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Features of selection of flow measurement methods and devices for flow measuring of liquefied petroleum gas in pipelines

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Abstract

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The purpose for the study was to get more knowledge about fluid and gases flow measurement methods and devices and to analyse these methods as well as to identify the advantages and disadvantages of each method for different applications and also to choose the best method and device to measure the flow of liquefied petroleum gas in pipelines.

The work consists of a theoretical part, which describes the principles of flow measurement and, directly, the analysis of the methods and its applications. All the data for this thesis was collected from network, books and lecture notes.

The result of the study shows a selection of the most useful methods and devices of flow measurement that are successfully used for liquefied petroleum gas measuring in the modern world.

Keywords: flow, analysis, methods, applications, liquefied petroleum gas

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List of abbreviations and symbols

LPG – Liquefied Petroleum Gas

Re - Reynolds number

V - Velocity of fluid

v - Kinematic viscosity

d - Diameter of the pipe

f - Frequency of sound

C - Velocity of the sound

Δf - Frequency difference

λ - Wavelength

1. Introduction

1.1. Basic information about flow and purposes of study

Flow measurement is widely used in accounting operations, as well as in the control, regulation and control of technological processes. For example, in the food industry the optimal management of many technological processes is based on the mixing of the various components and ingredients that make up the target product manufactured in strictly defined proportions, the change of which may impair the progress of processes and the production of low-quality finished product.

Firstly, it is important to know what is the flow, which is measured. The flow is the mass or volume of gas or liquid per unit time, which is passing through the section of the channel of flow measurement device. The flow can be measured with two flow rates – volumetric and mass flow rates (liters per unit of time or kilograms per unit of time).

Then, the flow of gas or liquid is measured by flow meters. Many flowmeters are intended not only to measure the flow rate, but also to measure the mass or volume of material passing through the measurement device for any chosen period of time. In this case, they are called flowmeters with counters. The mass or volume of the substance, which has passed through the counter is determined from the difference between two consecutive readings of reading device or integrator after period of time.

Nowadays, flow measurement techniques are developed quite well, but unfortunately, all the methods, which are used have their own flaws. Alternative methods of measurement are not reliable in expert's opinions. Therefore, the aim of the study is to compare and analyze the performance of gas flow measurement devices, which are most popular in modern world and to choose the best option for industrial purposes to measure liquefied petroleum gas in pipelines.

2. Fluid mechanics (Theory)

2.1. Laminar and turbulent flow

Laminar and turbulent flow are the two types of flow. Laminar is a flow with parallel fluid layers without interruptions between these layers (all the particles move to the same direction) (Wikipedia 2016). Turbulence is a chaotic movement of particles, schematically, it can looks like vortices in the flow. Turbulent flow is characterized by the instability of velocity and pressure in different time and space points in the pipeline. The main difference between laminar and turbulent flow is velocity. When the flow is laminar, the velocity of flow is the same in different points of pipeline. When it becomes turbulent – velocity becomes chaotic.

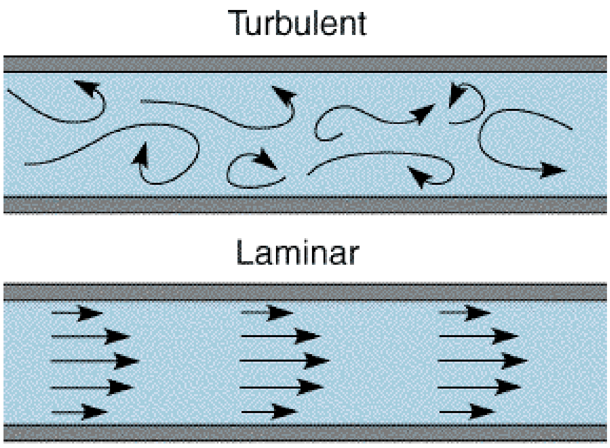

Figure 2.1. Schematic picture of Laminar and turbulent flow (Lorem Ipsum 2010)

2.2. The dependence of the flow on the Reynolds number

Reynolds number (Re) is a quantity without any measurement units, which is used to predict fluid flow behavior in different cases. Reynolds number defines which type of flow will occur in the pipeline. (Wikipedia 2016)

Re=2300 is most often used as the critical number to determine what flow it is – laminar or turbulent.

In cases, when Re < 2300 the flow is laminar.

In cases, when Re > 2300 the flow is turbulent.

The short definition of viscosity is ”resistance to flow”. Kinematic viscosity is used to determine Reynolds number and it is the ratio between dynamic viscosity and fluid density. (Sinkko, S. Lecture notes 2014)

Reynolds number can be defined from the formula:

$$Re = \frac{V\,d}{\nu} \qquad (1)$$

Where V – velocity of fluid, d – diameter of the pipe, ν – kinematic viscosity of fluid

3. Liquefied petroleum gas

3.1. Fractional distillation

Fractional distillation is the process step of cooling the gas (vapor) mixture, accompanied by sequential condensation of individual components or fractions. In industry, fractional distillation is used predominantly for low-temperature (less than 25 °C) separation of gas mixtures to obtain fractions with separate components. The ultimate cooling temperature of the gas mixture in each stage is determined by the requirements for the composition of the condensate. (Wikipedia 2016)

3.2. Fractions of oil

Depending on the temperature the range of boiling all oil fractions (separation of oil products) is divided into:

- Petroleum gas
- Naphtha
- Petrol
- Kerosene
- Diesel oil
- Lubricating oil
- Fuel oil

As it can be seen in the figure below, the LPG is the product of one of the oil fractions.

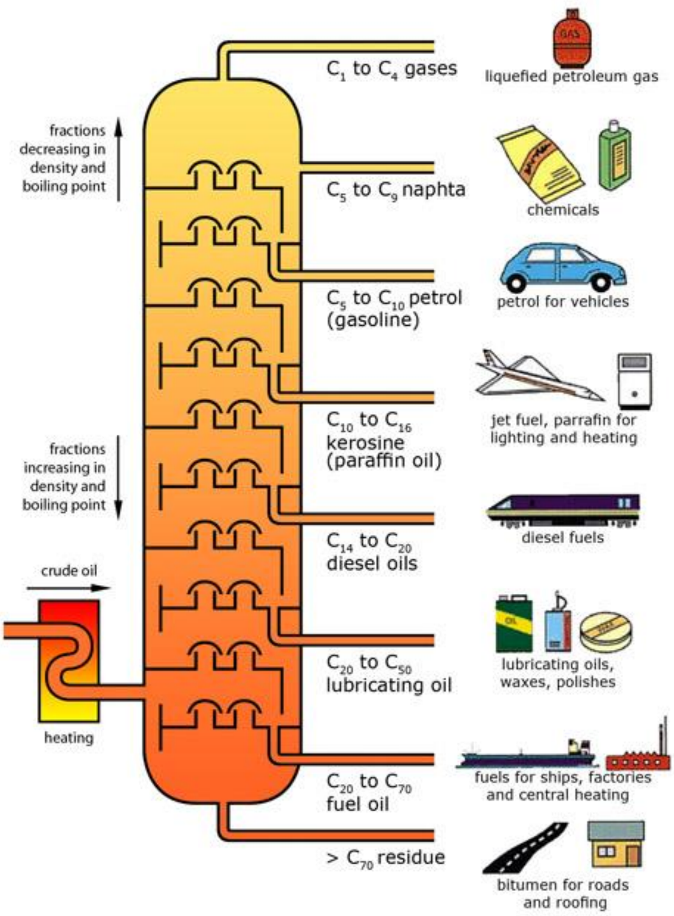

Figure 3.1. Fractions of oil with its applications (Jim Van Cura 2014)

3.3. Properties and applications of LPG

The components of LPG are propane and butane. LPG is a by-product of crude oil fractional distillation. The propane is colorless and odorless, so the LPG is colorless and odorless too.

It also evaporates quite quickly and its evaporations are not toxic. On the other hand, the main danger is that LPG is an extremely flammable and explosive gas according to its components (propane and butane).

The most common application of LPG is using it as a fuel in internal combustion engines. Usually this is a mixture of propane and butane. Then, it is used for cooking by millions of people all over the world. It can be used as an alternative to the electrical heating and kerosene in rural heating systems. (Wikipedia 2016)

4. Basic flow measuring methods

4.1. Pressure-based flow meters

There is a huge number of flowmeters, whose action is based on the differential pressure, but the most common pressure-based flow meters are Venturi flow meter and Rotameter.

4.1.1. Venturi flow meter

A Venturi flow meter is a meter whose work is carried out using a Venturi effect, which is named after Italian physicist Giovanni Venturi. Venturi flow meter looks like a restriction or throat in the pipeline with constant cross-section. The velocity and pressure in the throat are increasing and decreasing correspondingly. (Wikipedia 2016)

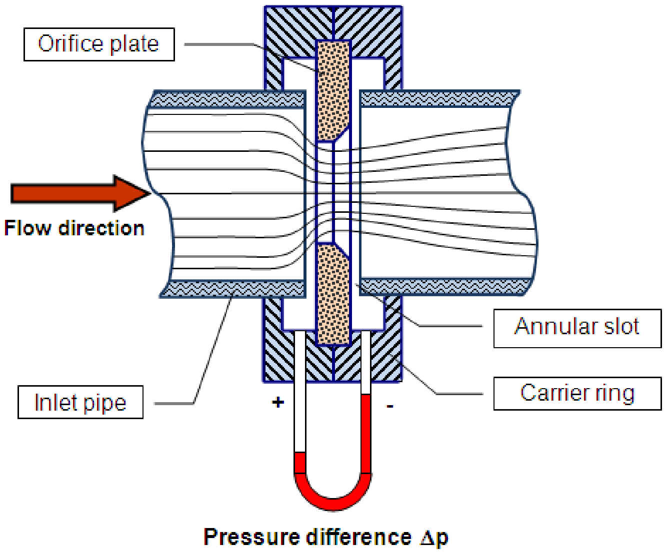

Figure 4.1. Principle of Venturi flow meter, which is based on Venturi effect (Wikimedia Commons 2014)

Advantages of Venturi flow meter:

- No moving parts
- Quite easy to install
- Suitable for gases (the main application)

Disadvantages:

- Quite large size
- More expensive (because of its size)
- Density, viscosity and temperature have an influence on accuracy

Applications:

- Power plants
- The measuring device is used in the pipelines, where the pipe diameter ranges from 50 to 1400 mm.

4.1.2. Rotameter

Rotameter is a device for measuring the flow in closed pipelines. Also these devices are well-known as “variable area meters” (Thermopedia 2016). It is one of the simplest devices for measuring the flow of liquids and gases.

The device is mounted on vertical pipelines, the flow in these pipes is directed upwards. The substance which moves through pipes falls on the float special grooves arranged in the upper part of the rotameter and causes rotation and motions up or down - the direction depends on the intensity of the flow.

The float takes a stable position when the power flow becomes equal to the force acting on a moving element on a conical tube of gravity. A "balancing" is possible because the width of the gap through which the fluid flow passes varies depending on what position the float is in the conical tube.

When the balance is reached all readings must be taken from the scale - the upper section of the float indicates the calibration value corresponding to the flow.

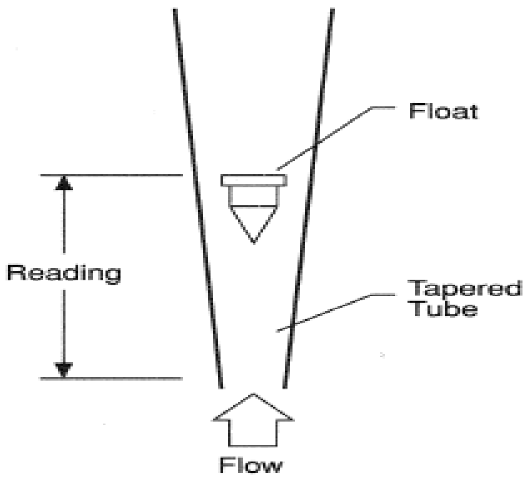

Figure 4.2. Rotameter working system (Thermopedia 2011)

Advantages of rotameter:

- The pressure loss is insignificant

- Simple and reliable device
- Does not require complex and expensive materials to manufacture device

The main disadvantage of the rotameter is the ability to use it only for vertical pipelines. This fact reduces the range of applications for these devices.

Key applications for rotameters are utilities, health, food, petrochemical, gas and paper industries.

4.2. Optical (laser) flow meters

The work of optical flow meters is based on the use of optical effects depending on the velocity of liquid or gas. There are several types of these devices:

- Doppler flowmeters, which are based on the measurement of the frequency difference caused by the reflection of the light beam moving stream of particles. It is rarely used to measure the flow.
- Flowmeters based on Fresnel-Fizeau effect, in which a measured parameter (or a shift of interference fringes shift frequency oscillation light) associated with the dependence of the speed of light in the transparent material of the moving speed of the latter. The main purpose of these flow meters – to measure the flow.

The main advantages of optical flow meters are:

- High accuracy
- High sensitivity
- Wide range of velocity measuring (0,1 m/s to 100m/s)
- No contact with the measured substance

But there are also disadvantages of using optical flow meters:

- Quite expensive

Optical flow meters have quite a big number of applications. They are applied to optically transparent liquids, which include water, kerosene, gasoline, alcohol, carbon tetrachloride, solutions of sulfuric and nitric acids, as well as gases.

4.3. Ultrasonic flow meters

To control and measure the flow of liquids and gases in industry from the 1960s ultrasonic (acoustic) flowmeters are used.

The principle of acting of ultrasonic flow meters is based on measuring the difference in propagation time. In this case, two ultrasonic sensors are located diagonally opposite to each other, functioning alternately as a transmitter and a receiver. Thus, the acoustic signal, generated by both sensors in turn, accelerates when it is directed with the flow and slows down when it is directed against the flow. Time difference arising as a result of the signal by measuring channel in both directions, is directly proportional to the mean flow velocity, from which it is possible to calculate the flow rate. Usage of several acoustic channels allows to compensate the distortion of flow profile. (KROHNE 2016)

Figure 4.3. Typical ultrasonic flowmeter. Two ultrasonic sensors are diagonally opposite to each other (transmitter and receiver) (GE Oil & Gas 2016)\

There are two basic methods for determining the liquid and gas flow by ultrasound:

- Doppler flowmeters
- Transit-time method

4.3.1. Acoustic properties of liquids and gases

It is important to know the acoustic properties of a substance for ultrasonic flowmeter. The picture below shows the velocities of sound in different substances, which are measured by ultrasonic flow meters more often. (KROHNE 2016)

For sound waves which are distributed using undamped state:

For liquids, ultrasonic flowmeters act with sound frequences in the range of 1 Megahertz (KROHNE Group 2016).

For gases, ultrasonic flowmeters act with sound frequences in the range of 100 Kilohertz (KROHNE Group 2016).

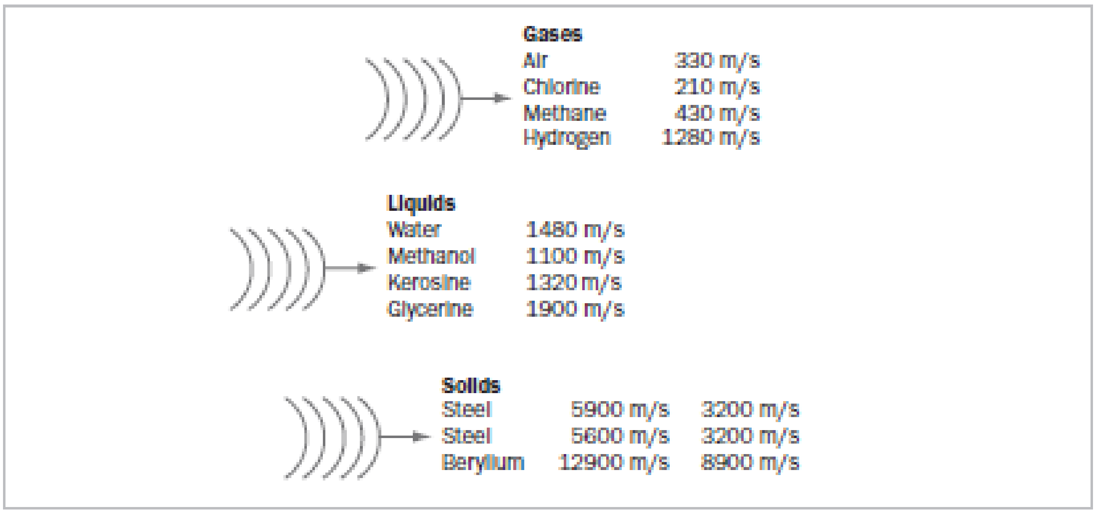

Figure 4.4. Velocity of sound when it penetrates through different substances (KROHNE Group 2016)

4.3.2. Ultrasonic Doppler flowmeters

To begin with, the work of Doppler ultrasonic flow meter is based on the Doppler effect, the effect which was discovered by Christian Doppler in 1842. (Wikipedia 2016)

Doppler effect is the change in frequency and, consequently, the emission wavelength, which is perceived by the observer (or receiver), as a result of movement of the radiation source and / or the motion of the observer (or receiver). (Wikipedia 2016)

The wave source moves to the left. Then, the left wave frequency becomes higher, and the right - lower, in other words, if the wave source is catching waves emitted by them, the wavelength decreases. If removed - the wavelength increases.

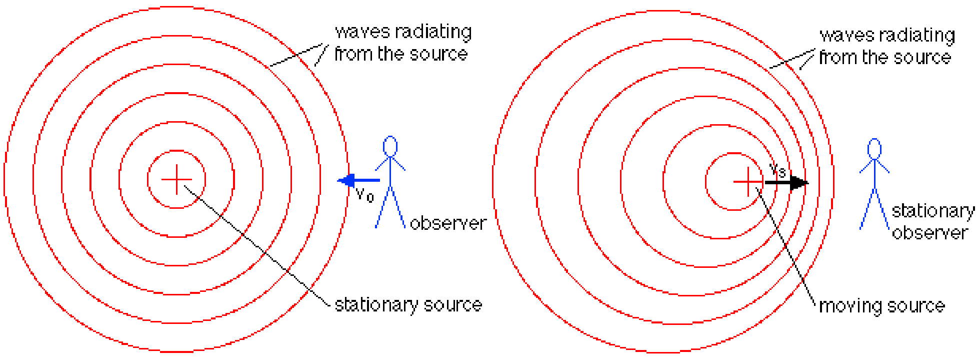

Figure 4.5. Doppler effect (BU Physics 2006)

The sensor of ultrasonic Doppler flowmeter consists of a transmitter and a receiver.

The emitter transmits ultrasonic waves of frequency f1 (In formula below) under an angle in a moving medium (frequency is about 1 ... 5 MHz) (KROHNE Group 2016). The wavelength calculated from the frequency f1 is given by:

$$\lambda 1 = \frac{C}{f1} \qquad (2)$$

Where C – velocity of the sound in medium

Then, because of reflecting particles moving, the receiver will perceive the reflected wave as a wave-shifted frequency and the wavelength will change as follows:

$$\lambda 2 = \frac{C - 2 \bullet V \bullet \cos\alpha}{f1} \quad (3)$$

where V - Velocity of the flow and cosα - the angle of ultrasonic waves

If Vp < C:

$$f2 = \frac{f1 \bullet c}{(C - 2 \bullet Vp \bullet cos\ \alpha)} \quad (4)$$

Frequency difference depends on the velocity of the particles (flow rate):

$$f2 - f1 = \Delta f = \frac{2 \bullet Vp \bullet f1 \bullet \cos\alpha}{C} \quad (5)$$

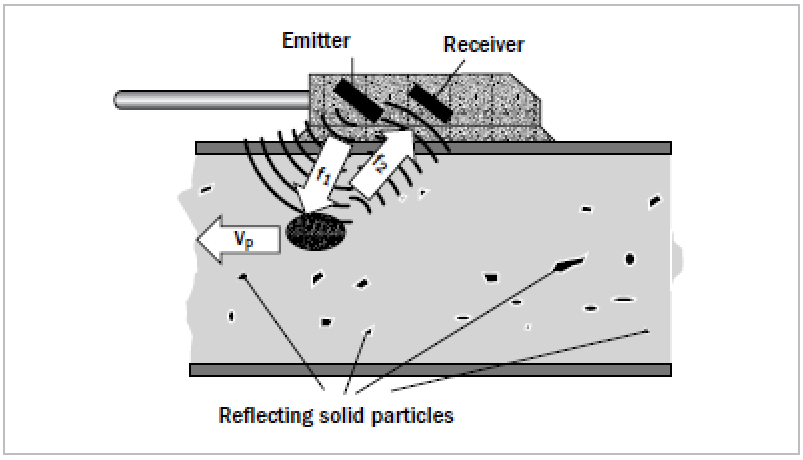

Figure 4.6. Working principle of Doppler ultrasonic flow meter (KROHNE Group 2016)

Currently, Doppler flowmeters are almost never used, since they have a number of disadvantages, compared to other ultrasonic flow meters (transit-time method)

4.3.3. Transit-time flow meters

Transit-time ultrasonic flow meters are flow meters in which the measured time difference of short pulses travels downstream and upstream on the path length.

Transit-time ultrasonic flow meter has two transducers (sensors). One transducer (sensor) operates like a transmitter and the other one is a receiver.

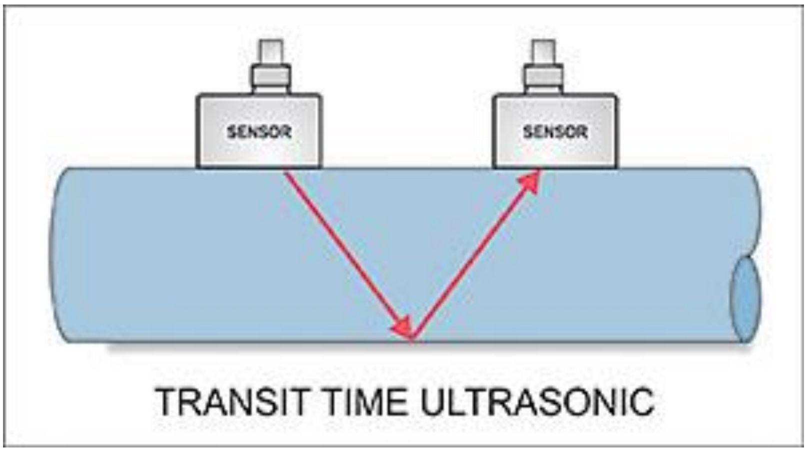

Figure 4.7. Transit time ultrasonic flow meter (Greyline Instruments Inc. 2015)

Transit-time flowmeters, in most cases, are single channel and of very short pulses with a duration of 0.1 - 0.2 ms sent in opposite directions simultaneously or alternately with a frequency for example 0.5 kHz. In common the transit time flow meter operates with frequency up to 2 kHz. (KROHNE Group 2016)

This type of ultrasonic flow meter measures the time it takes for ultrasonic signal of the second sensor after the pipe crossing (as shown on the picture above). Without flow, the transit time will be the same in both directions. With flow, the sound will move rapidly in the flow direction and slower in relation to the flow. Since the ultrasonic signal has to cross the pipe to the receiver, the liquid will not contain a considerable concentration of bubbles or solids. Else, the high frequency sound is too weak to pass through the tube. (Greyline Instruments Inc 2015)

4.3.4. Advantages and disadvantages of an Ultrasonic Flow Meter

There is a number of advantages and disadvantages for both types of ultrasonic flow meters.

Advantages of Doppler flow meter:

- Negligible pressure drop
- Negligible effect of viscosity, temperature, density
- Can measure flow of waste liquids

Advantages of transit-time method:

- Negligible pressure drop
- Negligible effect of viscosity, temperature, density
- Can measure both liquids and gases
- Very high accuracy
- No moving parts

Disadvantages of both flow meters:

- Quite expensive compared to other types of flow metering devices

Both types of ultrasonic flow meters have some common advantages, but the transit-time flow meter is more applicable than Doppler ultrasonic flow meter, also it provides very high accuracy of measurements.

4.4. Vortex flow meters

Vortex flow meter is the flow meter in which all the measurements occur by measuring the frequency of the pressure fluctuations. Such pressure fluctuations occur in the flow during the formation of vortices or oscillation of the jet, by some form of flow barriers, which are installed in the conduit, either by twisting the flow by other means.

Figure 4.8. Typical vortex flow meter (Emerson 2016)

Fluid or gas flow tries to come through the body installed in a flow meter, as a result the movement changes its direction and increases speed by reducing the pressure. (Wikipedia 2016) After passing the obstacle (the body) in the middle section, the pressure increases and speed decreases. Thus, the front part of the streamlined body has elevated pressure and at the rear - low pressure. Coming mid-section, the boundary layer flow separates from the body and under the influence of pressure difference (from high to low), formed by the body, changes its direction of movement, creating a vortex. The formation of vortices occur alternately on both sides of the body.

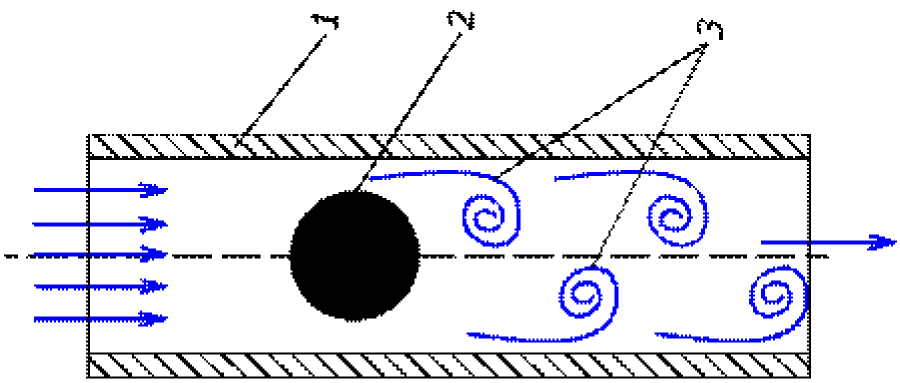

Figure 4.9. Working principle of vortex flow meter. 1 – Pipeline. 2 – Shedder bar. 3 – Vortices.

Vortex flow meter is applicable to different kinds of liquids and gases and also it is applicable to measure the flow of steam.

Advantages of vortex flow meter:

- Reliability
- Low installation cost
- High accuracy
- Digital flow signal

4.5. Electromagnetic flow meters

Electromagnetic Flowmeter or Magmeter is a device which is intended to account the medium flow and which works through the principle of the interaction of the flowing fluid through the magnetic field. The basis of this principle is the law of electromagnetic induction (Faraday's law). For this reason, a very important requirement for the environment, which is measured, is good electrical conductivity.

Figure 4.10. Typical Magmeter (Seametrics 2014)

The Faraday's law says that the voltage, which is induced across the conductor as it moves at right angles through a magnetic field is proportional to the velocity of that conductor. The figure below shows the practical application of this law to measure the flow of electrical conductive fluid.

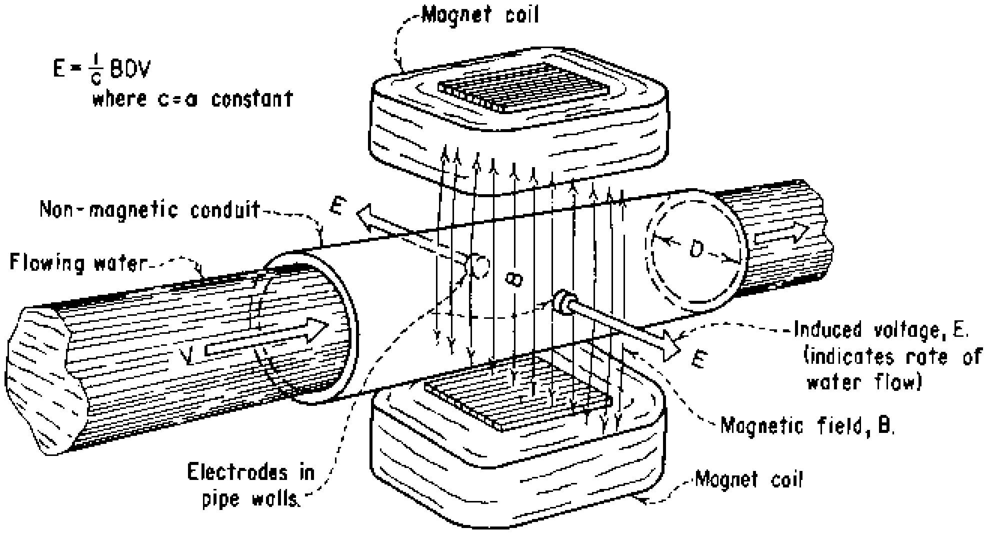

Figure 14-8.—Schematic view of a magnetic flowmeter.

Figure 4.11. Working principle for electromagnetic flow meter (TN Instrumentation 2016)

The main disadvantage of using an electromagnetic flow meter is the impossibility of using it to measure the flow of liquids, which have very small electrical conductivity or non-conductive (different insulators, for example, distilled water), gases and water vapor. Thus, the use of flowmeters may occur if the specific electric conductivity of liquid is more than 10^3 cm/m. So the electromagnetic flow meters are applicable to liquids, which are under this condition, for example any kind of water, which is not distilled, various juices, syrups, solutions, wastewater and also acids and alkalis.

Advantages of electromagnetic flow meter:

- High accuracy of flow readings. (Reliability)
- No dependence on the viscosity, temperature, density and other parameters of the medium
- No pressure loss in the flow meter
- Possibility to use with aggressive, viscous liquids containing abrasives.

A special and important advantage of the electromagnetic flow meter is that the results of measurement of this flow meter in the asymmetric flow and the same flow rate will be the same in laminar and turbulent flow.

5. Flow measurement method selection for LPG

5.1. Selection of type of the flow meter

The purpose of the study is to select the flow meter, which is the most suitable for measuring of the flow of liquefied petroleum gas.

From the types of flow meters, which are presented above, the least suitable is electromagnetic flow measurement method. This is due to the fact that this type of flow meter is not completely suitable for gas flow measurement according to very low electrical conductivity of LPG (propane-butane fraction).

There are some types of contact flow meters (Venturi flow meter, Rotameter, Vortex flow meter), which are suitable for measuring liquids, gases and steam, but all these flow meters have a significant drawback: the presence of a contact sensor to the controlled environment and as a result flow pressure loss of the medium. Because of high flammability and ability to easy evaporation (according to LPG properties), the presence of a contact sensor in the medium is also undesirable. Application of separation vessels, manufacture of narrowing devices made of special materials and the use of other special protection devices make the use of contact flow meters impractical because of the high cost of materials and maintenance complexity.

On the other hand, optical and ultrasonic flowmeters do not have the disadvantages mentioned above. It means that a deeper analysis between these two types of flow meters must be done. It is necessary to consider all the advantages provided by these flow measurement methods to choose the best one for measuring of the flow of LPG.

Optical (laser) flow meters have several benefits compared to flow measuring methods, which are presented above. These flow meters are non-contact, so it means that the pressure loss is insignificant. The accuracy of optical flow meters is high. But these flow meters are quite expensive. Also, the LPG is quite flammable and it is more suitable to use an ultrasonic flow meter to measure the flow.

The advantages of ultrasonic flowmeters are non-contact measurement, high accuracy, no pressure loss and no moving parts. All these advantages increase the service life of the device. In fact, explosion proof ultrasonic flow meters enable their use in the chemical industry. From an economic point of view, ultrasonic flowmeters are cost-effective for the customer after a short operating time. The accuracy of readings of this type of a flow meter depends only on the surface quality of the pipe walls. Therefore, it is ergonomical and more suitable to use an ultrasonic flow meter to measure the flow of LPG.

5.2. Selection of the model of selected type of flow meter

There are some companies, which manufacture ultrasound flow meters. The most well-known company is KROHNE Group. It is suggested to install a three-beam ultrasonic flowmeter UFM3030 by KROHNE company. The company is working with flow measurement technology with ultrasound for 36 years. Since 1980, over 30,000 reliable ultrasonic flow meters have been installed all over the world. (KROHNE Group 2016)

Figure 5.1. KROHNE UFM 3030 (KROHNE Group 2016)

Ultrasonic flowmeters KROHNE occupy a leading position in the global market of flow measuring devices. Three-beam flowmeter UFM 3030 has become a benchmark for many different applications. UFM 3030 demonstrates reliable and stable results according to more advanced electronics, digital signal processing and three-beam measurement technology. UFM 3030 has all the benefits of flow measurement by using of ultrasonic waves, the measurement accuracy is independent of the conductivity, viscosity, temperature, density and pressure of the medium. Transducer is smooth inside and outside, and has no moving parts. Therefore, there are no additional pressure losses, no need for recalibration of the device, and the need for maintenance is minimal. (KROHNE Group 2016)

UFM3030 is a universal device for the direct measurement of liquids, both simple and complex properties. Particularly highlighted is small conductive or non-conductive medium, such as demineralized water or hydrocarbons. Inorganic substances from molten sulfur to chlorine and organic compounds such as liquefied gases (LPG) do not pose problems for UFM 3030.

5.3. The principle of work of the selected flowmeter

The operating principle of UFM 3030 ultrasonic flow meter is based on the differential transit-time flow measurement method. Three pairs of ultrasonic transducers measured transit time of acoustic signals, which move downstream and upstream. The difference in transit time is proportional to the average flow velocity and the output signal is converted into volume and total flow. Measuring beams form a three-dimensional profile of the velocity distribution of the medium or fluid flow profile that runs along the measuring tube, through a third measuring beam. These measurement lines are arranged to minimize the impact of the flow regime. In combination with the latest technology of digital signal processing, it gives a stable, reliable and accurate flow measurement. (KROHNE Group 2016)

The third measuring beam allows UFM 3030 to consider the measurement condition in laminar and turbulent flow.

5.4. Summary

The selected ultrasonic flow meter KROHNE UFM 3030 has a very wide range of applications. This flow meter is equipped with three measuring beams, precision electronics and innovative digital signal processing technology that provides reliable and stable measurement results. The device does not require any special configuration, because transients do not affect his testimony.

The flowmeter UFM 3030 is a compact device that is easy to install and easy to operate. It can be installed in tight places, since there is no need to use filters, isolation from vibrations. The device has no moving parts and no pressure loss as a result.

The flowmeter UFM 3030 is not classified as a cheap instrument, but among modern ultrasonic flowmeters its cost is relatively low. The installation cost is significantly lower compared to similar costs for the installation of mass or vortex flowmeters.

In addition, the flow meter is versatile in terms of selecting the type of the medium. It is suitable for the oil and gas industry: everything from heavy crude oil to liquefied gases. It is possible to make a consequence that the given flow meter is perfectly suited for measuring the flow of LPG.

Considering all the above, it can be argued that the UFM 3030 ultrasonic flowmeter has excellent technical and metrological performance, a high degree of reliability and accuracy, and the perfect combination of price and quality. It is well suited for use in the oil and gas industry.

6. Conclusion

There is a plenty of methods for measuring the flow of liquids and gases under various conditions. All these methods are upgraded to improve the metrological and technical characteristics.

The result of the study was achieved – the knowledge about flow measuring methods was deepened and the most suitable flow measurement method for measuring the flow of LPG was selected. However, among all the flow measurement methods, which are presented in this thesis, ultrasound transit-time flow meters are the most appropriate for LPG flow measuring.

The advantages of ultrasonic transit-time flowmeters are: higher measurement accuracy, high reliability and no pressure loss (due to lack of moving parts), the possibility in principle of mass flow measurement and preservation of efficiency when changing the direction of flow, the ability to measure a large class of environments from the liquid metal to cryogenic liquids and gases.

All of these advantages can provide reliable results.

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