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Metering Associated Petroleum Gas (APG) - Field Experience with Ultrasonic Flow Meter

Sven Holzbächer, SICK AG, Dresden
Ekkehard Riedel, SICK AG, Dresden
Dr. Volker Herrmann, SICK AG, Dresden
Andrey Zubakin, Verkhnechonskneftegaz (VCNG)
Aleksey Ishutin, KuibishevTelecom- Metrology

1 INTRODUCTION

Associated petroleum gas (abbreviation “APG”) is a form of natural gas associated with crude oil (petroleum), either dissolved in the oil or as a cap of free gas above the oil.

The current situation shows that the biggest part of worldwide produced APG is flared. Considering the energy content, the APG can be the base for fuel products used in the power generating industry, processing industry or gas compressing and oil pumping stations. Due to variations of APG in composition and energy content, and due to contaminations with crude oil and other pollutions, the APG must be conditioned in gas processing plants prior to use.

The interest of the global energy and environmental and business community in the issue of associated gas utilization has grown dramatically in recent years due to both environmental and financial considerations.

The Russian company «Verkhnechonskneftegaz» (abbreviation “VCNG”) located in the territory of the Verkhnechonskoye oil, gas and condensate field, one of the largest oil fields in Irkutsk oblast, is one of main suppliers to the pipeline system “BCTO” (East Siberia – Pacific Ocean). VCNG estimated ultrasonic technology is best suited for metering of APG volume flow rate.

Besides harsh climatic conditions of Siberian region special challenges for the flow metering came up during the first stage of plant operation: the oil treatment unit was not completed in time so the gas stream in the pipe was carrying higher contents of crude oil and pollutions. The special configuration of the ultrasonic flow meter with high acoustic power and adapted signal algorithm enabled a reliable function. Practical experiences for about 11 months showed that signal transmission was the most important task but could be handled by the ultrasonic flow meter, despite strongly contaminated transducers, without any loss of the measurement.

Starting with a general view on energetic and environmental importance of APG worldwide and in the Russian market, this paper explains the special requirements for APG metering and is developing the field experience with ultrasonic flow meters in application conditions described above.

2 ASSOCIATED PETROLEUM GAS (APG)

2.1 Worldwide energetic and environmental importance of APG

Associated petroleum gas is a fossil combustible gas escaping from degasification during oil exploration processes. The gas is dissolved within the oil and is separated before the oil enters a pipeline. The separated APG is almost never a clean or dry natural gas suitable for use as energy source. It is an inhomogeneous mixture with varying levels of contamination and liquids (water, oil). Feeding APG into natural gas pipelines for long-distance transportation is not possible without performing a gas treatment before.
The gas is typically a mixture of hydrocarbons from methane to hexane including C_4-C_6 isomers. Furthermore non-hydrocarbons like CO_2, N_2, H_2 and hydrogen sulphides can be part of the gas mixture. The composition of APG can vary strongly and depends on the geological bed and the condition of the oil reservoir. Content of hydrogen sulphides depends on progress of oil reservoir exploration. The molecular weight of APG is between 15 and 50 kg/kmol; the content of a typical APG mixture is listed below [1].

- Methane CH_4 ~81%
- Ethane C_2H_5 ~5%
- Propane C_3H_8 ~6%
- Butane C_4H_{10} ~4%
- Nitrogen N_2 ~1%
- Carbon dioxide CO_2 ~0.15%
- Others balance

Typical methane content of West Siberian APG as the region with highest APG production quantities is around 60%. Nevertheless methane concentrations up to 90% or more are possible for Russian APG.

The following energetic assessment of APG, based on classification numbers for oil and gas industry in 2010, gives a view on the economic importance of the gas [2], [3]:

- Global oil production 2010: ~3.9 billion tons

The quantity of APG per ton of oil can strongly vary between 25 and a few hundred cubic meters, depending on oil composition, degasification process and geological conditions. As an assumption, taking only a lower quantity of only ~70 m³ APG per ton of oil in consideration, the following theoretical picture arises:

- Global APG production 2010: ~273 billion m³
- Energy content of APG: typ. ~40MJ/m³ s.c.
- Energy content of global produced APG in 2010: ~$10.92 * 10^9$GJ = $\underline{3.03 * 10^9 \text{MWh}}$

Using an efficiency factor of about 20% for conversion of the gas energy into electric energy, an amount of ~600 million MWh electric power results. This represents an energy value which nearly equates to the total yearly consumption of electricity currently used in Germany!

Flaring of APG basically is wasting of valuable energy resource. Based on satellite observations in recent years, the total global volume of associated gas flared is within 150-170 billion cubic meters per year. This translates into an amount worth of approximately 30.6 billion USD. This is equivalent to 30% of natural gas consumption by the European Union countries or equivalent to 25% of natural gas consumption by the United States [1].

Current worldwide flaring of APG results in yearly emissions of about 400 million tons of greenhouse gas carbon dioxide into the atmosphere. This corresponds to approximately 1.2% of total global CO_2 gas emission [4].

But, emissions of greenhouse gas associated with global warming, is only one factor. Associated gas flaring can be dangerous for health. The flaring generates compounds such as carbon, sulphur and nitrogen. If the APG combustion does not work efficiently, compounds such as methane, with a much higher potential of greenhouse gas effect than carbon dioxide, are directly emitted into the atmosphere.

Monitoring and control of APG flaring, therefore, becomes of high importance. In most countries there are anti-flaring legislative rules in place that define legal flaring limits combined with stringent monitoring and reporting and escalating penalties [5].

2.2 Associated Petroleum Gas in Russian Oil and Gas Industry

2.2.1 APG flaring and potential of APG utilization

The Russian Federation is world's largest gas producer. In 2006 the Russian gas production was approximately 600 billion cubic meters. In the same time the produced APG from Russian oil exploration was about 57.9 billion cubic meters which corresponds to 9.65% of total gas production. Nearly 43.8 billion cubic meters of the produced APG was utilized, approximately 14.1 billion cubic meters were flared [6].

If all Russian APG is burned, Russia's APG flaring creates carbon dioxide emissions of between 30 and 100 million tons annually. When flares do not work effectively, producers may vent methane, a much more potent greenhouse gas than CO_2 [6].
However, APG flaring is also of economic importance for Russian Federation. According to the Russian Federation Ministry of Natural Resources the loss of economic value due to flaring of APG in 2007, was about 139.2 billion Rubles which corresponds to approximately 4.15 billion USD, based on current exchange rates. Now, approximately 80% of Russia's burnt Associated Petroleum Gas can be used with high economic efficiency: this may provide billions of dollars in profits, and reduce carbon dioxide emissions significantly [19].

2.2.2 Legislation situation

Considering the background of the Kyoto protocol on one hand, and the increasing gas production including APG flaring at the other hand, the Russian government authorities (Ministry of Natural Resources, Ministry of Industry and Energy) initiated decisive measures to stop associated gas flaring starting from summer 2007.

Government Decree No. 7 dated January 8, 2009 "On Measures to Stimulate Reduction of Atmospheric Air Pollution with Associated Gas Flaring Products" stipulates more liberal conditions of transition to the system of associated gas flaring penalties for oil companies. It was drafted by the Ministry of Natural Resources and agreed with the Ministry of Economic Development, Ministry of Finance, Ministry of Energy and Ministry of Public Health and Social Development. Decree No. 7 was scheduled to entry into force at January 1st 2011 but was later postponed for one year until January 1st 2012. The main topics of Decree No. 7 are:

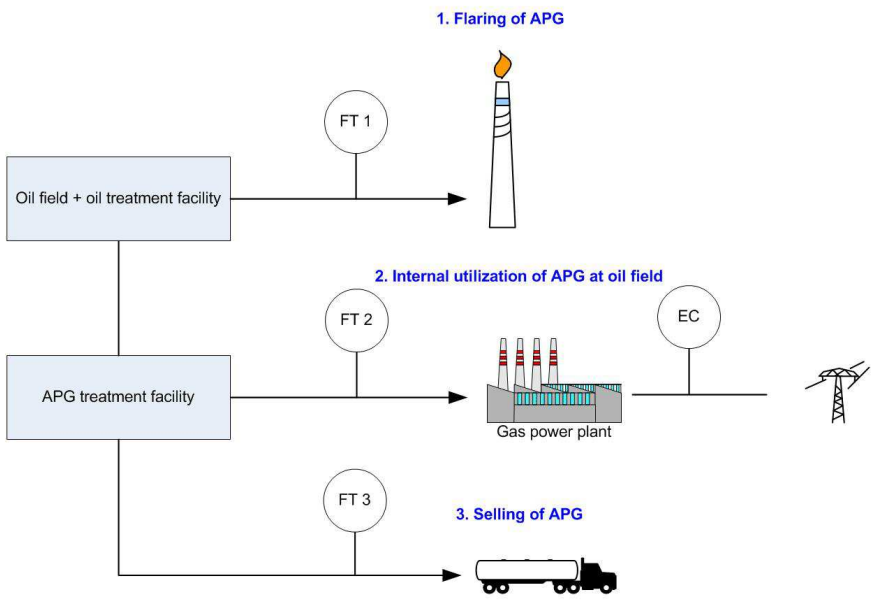
- A targeted APG utilization rate of 95%, starting from 2012 and subsequent years.
- Reporting about APG flaring.
- Payment of emission fee acc. to Government Decree No. 344, annex 1 of June 12, 2003 for burning of Associated Petroleum Gas:
    - The calculation of payment for pollutant emissions is based on considering different substances in the gas and different burning with or without soot.
    - The amount of payment is depending on defined coefficients. There are different coefficients for Western Siberia (1.2) and Far North region (2.0) which are valid for emissions within the emission limits.
    - For exceeding the limit of 5% for combustion of Associated Petroleum Gas (5%) the payment calculation applies an additional factor of 4.5. In the absence of metering an additional factor of 6 is used.

As a result, the amount of payments of oil companies for harmful emissions into the atmosphere in 2012 will increase by 50 times and will be 16.7 billion rubles [6], [7].

2.2.3 Production and measurement of APG

Oil-gas separators are used to split the oil-water-gas mixture into single fractions and to remove sludge or sand. Most used types of separators are gravity type.

The separation process involves several separation stages. For best separation of volatile components the operation pressure is reduced step-by-step. The target is to achieve maximum liquid oil recovery, separation of water and stabilized gas fraction.
The separated APG is going to flare or to a gas treatment facility. The treated APG is utilized direct at the oil field or selled as energy source. An APG flow rate measurement is required for all 3 channels.



Monitoring point	Location	Monitored value
FT1 (Flow transmitter)	Flare stack	Standard volume flow rate (m³/h)
FT2 (Flow transmitter)	Exit of treatment block	Standard volume flow rate (m³/h)
FT3 (Flow transmitter)	Exit of treatment block	Standard volume flow rate (m³/h)
EC (Electricity counter)	Feeders from Gas power plant	Electricity (GW/h)

Fig. 1 - Monitoring points at exemplary oil exploration and treatment plant [11]

Currently in Russia approximately 49% of all flares are equipped with metering devices [6].

3 MEASUREMENT OF ASSOCIATED PETROLEUM GAS (APG) IN RUSSIAN FEDERATION

3.1 Requirements of APG measurement in according to legislations

The APG measurement in Russian Federation covers some important challenges and requirements. Specification of a flow meter used in an APG application, has to be certified acc. to Russian standard GOST for overall specification.

Standard GOST R 8.615-2005 - Measuring of quantity of taken from bowels oil and oil gas. General metrological and technical requirements [12]:

- APG has to be measured at all gas pipelines which exist at each particular oil field, including flares lines.
- Volume flow rates have to be measured and calculated to standard conditions of 20°C and 1atm.
- Total uncertainty of measurement must be 5% or better.

Standard GOST R 8.733-2011 - System for measuring of quantity and parameters of free oil gas. General metrological and technical requirements [13]:

- Actual Russian standard which defines demands for measurements of oil and associated petroleum gas (APG).
- APG must be measured at all gas pipelines which exist at each certain oil field including flares lines.
- APG must be measured as volume flow rate in standard conditions at 20°C and 1atm.
- APG measuring stations are divided in 4 different categories, depending on volume flow rate range:
  - Category I (high capacity) – volume flow rate > 10^5m³/h
  - Category II (high performance) – volume flow rate > $2x10^4$ to 10^5m³/h
  - Category III (low capacity) – volume flow rate > 10^3 to $2x10^4$m³/h
  - Category IV (minimum performance) – volume flow rate < 10^3m³/h.
- The APG measuring stations are divided in 3 different classes depending on type of application:
  - Class A - APG measuring stations for custody transfer measurements (e.g. selling of APG after gas conditioning)
  - Class Б - APG measuring stations where APG is used for internal needs e.g. for field boiler
  - Class B - APG measuring stations at process measuring tasks and flares.
- Uncertainty demands of APG measuring stations (APGMS), depending on their category and class:

Table 1 - Uncertainty demands for APG measuring stations [13]

Category of APG measuring station	Maximum permissible uncertainty of standard volume flow rate (%)		
	class A	class Б	class B
I	+/- 1.5	+/- 2.5	+/- 5.0
II	+/- 2.0	+/- 2.5	+/- 5.0
III	+/- 2.0	+/- 3.0	+/- 5.0
IV	+/- 2.5	+/- 4.0	+/- 5.0

- There are different demands for the configuration of APG measuring stations, depending on their category and class (e.g. redundant configuration of APG measuring station for category I or II and class A).
- Gas flow meters are divided based on measuring principle.
- There are certain demands for flow computers:
  - Data logging functionality
  - Gas counter functionality + data saving in archives
  - Serial interface
  - Protection of information and parameters via CRC sum
  - Special demand to recalculation method for not fully prepared APG clearly mentioned that MR113-03 method has to be used. Recalculation method MR113-03 is applicable only for wet and not finally prepared APG. If APG is dry and clean, methods for natural gas must be used.
- Most preferred measuring principle is the ultrasonic principle. Thermal mass flow meters are only allowed to use at APG measuring stations with category III or IV. In general it means that it's not allowed to use thermal mass gas flow meters at most APG measuring points anymore.
- There is a certain demand to measuring points with not prepared (wet and dirty) APG – electrical heating of inlet and outlet pipes in order to prevent ice formation at internal pipe surface.

3.2 View on recalculation algorithm MR113-03

The Method MR113-03 was designed by "All Russian D.I. Mendeleev Research Institute for Metrology (VNIIM)" to calculate gas property values for compressibility factor, density, adiabatic index and dynamic viscosity. As mentioned previously, Russian legislations requires the utilization of this algorithm for calculation of normalised volumes in APG applications.

The algorithm contains some minor differences in comparison to other methods such as GERG2008 and AGA8. Due to the importance of Associated Petroleum Gas measurement there was a requirement to optimize the algorithm for use in this application especially. Therefore the algorithm considers all components of gas which are occurring in APG conditions and contains methane, ethane, propane, iso-butane, n-butane, n-pentane, N_2, CO_2, water, H_2S, hexane, heptane, O_2, iso-pentane. For use in typical dry natural gas mixture applications, and process conditions between $0.1 \leq p \leq 15$MPa and $0 \leq T \leq 225$°C, the uncertainty of density is given with 0.2%. The uncertainty of density increases to 0.4% when used in wet gas conditions. Additional information about expected uncertainty is described in [18]. Larger hydrocarbons like octane, nonane and decane will not be handled by using of MR113-03 method due to there are less present and they do not appear in natural sources.
However it would be interesting to compare the result between AGA 8 and GERG 2008. The example which is shown below is based on a typical North Sea gas composition. It has been used because the gas mixture can be managed by all of the 3 methods.

For all of the 3 methods the compressibility was calculated because of their importance in consideration of volume normalization. The uncertainty which can be expected due to the methods specification shall be in a range of 0.3%. Figure 2 shows the calculated compressibility for different pressures for all 3 methods.

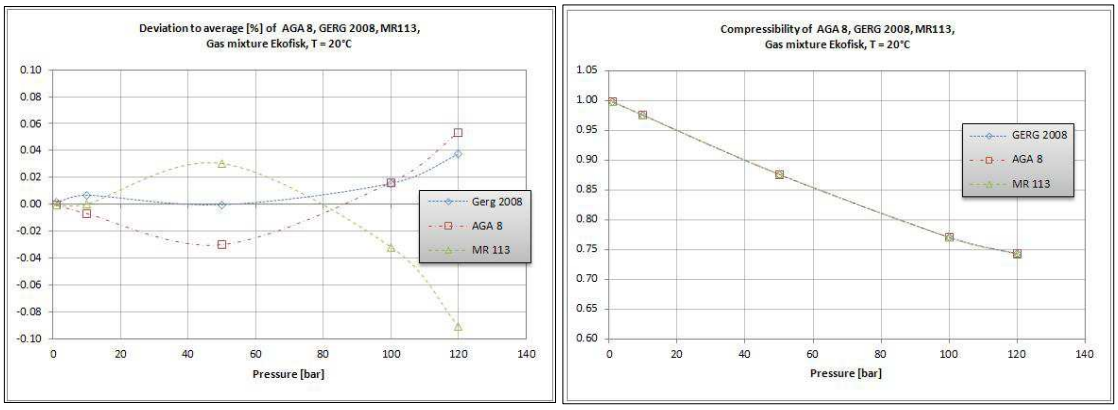


Fig. 2 - Comparing result of compressibility value

To compare the methods, average compressibility was calculated at each given pressure. The diagram to the right shows the percentage deviation to the average value of each single compressibility value. The result shows a deviation between the methods smaller than +/- 0.1%.
The investigation of MR113-03 during the implementation has shown there is a respectable compliance between the 3 different methods.

Before the installation and use of an ultrasonic flow meter, a certification process by the “All-Russian Scientific Research Institute of Flowrate Measurement (VNIIR)” must been completed. The correct implementation of the algorithm and measurement behavior of the entire device must be validated in accordance to GOST GSSSD MR 113-03, GOST R 8.615-2005 and GOST R 8.733-2011.

3.3 Operational challenges for APG measurement

Beyond the regulatory requirements, some special challenges, typical with an APG measurement, need to be considered. Process conditions and environmental conditions require an adaptability of the measurement device.
Within the APG measurement, rapid changes in flow regimes are common. The meter has to measure gas flow velocities down to zero. Maximum gas velocity is typically ~60m/s but can be much higher depending on composition and degasification of oil. In addition, the flow measurement needs to operate with short response time for reliable gas flow monitoring and process control. Operating pressure down to near zero gauge is typical. Changing gas compositions have to be handled as well as a significant amount of corrosive components.

Also influences on signal strength, resulting from low pressure and components with high degree of attenuation like CO_2, must be considered.

Another main challenge is the contamination of the gas stream by liquids (water, oil) and pollutions (sand). A meter must be able to handle these conditions by either tolerating the harsh process conditions or indicating the problems by diagnostic means.

From environmental point of view, there are exceptional hard climatic conditions in the Siberian area. Any metering system must fulfill hard demands due to ambient conditions with minimum temperature specification starting at -60°C as a standard requirement.

A more process related question arises for the user – whether the metering system can still operate within the specification, and how he/she can trail and interrogate functionality of the equipment over the live time of the device. This rigorous demand require suitable diagnosis capabilities of the flow meter.

For reporting purposes an APG flow meter needs to provide non-volatile data archives to create measurement reports according to defined intervals.

3.4 Ultrasonic meter as lead technology to fulfill requirements and challenges of APG measurement

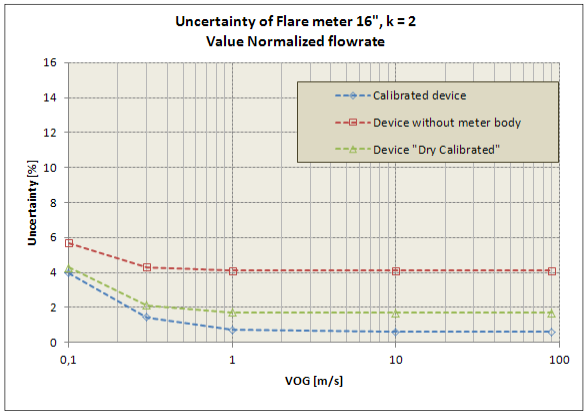
In a variety of flow measurement applications, ultrasonic measurement has become the leading technology. High accuracy, combined with strong diagnostic capability, are appreciated in custody transfer market. The high reliability and robust behaviour against any pollution/contamination are the key benefits/features if ultrasonic meters are applied in process or APG applications. This chapter will demonstrate the most important ultrasonic capabilities to ensure the requirements of APG measurement.

3.4.1 Measurement Uncertainty

In general, there are different ultrasonic flare meter configurations to fulfill different uncertainty demands:

- Devices installed in the field (hot tapping) without meter body or calibration
- Devices with meter body and geometric measurement ("dry calibration")
- Devices with meter body and flow calibration.

While hot tapped metering solutions offer the most flexibility in application, a sufficient but limited uncertainty value can be reached, even taken special measures into account, which guarantee adequate parameterization of the path length and the path angles. The system including the meter body ensures a better parameter measurement leading to a reduced uncertainty. The uncertainty can be further reduced with a lab calibration.



The figure 3 at left shows the GUM Uncertainty Calculation ("***G**uide to the Expression of **U**ncertainty in **M**easurement*") for the measuring value "Normalized flowrate" of an ultrasonic flow meter. The calculation considers the given velocity points and the different types of meter configuration. It will be clear that the best uncertainty will be achieved by use of a calibrated meter which includes a meter body certainly.

Fig. 3 - Uncertainty result for measurement value "Normalized flowrate"

With respect to the requirements, an ultrasonic flow meter can be used for APG measurements for classes A and B acc. to GOST standard (see 3.1), taking different installation types into account.

A 2-path configuration can be used, if a reduced uncertainty at strongly disturbed flow profiles is required or unstable flow conditions close to zero flow occur. Multi-path configuration also offers path redundancy for increased measurement availability.

Table 2 - Typical uncertainty specification of ultrasonic flow meter

Path configuration	Installation	Measuring range [m/s]	Uncertainty [%] *)
1-path	hot tapping	0.3 … 120	≤ 5
	device with meter body + geometric measurement		≤ 1.5
	device flow calibrated		≤ 0.5
2-path	hot tapping	0.3 … 120	≤ 3.0
	device with meter body + geometric measurement		≤ 1.0
	device flow calibrated		≤ 0.5

*) for fully developed flow profile

3.4.2 Operational challenges

A combination of sensor design and signal processing algorithms ensure the reliable operation.
Modern ultrasonic transducer technology enables operation at atmospheric pressure conditions without limitations to any functional parameters. Combined with a time resolution down to +/-5ns of device in practical applications, the flow meter is suitable to provide a precise measurement at low flow conditions near zero flow.

Changing gas compositions or corrosive process conditions can be served by optimized transducer design. Using ultrasonic transducers with large bandwidths and large amplitudes are operating in gas compositions starting at 2g/mol up to 120g/mol without a significant effect on signal performance. Nevertheless gas composition is always an optimization task considering ultrasonic beam lobe and signal transmission distance. High power transducers are able to ensure a high availability of measurement and can be used for cross-duct measurement also in very large pipe sizes up to 72inches, and for highly attenuating gases like high amounts of CO_2 in the mixture.

Fig. 4 - High power version of ultrasonic flow meter

Modern ultrasonic flow meters are typically manufactured with hermetically sealed full-metal titanium transducers. For aggressive gas compositions special alloys like Hastelloy are used as transducer material.

Ultrasonic flow meters have a low sensitivity to entrained liquids and to contaminations. Contaminations on the surface of ultrasonic sensors can be monitored by meter diagnostics using the parameter “Automatic Gain Control (AGC)”. Depending on the contamination rate of the ultrasonic sensor, the gain for signal transmission is automatically adjusted.
If the sensors experience heavy contamination, the gain of the signal transmission will increase to overcome these effects. The resulting AGC level is an indicator to determine contamination of a specific sensor.

Once the gain value has reached a defined limit value, the meter control unit will indicate a maintenance request message. The meter will continuously operate and read accurately, and the maintenance request message will alert the operator that the sensors need cleaning.
Low frequency transducer types can best compensate the effects of signal loss by contamination due to higher signal power reserve.

Fig. 5 - Ultrasonic transducers: high frequency type / low frequency type

Installation capabilities can also play an important role for hard accessible installations in Siberia with extreme weather conditions. Considering a digital communication between sensors and evaluation electronics the control unit can be placed up to 1,000m away from measurement point in a heated control room. Remote setup of the control unit provides additional flexibility and is a more easy solution for conflations of several metering systems into one control system at site.

3.4.3 Meter field verification

The performance of ultrasonic meters is verified by special test procedure at the factory. Nevertheless, a performance validation of the meter in the field can ensure a continuous audit trail of the system and document the operation within the specification limits. To realize such a validation, a field verification procedure is recommended.
For regular field verification ultrasonic meter can be individually tested for proper zero and speed of sound calculation outside the pipeline within a special “Field Zero Flow Test Box”.
The velocity of gas and the velocity of sound are determined at a flow rate of ~0m/s within this box. The special design of the field verification box reduces flow rate fluctuations and effects of temperature have been almost fully eliminated.

Fig. 6 - Zero Flow Test Box for field use

Figure 7 below shows a typical result of a recorded velocity of gas in special “Flow Test Box” which is part of the factory standard quality control.

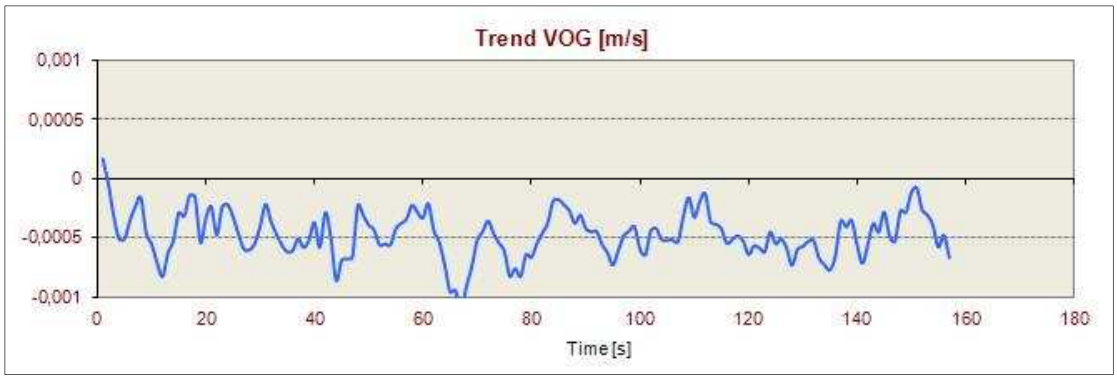


Fig. 7 - Measured velocity of gas (VOG) inside the “Zero Flow Test Box”

Measured speed of sound can be compared to theoretical values and used as a reference value. Unusual trends in speed of sound would give indications of thermal influences.

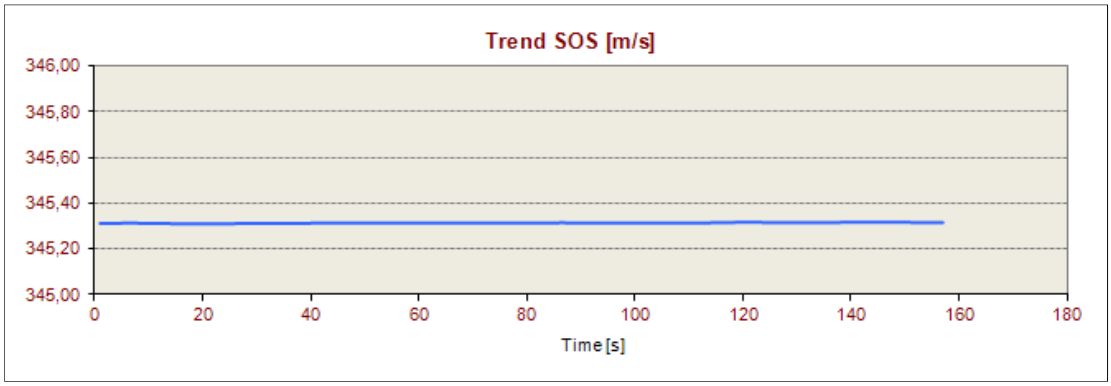


Fig. 8 - Measured speed of sound (SOS) inside the “Zero Flow Test Box”

In addition, based on the recorded measured velocity values, it is possible to check resolution and general measuring signal noise of the device. The test is successfully finalized if the recorded data is within the specified limits. Automatic documentation of all measurement and diagnostic values helps to build a continuous live time file and audit trail.
For periodic testing while the sensors remain in-line in the pipe, an alternative testing method is possible. Using an integrated check cycle the meter functionality is automatically checked at zero point and span test value.

Verification of recalculation method MR113-03 (see 3.2) is a further requirement for meter test in the field and is part of the developed verification procedure. Russian oil company VCNG also uses software "Расходомер ИСО" for the verification of correctness of the calculation of compressibility factor via MR113-03 method.

While all these features are implemented into the meter during product development, the final test can be performed in practice only. That is, operational experiences must show, how the ultrasonic meter deals with the special requirements of an APG measurement in Siberia.

4 APG MEASUREMENT AT COMPANY “JSC VERKHNECHONSKNEFTEGAZ (VCNG)”

4.1 VCNG – Major oil exploration company at Verkhnechonskoye oil and gas field

The Verkhnechonskoye oil and gas field is the largest oil field in Eastern Siberia region and is situated by the Chona River, 1.100 km to the north of Irkutsk in Eastern Siberia. It is a thinly populated and remote area, which creates a number of challenges, including:

- Extremely low ambient temperatures down to -60°C.
- Materials and equipment can only be supplied seasonally.

- Field workers are on a rotational timetable, and can only reach the field by helicopter from the nearby Ust-Kut airport.
- Due to the lack of electricity the company had to build its own power plant operating on associated petroleum gas. This partially resolves the problem of associated petroleum gas (APG) utilization [9].

Fig. 9 - Verkhnechonskoye oil and gas field – remote located in eastern Siberia [9]

The field was discovered in 1978 and remained unexplored for a long time due to the lack of infrastructure to transport oil to potential markets. Field development began with the construction of the Eastern Siberia – Pacific Ocean (ESPO) pipeline that passes through 80 km of the field.

The field development started in 2002. Pilot operation of the field was started in 2005 and first commercial oil produced at the Verkhnechonskoye field was delivered into the ESPO pipeline in October 2008.

The field is operated by Open Joint Stock Company “JSC Verkhnechonskneftegaz (VCNG)”, a joint venture of TNK-BP (74%) and Rosneft (26%). It is TNK-BP’s first major project in the development of oil fields in Eastern Siberia.
VCNG is one of the largest companies in the exploration of oil in the Irkutsk region. The main activity is exploration and production of oil in the Verkhnechonskoye field.

The geological structure of the field is one of the most complicated, not only in Russia, but in the world. It is unique for its combination of geological and geophysical factors (hard rock, salt deposits, low reservoir temperature) as well as for the presence of gums and paraffin in the oil. Until the end of 2012 it is planned to drill 64 wells: 1 for exploration, 44 for production and 19 for injection. Drilling operations are conducted according to the schedule - at the beginning of April 11 wells where already drilled [8], [9], [14], [15], [16], [17].

4.2 Production and use of APG

The total proven reserves of Verkhnechonskoye field were estimated in 2007 with 409 million barrels of oil equivalent, and proved, possible and probable reserves amounted to 1.886 billion barrels. Natural gas reserves are 95.5 billion cubic meters. In 2009 the field produced through 41 oil wells 1.181 million tons of oil, equal to 23,500 barrels per day. For 2012 an oil production of 6.83 million tons is planned. Peak production is expected at around 7.5 million tons [8], [9].

As earlier described, the quantity of APG is strongly depending on oil composition, degasification of oil and geological conditions.

For determination of produced APG only an estimation is used:

- Expected crude oil production in 2012 = 6.83 million tons.

- Expected APG production with typical gas factor of 95 cubic meters APG per ton of oil = 648.85 million cubic meters.

Due to the remote location of the oil and gas field there is no potential demand for power in the near area around the field. The actual utilization level of associated gas will be 9% in 2012, the level of associated gas should reach 95% by 2015. At this time most of the APG goes to the flare, and some of the gas is used for the energy center, boiler and process heating ovens.
The company TNK-BP decided to apply gas injection technology to temporarily store associated petroleum gas underground. The cost of the project - five billion rubles, of which 184 million have already spent. Furthermore there is an option for a gas supply to gas transport system of "Gazprom" on the basis of the Chayanda field in Yakutia [8], [9].

4.3 APG measurement

The VCNG company program for measurement of APG started in 2009 after the modernization of outdated measurement systems, and is still ongoing on within the expansion of infrastructure due to the increased volume of produced oil and APG and construction of new facilities.

Since 2011 JSC Verkhnechonskneftegaz is using ultrasonic flow meters for APG flow rate
At the moment VCNG is using two technologies of measurement of the APG amount: ultrasonic and vortex technology. Based on all field experiences the ultrasound technology is the preferred solution:

1. For gases carrying higher liquid contents (droplets).
2. For all measurements with harder operating conditions in general, e.g. mechanical impurities, heavy fractions of hydrocarbons, condensate in the gas.
3. For operation in large gas pipeline diameters.
4. For all measurements where the metering system may not cause flow resistance in the pipeline which is a general safety demand in Russian Federation for flaregas metering.

The vortex technology allows the use in cleaned gas after gas treatment only (gas cleaned from mechanical impurities and dropping liquids).

4.4 Installation and operation conditions

The installed ultrasonic flow meter is used for flow rate measurements at oil/gas discharge on flare with following demands:

- Measurement of APG under obligation of legal requirements (Government Decree No. 7).
- Uncertainty acc. to standard GOST R 8.733-2011 [13] is 5% of measured value or better.
- The measurement is base for calculation of emission fee for “Emission of harmful substances (pollutants) generated by the burning of APG in flares”.

Table 3 – Operation conditions of APG measurement at JSC Verkhnechonskneftegaz

Measuring components	Volume flow rate in standard conditions (m³/h s.c.)	
	Mass flow rate (kg/h)	
Measured gas details	Methane CH_4 (vol%)	78
	Ethane C_2H_6 (vol%)	13
	Propane C_3H_8 (vol%)	5
	Buthane C_4H_{10} (vol%)	1
	others	3
Operating conditions	Max. gas velocity (m/s)	120
	Max. volume flow rate (m³/h a.c.)	30,000 … 186,000
	Process pressure (MPa)	0.002 … 0.5
	Process temperature (°C)	0 … 50

Installation conditions	Pipe size	DN820
	Wall thickness (mm)	12
	Pipe material	LTCS-09G2S
	Place of mounting	outside
	Distance between sensors and control unit (m)	~100
	Power supply	230 V AC
Ambient conditions	Temperature (°C)	-60 … +50
	Area classification	ATEX Zone 2
Special requirements	Volume flow rate normalized acc. to Russian standard MR113-03	
	Gas counter incl. data archives	
	Russian language for user interface (software + display)	
	Harsh climatic conditions of Siberian region	

Installation of the ultrasonic flow meter was realized in an open area of the oil treatment. Special challenge was covered with ambient temperatures in winter times down to -58°C.

Fig. 10 - Oil/gas separation unit and installation point of ultrasonic flow meter

4.5 Meter configuration

An ultrasonic flow meter with retractable sender/receiver units was configured for the APG measurement. The field operator decided on a 2-path configuration for the following reasons:

- Best metrological characteristics / more precise measurement for accurate monitoring of APG means mostly lower emission fee payment.
- High reliability of measurement. If a one path fails the flow meter is able to continue the measurement with the second path (automatic path compensation function).

Device specification:

- FLOWSIC100 Flare, cross-duct measuring system, manufacturer SICK AG Germany
- Sender/receiver unit FLSE100-EXRE, stainless steel high power transducer with retractable probe design
- Explosion protection ATEX II 3 G Ex nA II T4
- Gas pressure -0.5 … +16barg
- Gas temperature -70 … +180°C
- I/O: 1x analog output, 2x analog input, 5x relay outputs, interface Modbus RS485

To minimize geometric uncertainties and misalignment, the installation of the sensor nozzles in a pipeline section was performed at the plant of "HMS Neftemash" in Tyumen city.
The pipeline section with installed nozzles was delivered to Ust-Kut city (Irkutsk region) by motor vehicles and transported by helicopter to Verkhnechonskoye field. After welding the

pipeline section in the main line, the installation of the ultrasonic flow sensors was completed. Installation of sensors with lubricators on the field was made as quickly as possible and did not require much effort.

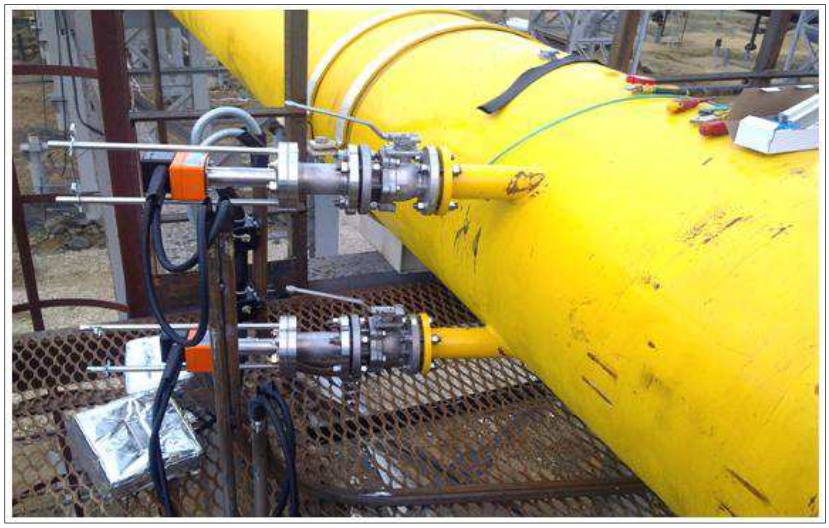


Fig. 11 - Ultrasonic sensor installation

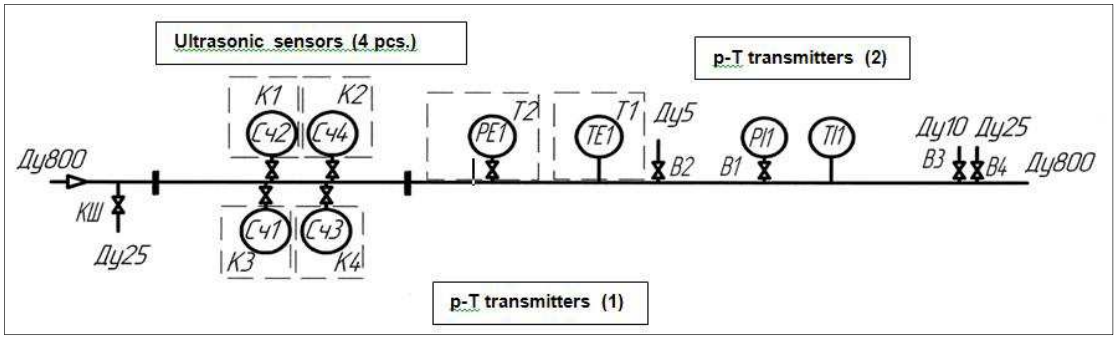


Fig. 12 - Installation drawing

4.6 Operation experience

The flow meter was commissioned at October, 6th 2011. After connecting the power supply the setup of the meter was completed via the user software.

A specific challenge for the measurement came up immediately following the installation and commissioning of device, when a high content of liquid petroleum fractions was determined in the pipeline. Oil separators are usually designed on volumetric delivery of oil. At Verkhnechonskoye field the produced quantity of oil was much higher than expected. The first installed oil separator could not perform well, and as a result, the associated petroleum gas was carrying a much higher content of oil and other pollutions. Flooding of the lower sensor pair with liquid oil could not be excluded.

In a standard setting of the device a temporary instability of the lower sensor pair was detected. In this case the internal “path compensation function” of device enabled continuous operation by using the second sensor pair only. The meter was periodically signaling a warning message. After further verification of meter performance, a stabilized measurement of the entire system could be achieved by optimizing the internal device parameters.

A later check of the meter revealed additional information:

- A periodic process debugging due to ongoing expansion of infrastructure at site and due to huge temperature differences the flow sensors were covered by sediments in the form of heavy hydrocarbon fractions and ice.
- Nevertheless, this condition did not affect the uninterrupted operation of the flow meter, and did allow continuous generation of flow volume data.
- Contamination of the measuring device, in particularly the installed sensors where highly contaminated.
- The separation unit was replaced by a larger unit, but still the quantity of oil was too much and the gas was highly polluted with oil.

Fig. 13 - Ultrasonic sensor polluted with liquid oil after retraction from pipeline

Against first expectations of the field operator the installed ultrasonic meter continued operation without loss of function. Inspection of the meter gave the following result:

- Significant contamination of all 4 ultrasonic transducers, after retraction liquid oil was dripping down from sensors.
- Increased number of error rate, but below the critical limit of the device.
- Reduced measurement performance but within the limits for continuous operation, no failure of measurement.

4.7 Evaluation of diagnostic parameters

As mentioned in section 3.4 the ultrasonic technology provides extended diagnostic capabilities by monitoring specific parameters. The most important diagnostic values are the Automatic Gain Control (AGC) level, Signal-Noise-Ratio and the meter characteristic Error Rate.

All diagnostic values can be monitored and evaluated continuously under ongoing operation of the flow meter. Monitoring of diagnostic values over defined time periods enables the user to detect changes of meter performance and possible drift of measured values. In general effects like:

- Sensor contamination,
- Disturbing noise,
- Collection of depositions and sediments in pipeline at measurement point or before,
- Sensor wear,
- Sensor failures

can be detected reliably before total failure of measurement device. Additionally detection of leakages and changes in gas composition can be detected.

At commissioning of APG flow meter at Verkhnechonskoye field the mentioned diagnosis values were read-out and recorded by using the device software. Saved values from start-up of the meter were used for comparisons with values taken at later points of the operation. This enabled value comparison and general evaluation of meter performance after a defined period. The following diagrams represents the recorded „Error Rates“ after commissioning of device and one year later.

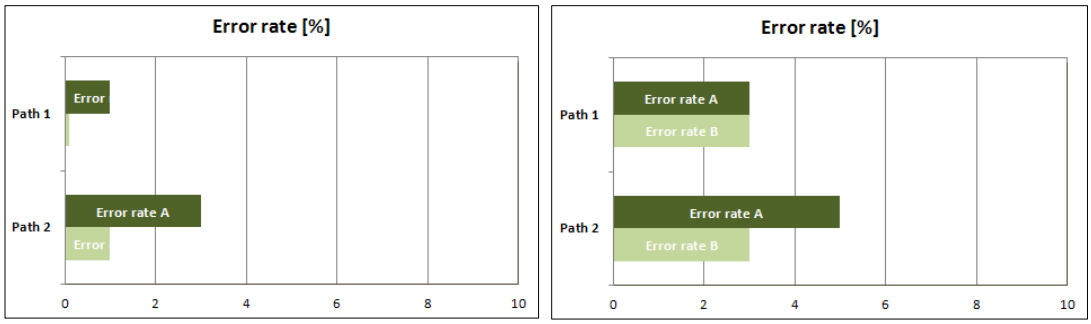


Fig. 14 – Meter Error Rate at commissioning 05/08/12 and at inspection 15/08/12

The parameter „Error Rate“ complies with the percentage of signals which are not used for calculation of measured values due to exceeding of internal limit values. In addition to the mentioned parameters Signal-Noise-Ratio (SNR) and Automatic Gain Control (AGC), a defined number of further signal characters are checked for the calculation of parameter “Error Rate”:

- Mean Square Error (evaluation of signal shape)
- Plausibility of zero-crossing detection
- Width of signal burst.

The diagrams shown in the figure above are indicating an Error Rate in a range of 1 to 5%. In this condition appr. 95% of signals are appropriable for calculation of gas velocity and volume flow rate. Based on these diagnostic results, a measurement function without any functional limitations can be stated.
For the evaluation of meter performance, the diagnostic value Automatic Gain Control (AGC) becomes of high importance. The diagrams in figure 15 below are showing values of appr. 33dB. With a maximum possible AGC level of 75dB, a signal gain reserve of appr. 42dB results. Based on these values, the signal transmission of the meter can be stated as non-critical. Figure 15 is furthermore showing, that sensor contaminations could not lead to noteworthy increase of AGC level between commissioning and inspection one year later.

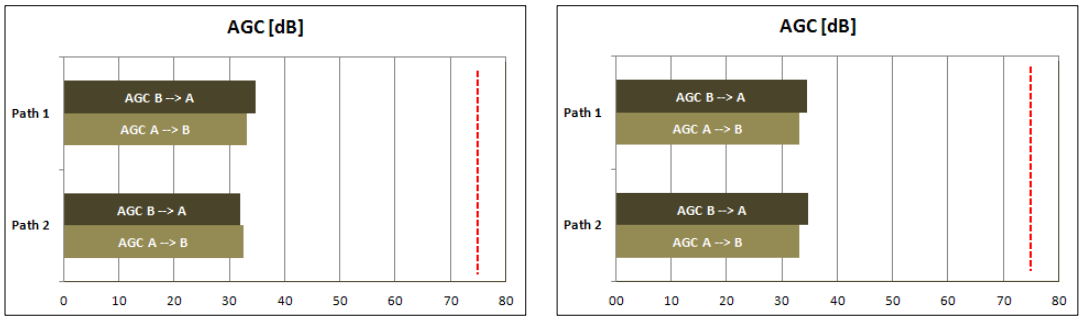


Fig. 15 – Meter AGC level at commissioning 05/08/2011 and at inspection 15/08/2012

For the evaluation of ultrasonic signals usually a Signal-Noise-Ratio (SNR) is used. The signal algorithms of ultrasonic flow meters use the following equation (1) for calculation of Signal-Noise-Ratio (SNR):

$$SNR = 10 * \log\left(\frac{MaxSignalAmpl}{AvgNoiseLevel}\right) \qquad (1)$$

Figure 16 below represents a comparison of SNR values taken at commissioning of device and at inspection one year later. In general, signals with a SNR of more than 6dB can be evaluated and used for calculation of signal transit time. The recorded SNR values at installation at Verkhnechonskoye field of appr. 32dB showed a good signal quality. Furthermore, it could be stated, that there was no significant change of signal quality in the first year of operation.

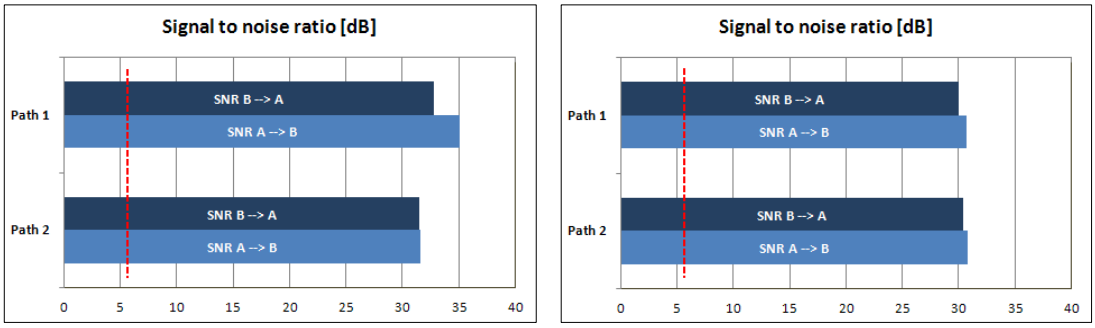


Fig. 16 – Meter SNR level at commissioning 05/08/2011 and at inspection 15/08/2012

For transit time measurement validation on ultrasonic meters, velocity of sound can be used. In general, velocity of sound is independent on velocity of gas. Therefore, it is possible to use the velocity of sound for diagnostic purposes under running pipe conditions. It has to be considered, that direct sun radiation can cause different temperature layers (thermal convection) in the pipeline. A deviation of velocity of sound at one or both paths would be the result and could lead to wrong interpretations.
Basically velocity of sound validation can be carried out in two different ways. If an analysis of current gas mixture is available, a theoretical velocity of sound can be calculated and compared to measured velocity of sound of the device. A second approach would be to compare the path velocity to each other. Due to the fact that all transducers are affected by the same gas, equal temperature and pressure, the velocity of sound values on the different ultrasonic chords should be close together.
In figure 22 below the velocity of sound values from commissioning of device and after 1 year of operation are shown. It is visible, that velocity of sound values of path 1 and 2 differ approx. 0.5% to each other. For explanation of this deviation the transducer mounting procedure has to be considered. During the installation the transducer nozzles would be welded on an existing pipe under field condition. In consideration of the possibilities during a field mounting procedure the measured deviation is covered by the expected uncertainty of the mounting procedure. However, the diagram also shows the same difference between the path's values after 1 year installation. The constant deviation gives an indicator that there is no drift of any single transducer.

As mentioned previously, the velocity of sound validation value is always to be considered in regards to process conditions. Due to different gas temperature and gas composition, the average value of velocity of sound from commissioning, and up to and including the following 12 months, show a distinction between 7m/s. Therefore, it can be estimated that the varying application conditions have no effects on the interpreted results. Figure 17 at left contains typical signals which were collected after 1 year installation.

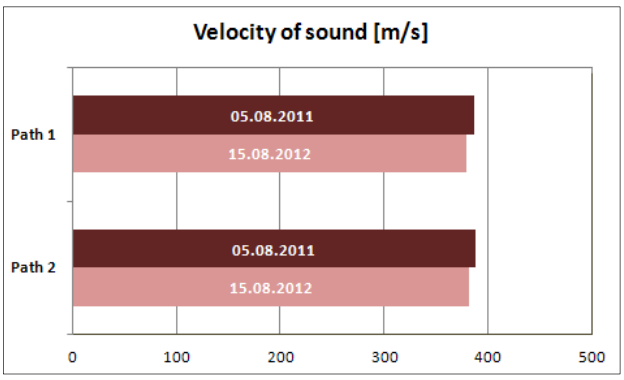


Fig. 17 – Comparison of VOS values commissioning 05/08/2011 and inspection 15/08/2012

A well experienced expert is certainly able to evaluate the quality of signal shape and can give statement about meter performance.

As already demonstrated during the diagnostic value analysis, there are no critical influences. The meter receives typical signals under field application conditions and no problems are currently to be expected.

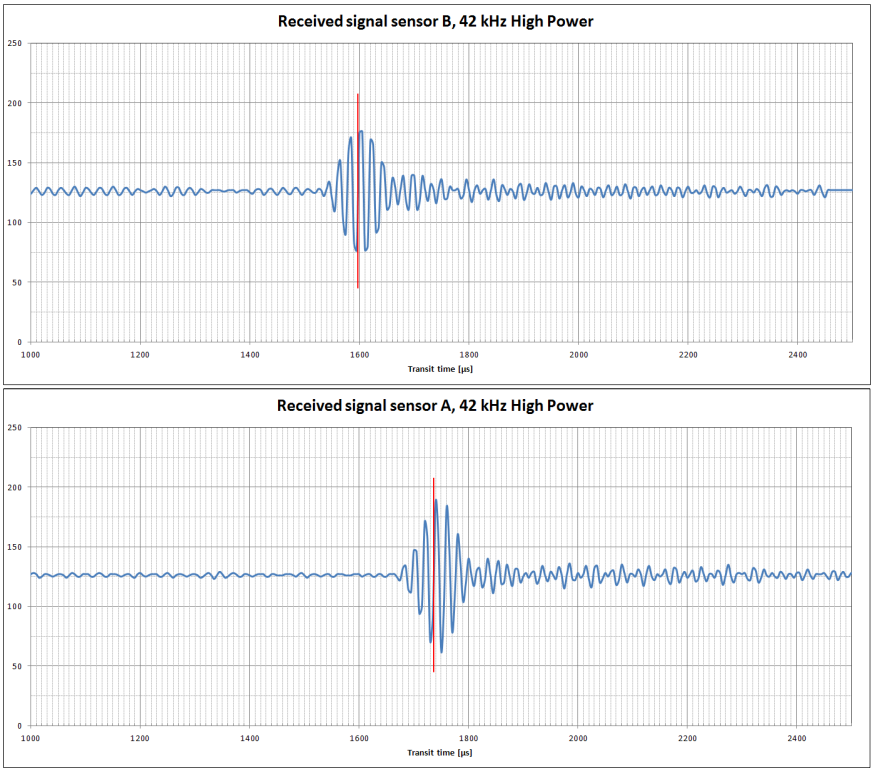


Fig. 18 – Signal quality for both measurement paths after one year of operation

4.8 Ensuring measuring accuracy

Due to technical and local reasons a comparison meter suitable to serve as reference meter for a 2-path measurement was not available at Verkhnechonskoye oil and gas field.

The measurement accuracy was ensured by an initial testing the flow meter according the requirements of standard GOST R and in order to establish the type of the flow meter according to the procedure Rosstandard RF and the Federal Law of the Russian Federation "On ensuring the uniformity of measurements".
Accuracy and uniformity of measurement at VCNG was ensured through verification according to procedure approved by the initial testing of the meter. During the verification on site the institute “All Russian D.I. Mendeleev Research Institute for Metrology (VNIIM)” was conducted to compare flow rates issued by the standard verification station with data of used flow meter.

The positive result of verification at site was issued in a certificate, which confirms the metrological characteristics declared by manufacturer [21], [23].

Fig. 19 – Metrological certificate / device passport of installed flow meter [23]

4.9 General assessment of meter function by customer JSC VERKHNECHONSKNEFTEGAZ (VCNG)

After 11 months of successful operation the meter performance is summarized by customer JSC VERKHNECHONSKNEFTEGAZ (VCNG), excerpt of quote Mr. Andrej Zubakin [21]:

- *The reliable measurement of APG in accordance with the requirements of TNK-BP and GOST 8.733 allows providing of fulfillment of the requirements of the Russian Federation Government as well as to provide correct geological, technical and organizational measures for the effective production of hydrocarbons in VCHNGKM.*

- *The reliability of measurements is rather high, because the meter has never failed and did not issue a diagnostic error messages in the current climatic conditions and continuous operating mode during 11 months. The availability of measurements is satisfactory.*

- *The performance of the flow meter allows measurement of associated gas in a huge range of gas flow rate (from 0 to 120 m/s). At the time of making the decision on the type and brand of the meter on this section of pipeline, the chosen meter type was the only meter certified in Russia able to perform this task.*

- *The meter's diagnostics abilities are quite extensive. Self diagnostic of the meter (which is officially checked and approved by VNIIR) is very good and looks like only way how to check the device in field conditions… That's why we chose it and like your device…*

- *Maintenance service and geology of VCNG are satisfied with the results of the APG*

5 CONCLUSION

The following conclusions can be summarized:

1. The measurement of Associated Petroleum Gas becomes an increased importance due to environmental and economic reasons.

2. The measurement of Associated Petroleum Gas is one of the most challenging gas flow measurements. The application covers hard requirements on measuring systems mainly caused by:
    a. The gas conditions.
    b. The ambient conditions in regions like Siberia.
    c. The remote installation on oil fields in hard accessible regions.

3. At present ultrasonic flow meters are providing best suitable technology for APG measurement. Nevertheless the measurement system has to be optimized considering the application requirements.

4. Under consideration of the specific requirements a reliable metrological solution for APG measurement can be realized with ultrasonic technology.

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