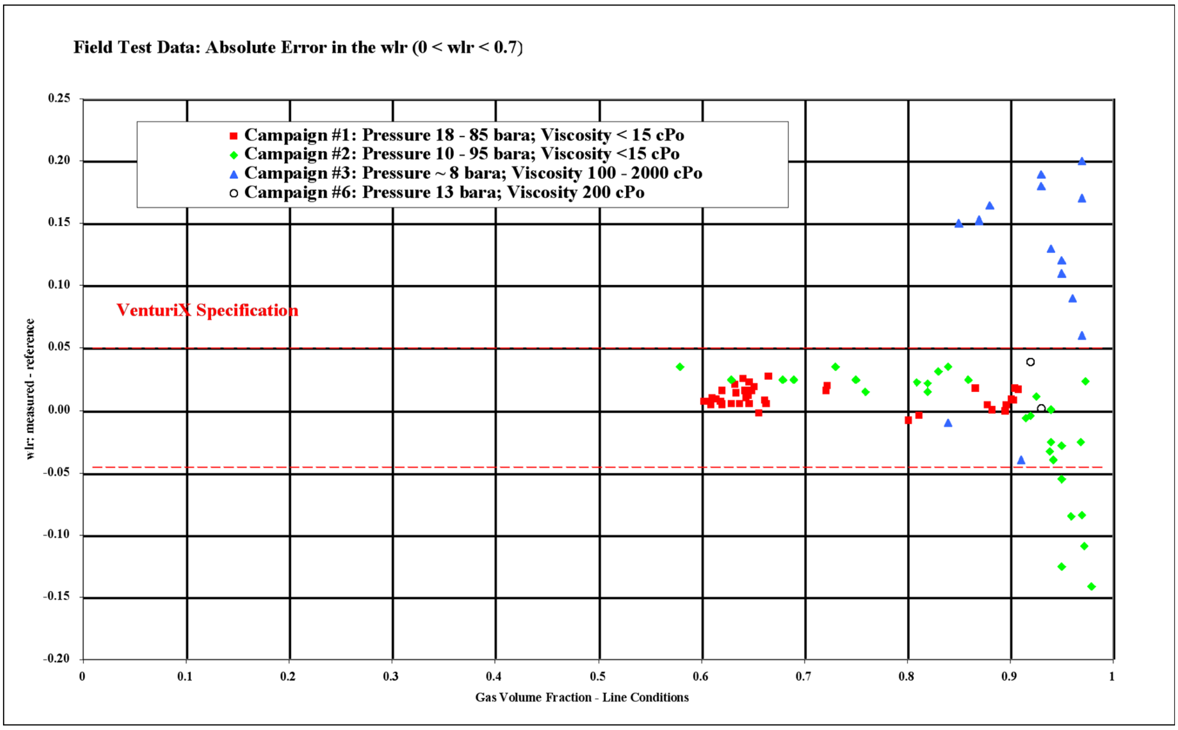


Predicted Liquid versus separator liquid (standard conditions) Fig. 7



Predicted gas versus Separator gas (standard conditions) Fig. 8

Field Tests against Test Separators

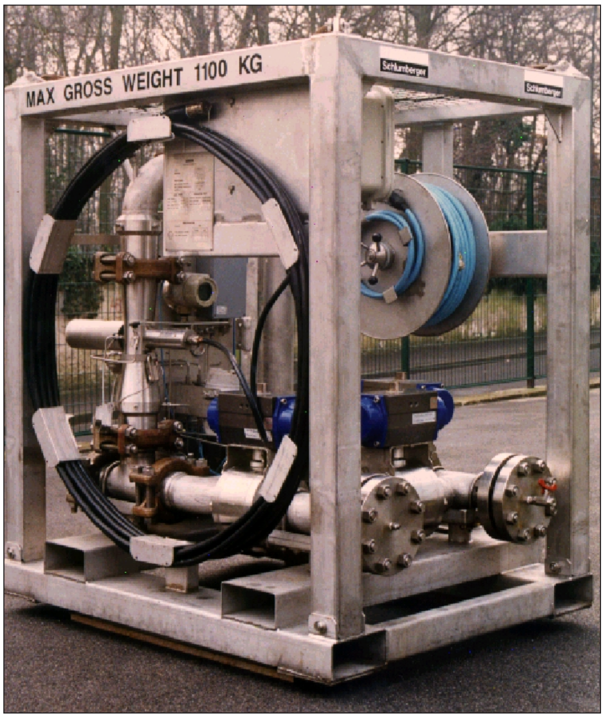


Predicted WLR versus separator or sample Fig. 9

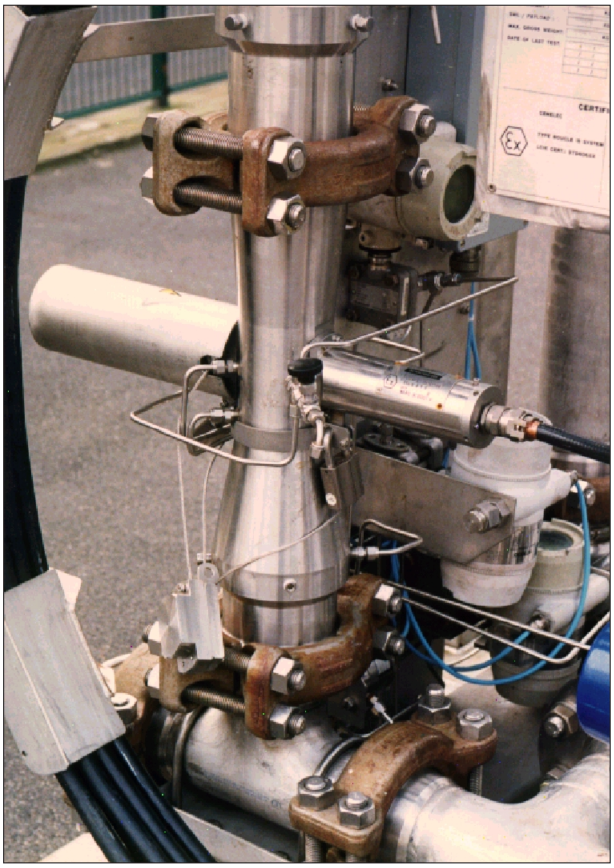
Field test picture Fig. 10

VenturiX Prototypes 1, 2 & 3 (1440 psi)

Skid assembly



Measuring Section



VenturiX Commercial Version (5000 psi)

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.