XIX IMEKO World Congress
Fundamental and Applied Metrology
September 6−11, 2009, Lisbon, Portugal

RADIOFREQUENCY TECHNOLOGICAL MEASUREMENTS UNDER PIPELINE TRANSPORTATION OF LIQUEFIED PETROLEM GAS

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Abstract – Radiofrequency methods and devices for on-line measurement of technological parameters of liquefied petroleum gas (LPG) in a pipeline are suggested. RF temperature-independent LPG density measuring device is considered. Designed automated system for determination of LPG density and water content under LPG pipeline transportation and water removal from LPG is described.

Keywords: liquefied petroleum gas, pipeline, measurement, radiofrequency

1. INTRODUCTION

Liquefied petroleum gases (propane, butane, and their mixtures) are widely used as fuel in thermal aggregates of municipal, industrial and agricultural objects; LPG becomes also popular as motor fuel [1, 2].

Liquefied petroleum gases are produced at gas-condensate fields and oil-producing plants and delivered to gas-filling stations by railroads, motor vehicles or pipelines. In gas-filling stations LPG is stored, gets water- and contaminations-free and is supplied to consumers. Such supply covers wholesale trade, filling in of balloons, delivery to group installations (for gasification of small towns and settlements where consumption of LPG is widely spread) and delivery to car gas-filling stations.

LPG is pumped by pipelines under its receipt and supply to consumers. Mass flow of LPG (that is related to mass of pumped LPG) is measured and LPG quality (that means absence of water and contaminations in LPG) is determined during LPG pumping. LPG pumping is done often by a compressor that allows to increase pressure of gaseous LPG up to 1 – 1,5 MPa in a chosen reservoir and to decrease the pressure up to 0,2 – 0,5 MPa in another chosen reservoir. Fast pumping of liquid LPG takes place if drop of pressures for gaseous LPG is created (a railway tank with volume 55 m^3 is poured off into a reservoir of a gas-filling station during 10 – 15 min). LPG pumping by a highly-productive pump is impossible because such pump during sucking in creates decrease of LPG density in a pipeline resulting in LPG boiling. Thus under LPG pumping two pipelines are often used: for gaseous and liquid LPG phases where LPG is pumped in the opposite directions.

Under operation of a compressor LPG is boiled (evaporated) in a reservoir with decreased pressure while in a reservoir with increased pressure LPG condensation takes place. It results in the change of temperatures that can reach 10 – 15 °C.

Volume flow and density of both liquid and gaseous fractions of LPG in pipelines should be measured in order to determine accurately LPG mass flow.

Highly accurate measurement of LPG density and water content is also very important under LPG pipeline transportation and storage. Free water should be absent in supplied LPG; however rather much amount of dissolved water can be present in LPG.

It is shown in the paper, that radiofrequency method can be effectively used for measurement of LPG technological parameters in particular of density and water content under LPG pipeline transportation. RF method is suggested for highly accurate measurement of LPG quantity contained in a reservoir [3, 4].

2. RADIOFREQUENCY MEASUREMENT OF LPG DENSITY

Measurement of various physical parameters (density, concentration, water content, etc.) of substances in reservoirs and pipelines is needed in many industrial applications. In particular measurement of density of oil, liquefied natural and petroleum gases is the actual problem to be solved.

2.1. Problems of LPG density measurement

LPG density depends on its composition (it differs on 13 % for propane and butane) and on temperature (density is changed on 3-4% at the change of temperature on 15°C). Correction of density by temperature is not effective because LPG composition can be changed in broad limits (really from pure propane to pure butane). Temperature and pressure in pipelines for liquid and gaseous LPG phases are changed in broad limits under LPG pumping by a compressor. Accordingly density is also changed.

Temporal diagram for LPG density determination in the pipeline at a car gas-filling station is shown in Fig. 1. Monitored substance is the mixture of propane and butane; relative contents of propane and butane are near 65 % and near 35 % correspondingly. Temperature is – 1°C.

If pumping is started then LPG density is decreased from 559,8 kg/m^3 to 557 kg/m^3. Density is unstable during pumping (it is changed on ± 0,5 – 0,8 kg/m^3 under pumping). Density can return to its previous value after pumping or can have a new value.

Value of density depends on both temperature (pipelines and reservoirs are heated in the day-time and density is decreased) and LPG composition. Propane is pumped basically as gaseous LPG under operation of a compressor; correspondingly composition of LPG in reservoirs is changed.

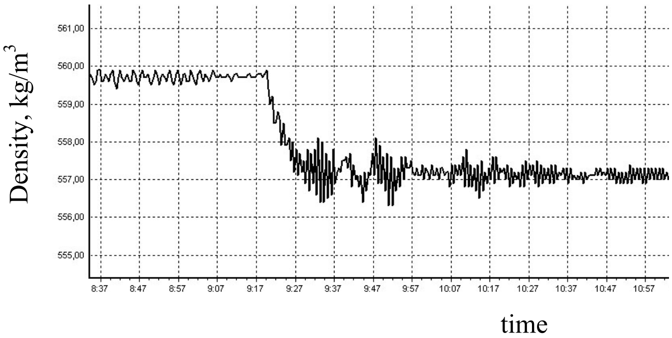

Fig. 1. Temporal diagram for LPG density.

LPG density decreased after starting of filling in of cars by LPG and data became unstable. Decrease of LPG density results from higher temperature and accordingly lower density of LPG coming from a reservoir as compared with the temperature and density of LPG in a pipeline. Non-stability of data results from presence of dissolved more light fractions (ethane and methane) in LPG having low values of concentration (up to assumed 4 %). These fractions can boil and condense under movement in a pipeline resulting in decrease of LPG density. Non-stability of data is decreased at long-term operations.

Application of RF coaxial sensors can be effective for LPG density measurement taking into account LPG specific features. Averaging and decrease of non-stability (noise) of received data are provided by the choice of large areas of conductors and of gaps between them. LPG density is calculated by the formula of Clausius-Mossotti [5].

Flowed-through density sensor is installed in an enlarged section of a pipeline at its knee or at the connection point of a hose for reception or delivery. Mounting of density sensor at the pipeline for LPG reception gives ability to measure LPG density and temperature directly during its reception and to determine composition of received LPG on-line.

There should be also hermetic coupling element in coaxial sensor reliably operable at high values of pressure taking into account LPG properties. Such coaxial sensor has small electric capacitance and significant electric capacitance of hermetic coupling element because of design features. These features as well as ways to provide highly accurate LPG density measurement are considered in the next subsection.

2.2. Radiofrequency temperature-independent measurement of LPG density

RF sensors that are sections of coaxial lines in particular, can be applied for density determination of various liquids [6, 7]. However measurement accuracy depends on temperature because such sensors contain components with temperature-dependent parameters. In first turn, hermetic coupling element is among such components: it has metal body with dielectric seal.

In particular, in coaxial sensor hermetic coupling element should contain dielectric seal and provide high degree of seal at long-term exploitation under high redundant pressure (such pressure is up to 1,6 MPa in pipelines and reservoirs with LPG). It is not possible to realize hermetic coupling element with needed low value of electric capacitance. Electric capacitance of hermetic coupling element is 12 pF if Teflon is applied as dielectric seal. Dielectric permittivity of such seal is changed at changes of temperature resulting in the change of capacitance of hermetic coupling element. If temperature is changed on ± 10°C then the seal capacitance is changed on ± 0,06 pF (that is ± 0,5%). In real conditions temperature can be changed within ± 30°C; in this case the capacitance is changed only on ±0,2 pF that is ± 1,5 %.

Change of electric capacitance of the sensor under its filling in by LPG is 20 pF while change of the seal capacitance on ± 0,2 pF results in error of LPG density measurement ± 5 kg/m^3 that is near 1%. Correction of the error caused by temperature change of the capacitance of the hermetic coupling element should be done in order to provide error of LPG density measurement not more than ± 1 kg/m^3. It is enough to provide measurement of the temperature with error not more than ± 5°C; in this case uncompensated value of the capacitance change of hermetic coupling element is ± 0,03 pF. It results in the appropriate error of LPG density measurement not more than ± 1 kg/m^3.

Therefore it is very important to provide independence of LPG density measurement results from temperature of environment (that is the temperature of the device). For solution of this problem temperature sensor (thermo resistor or other temperature-dependent element) is installed in metal body of the hermetic coupling element. The metal body has heat-protection cover. This sensor is connected with one of the two inputs of functional transducer.

Scheme of RF measuring device is shown in Fig. 2. Severe construction of the coaxial sensor is realized by the set of metal body 1, outer conductor 2, inner conductor 3, metal washer 4 welded to the end of the conductor 2, dielectric seal 5, fixed via the washer 4 at its one end and via movable metal washer 6 or female screw 7 at the other end. Screw joint 8 serves for connection of the sensor to a technological reservoir or pipeline. The screw 9 serves for fixation of the conductor 10 connecting the end of the inner conductor 3 and electronic unit 12. Outer conductor 2 of the coaxial line is also connected to the unit 12 via conductor 11. Through orifice 13 is present in the outer conductor 2 in order to provide access of a monitored substance (liquid, gas) into the space between conductors of the coaxial line. Temperature sensor 14 is located in the metal body 1 and measures its temperature. The sensor has the following dimensions: length 350 mm, diameters of the inner conductor and the outer conductor are 22 mm and 51 mm respectively. Frequency range of the sensor: 6 – 16 MHz.

In order to provide accurate measurement results corresponding to the temperature of the seal 5 namely, the metal body 1 has heat-protection cover 16. It gives ability to have for the seal 5 and the body 1 the same temperature during operation of the measuring device.

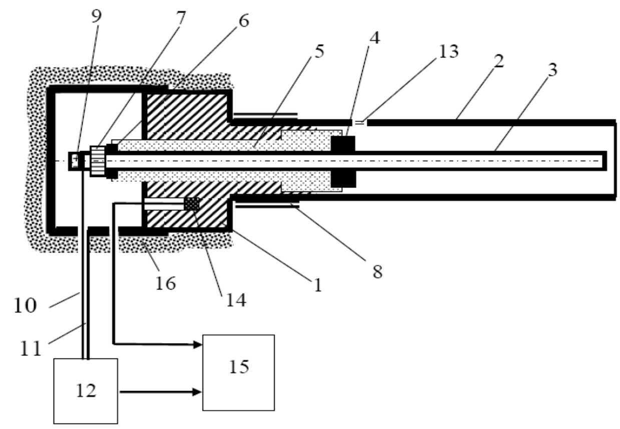

Fig. 2. Scheme of RF measuring device with temperature sensor of hermetic coupling element.
1 – metal body; *2* and *3* – outer and inner conductors; *4* – metal washer; *5* – dielectric seal; *5* – washer; *6* – metal washer; *7* – female screw; *8* – screw joint; 9 – screw; *10* and *11* – conductors; *12* – electronic unit; *13* – through orifice; *14* – temperature sensor; *15* – transducer; ***16*** – heat-protecting cover.

RF coaxial sensor is connected to the electronic unit 12. This unit contains RF oscillator and the unit for measurement of an informative parameter of the sensor. As such RF sensor can be: 1) section of coaxial transmission line being resonator; resonance frequency of electromagnetic oscillations can be as informative parameter; 2) coaxial capacitive sensor; its electrical capacitance can be as informative parameter. Output of the electronic unit 12 is connected to one of inputs of the functional transducer 15. The temperature sensor 14 is connected to its second input. Joint processing of these input signals provides density measurement being independent on environmental temperature influencing on temperature of the hermetic coupling element.

Empirical and calculated data can be used in order to found this functional processing. These data characterize temperature dependence of dielectric permittivity for various dielectric materials used in coaxial cables. So, temperature changes of dielectric permittivity ε of fluorine polymers used as dielectrics can be 4 ÷ 6 % in the environment temperature T range. In the real range of temperatures the dependence $\varepsilon(T)$ may be expressed so [8]:

$$\varepsilon(T) = \frac{(\varepsilon_{293} + 2)k(t) + \varepsilon_{293}}{(\varepsilon_{293} + 2)k(T) + 1} \quad (1)$$

Here ε_{293} is dielectric permittivity at 293ºK (that is 20ºC); k is coefficient of linear thermal expansion or compression relative to normal conditions, having negative values at temperatures lower 293ºK and positive values at temperatures higher 293ºK. It follows that for fluorine polymers (Teflon et al.) the dependence $\varepsilon(T)$ is monotonic (ε is decreased under the increase of T). So, for Teflon-4MB the mean calculated value $\varepsilon \approx 2{,}09$ at 0ºC is changed from 2,11 up to 2,07 (that is ± 1%) under temperature change from – 30ºC up to + 30ºC. Knowing the dependence $\varepsilon(T)$ for a dielectric material, applied as dielectric seal 6 of coaxial line, it can used as one of two equations for joint processing of signals from the units 12 and 14 in the functional transducer 15 in order to do measurement results temperature-independent. Output signal of the unit 15 can be as the output signal of the measuring device or/and can be used for controlling the technological process.

Presence of temperature-dependent electrical capacitance $C_h(T)$ of hermetic coupling element influences on informative parameter of the RF sensor. In particular for a capacitive sensor with equivalent capacitance C_{eq} depending on physical properties, total electrical capacitance C is expressed so:

$$C = C_{eq} + C_h(T) \quad (2)$$

The dependence $C_h(T)$ is received by calculations or experimentally for a sensor. Thermo resistor or other temperature-dependent element with known output characteristics may serve as temperature sensor 14. Such a sensor may be installed in a metal body 1 (Fig. 2); heat-protecting cover 16 is needed over metal body 1 in order to equalize temperature in it and in a dielectric seal 5.

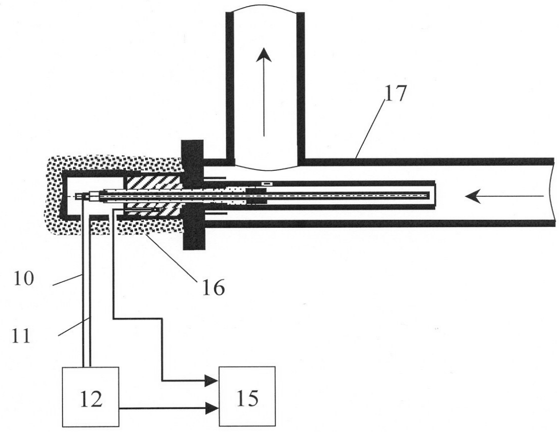

Fig. 3. Location of the sensor for measurements in a pipeline.
10 and *11* – conductors; *12* – electronic unit; *15* – transducer; *16* – heat-protecting cover; *17* – pipeline.

So, influence of temperature of hermetic coupling element on output signal of the measuring device is removed in this device. Thus permissible measurement accuracy of LPG density is provided, error is not more than ± 1 kg/m^3.

The sensor of the device for a pipeline 17 (Fig. 3) is installed along LPG flow in one part of this pipeline that is placed perpendicular to the adjacent part (flow direction is marked by arrows).

3. AUTOMATED SYSTEM FOR MEASUREMENT OF LPG TECHNOLOGIAL PARAMETERS AND REMOVAL WATER FROM LPG

Water is separated from oil products and LPG under their production and removed. Some amount of dissolved water is really always present besides of “free” water.

Maximal value of water content exists for every substance that can be in it in the dissolved form at an appropriate temperature. For example, for benzene this value doesn't exceed 0,2 kg/m^3 at the temperature 0 °C, 0,4 kg/m^3 at 20 °C, 0,65 kg/m^3 at 40 °C [9].

In oil products condensation of water can be if temperature is decreased while free water can be dissolved at the increase of temperature. Solubility of water in LPG is several times higher than in other oil products.

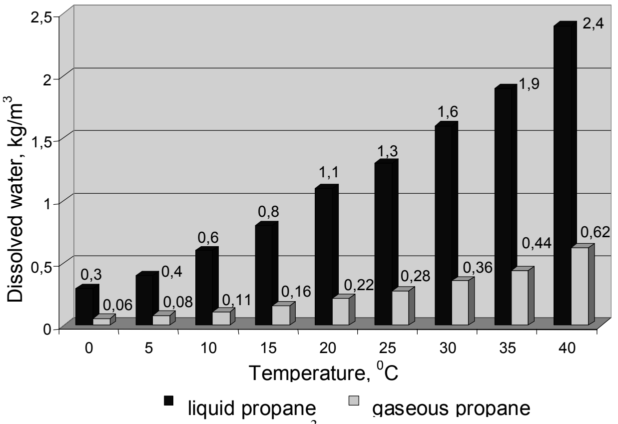

Fig. 4. Water dissolved in 1 m^3 of liquid and gaseous propane versus temperature.

A lot of water can be present in both liquid-phase and gaseous-phase LPG (unlike other oil products). LPG is stored in reservoirs under pressure so it if not possible to use simple (manual) methods for determination of water presence in LPG and removal of water. A lot of free water is appeared in reservoirs in gas-filling stations at low environment temperatures (mainly during winter period). Condensation of dissolved-in-LPG water under temperature decrease during the period from LPG reception from a supplier and up to the delivery to a gas-filling station is the main reason of it. Diagram for possible values of water dissolved in 1 m^3 of liquid and gaseous propane depending on temperature is shown in Fig. 4. Mass values of condensed water in a reservoir (volume 200 m^3) filled in on 50% of its maximal volume by liquid propane versus change of temperature on 5°C is presented in Fig. 5 for different temperature ranges. These diagrams are received on the base of data in [10].

Several tons of condensed water per week can be really saved up at a big gas-filling station in winter. In order to provide a consumer by high-quality LPG there is a need to transfer water in time from LPG-containing reservoirs into a water-gathering tank, removal of water from the later into a water tank-car and transfer of "clean" LPG from a water-gathering tank into a LPG-containing reservoir. Preparation (connection of a reservoir, switching on a compressor and provision of a pressure needed for a liquid transfer) are done by an operator in the automated system.

Processes of water transmission from a reservoir into the water-gathering tank 7, of water removal from it into a water tank-car, of "clean" LPG transmission from the water-gathering tank into a LPG-containing reservoir after starting the program from computer 9 are realized automatically (they are started and stopped by commands from the electronic unit that are formed according to prescribed algorithms depending on data of sensors).

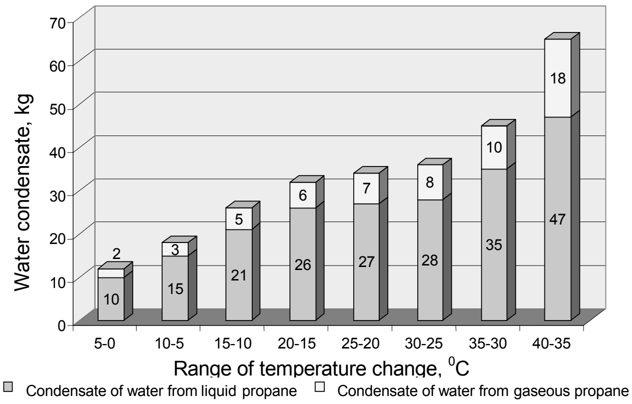

Fig. 5. Condensed water mass in a reservoir versus temperature.

The designed automated system for removal of water from LPG contains RF density, water content and level sensors (3, 4 and 6 correspondently), two electromagnetic valves 1 and 2, control system 8 and computer 9 (Fig. 6). Preparation (switching on a reservoir, a compressor and production of drop of pressure needed for pumping) is done by an operator.

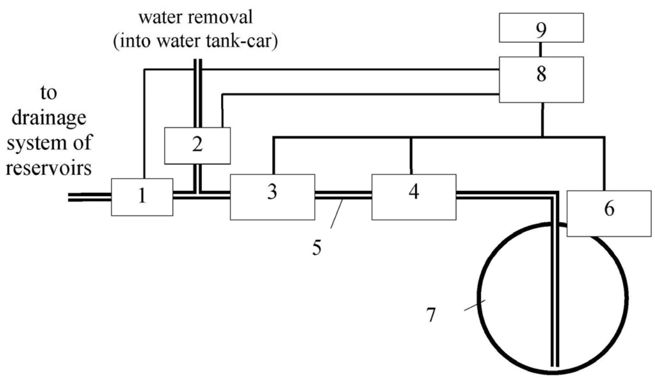

Fig. 6. System for measurement of LPG technological parameters and removal water from LPG.
*1*and *2* – valves; *3* – density sensor; *4* – sensor of water content; *5* – pipeline; *6* – level sensor; *7* – water-gathering tank; *8* – control unit; 9 – computer.

RF coaxial level sensor 6 is vertically installed in a water-gathering tank 7. The sensor is used for determination of "dirty" LPG and water level. The coaxial sensor has Teflon-coated inner conductor. The sensor has the following dimensions: length 1850 mm, diameters of the inner conductor, the coating and the outer conductor are 10 mm, 14 mm and 30 mm respectively. Frequency range of this sensor: 6 – 10 MHz.

Flowed-through RF LPG density sensor 3 (for determination of LPG density and cutting of LPG pumping that have higher density) and water content sensor 4 (for determination of water percentage) are installed into drainage pipeline 5. Each of the coaxial sensors is mounted along the pipeline. The sensors have equal length 350 mm. Coaxial sensor of water content 4 (0-100%) has Teflon-coated inner conductor (Fig. 7). Diameters of the inner conductor, the coating and the outer conductor are 22 mm, 30 mm and 51 mm respectively. Similar RF density sensor has inner conductor without any coating. Frequency range of these sensors: 6 – 16 MHz.

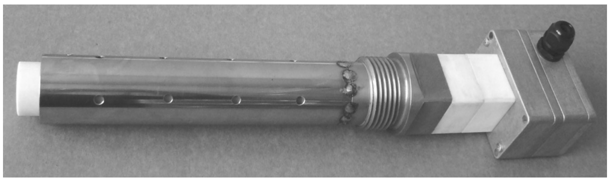

Fig. 7. Sensor for on-line measurement of water content.

Data are transmitted from the sensors 3 and 4 to the control unit 8 and then to the computer 9. Value of LPG density measured by the sensor 3 is taken here into account at determination of LPG water content. If LPG doesn't contain water then current data on LPG density and zero value of water content are received by the computer 9 from corresponding sensors. If LPG contains water then processing of data from the density sensor 3 is stopped; it is done when amplitude of received signals is decreased because of water (high-loss dielectric) appeared in LPG. In this case a minimum value of density during last 15 minutes stored in the computer 9 is used for calculation of water content under processing of data from the sensor 4. If water content is decreased again up to the zero value then the processing is done receiving data from both sensors 3 and 4.

Two electromagnetic valves 1 and 2 are mounted at the bypasses of the drainage pipeline 5; the bypass valve 1 is needed for control of water transmission from LPG-containing reservoirs into water-gathering tanks and from the latter – into a LPG-containing reservoir. The bypass valve 2 is needed for control of water removal from a water-gathering reservoir into a water tank-car.

Modules of spark-protection, switch and commutation components are placed in the control unit 8. The module of spark-protection provides data acquisition from sensors, realization of control functions, generation of control and indication commands and interaction with computer. Sensors are connected by four-conductor scheme through separate interface RS-485 (spark-safe circuits). The module connected to computer via adapter USB – RS-485.

Drainage pipeline 5 connects all the reservoirs and allows taking a liquid from the bottom of a reservoir. All operations under pipeline transportation of a liquid are done by pumping a liquid via a compressor. Preliminary a needed drop of pressure is done and a tap is opened on the drainage pipeline of a LPG-containing reservoir from which water will be pumped.

Control of pumping is done automatically by computer 9. There are tree program modules (program functions) that correspond to water transmission from a reservoir into a water-gathering tank; to water removal from water-gathering tank into a water tank-car; to LPG transmission from water-gathering tank into a LPG-containing reservoir. After a program starting up under water pumping from a reservoir into the water-gathering tank (the first function of the program) electromagnetic valve 1 is turned on. A volume of pumped liquid in the water-gathering tank is monitored by a RF level sensor 6; composition of a liquid in the pipeline is determined by flowed-through RF sensors of density 3 and water content 4. If pumping of "clean" LPG starts through the pipeline 5 then electromagnetic valve 1 is shut off and pumping is automatically stopped. Control of water pumping from the water-gathering tank into a water tank-car (the second function of the program) is done similarly but the other electromagnetic valve 2 is used. The third function of the program is control by pumping of LPG from the water-gathering tank 7 into a currently used reservoir. The pumping is stopped when the density sensor 3 measures low values of density (that means presence of vapor in the pipeline). Additional functions of the program are graphic and mnemonic imaging of processes, archive, report and counting of LPG losses because of water presence.

4. CONCLUSIONS

Thus highly accurate measurement of LPG density is provided. Influence of temperature of hermetic coupling element on output signal of the measuring device is removed in this device. Similar approach may be used also for RF measurements of various technological parameters. The considered RF measuring devices provide high accuracy of LPG monitoring under pipeline pumping and storage, improvement of supplied LPG quality, removal of water from LPG. These devices provide also high measurement accuracy of LPG technological parameters at any LPG phase state, under temperature and pressure changes during measurements.

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