

Analysis of Linear Hydraulic Slope and Resistance in Non-Metallic Pipes

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Abstract—The article provides information on the theoretical and experimental study of linear hydraulic resistance in non-metallic pipes, and based on them, practical formulas for calculating hydraulic slope and resistance are proposed. As a result of the research, comparative characteristics with widespread metal pipes are given, and the results obtained by various researchers during the study of linear hydraulic resistance coefficients and hydraulic slope in new generation non-metallic pipes are presented and analyzed. As a result of the research, it was determined that the empirical formulas proposed on the basis of theoretical and experimental studies conducted by us are recommended for use in design and calculation works by calculating pressure loss in a wide range of Reynolds numbers.

Keywords— fluids, types of fluid motion, Reynolds number, linear hydraulic resistance and slope, pipelines, pressure loss

I. INTRODUCTION

The rapid development of industry, construction and agriculture is inextricably linked to various pipeline facilities. Until modern times, steel and cast iron pipes played an important role in the construction of water supply systems, the manufacture of which is also labor-intensive and, in some cases, economically unprofitable. The main disadvantage of steel and cast iron pipelines is that they are subject to chemical and electrochemical corrosion, and the inner surface of the pipe tends to be covered during the flow of water.

The development of new areas of the pipe industry has led to the introduction of various non-metallic materials that can replace steel and cast iron pipelines. Pipes made of non-metallic materials surpass metal pipes due to their hydraulics, installation, operation and a number of features [1].

Non-metallic pipes include polyethylene and vinylplast, as well as glass and plywood pipes made of various synthetic materials, which have great prospects. Non-metallic pipes are not subject to corrosion and the shocking effects of electric current, which protects them from damage and spillage. Because non-metallic pipes have a smooth surface, they have good fluid permeability compared to metal pipes.

When evaluating the field of application of plastic pipes, in addition to mechanical, chemical and other properties, it is important to know the hydraulic characteristics of these pipes. It is important to study the exact hydraulic characteristics of plastic pipes in order to study whether the hydraulic properties of these pipes change during the passage of liquid and whether they are prone to corrosion. [2,3]

Plastic pipes formed the basis of rapid development in the second half of the 20th century, based on the unlimited possibilities of processing raw materials of high molecular weight compounds. The Second World War was the reason for the intensification of the search for new types of materials, convincingly confirming that metals without the necessary additives or protective coatings would not meet such quality indicators as reliability and durability.

Pipes, first made of polyvinyl chloride, and after 10-12 years from polyethylene, surpassed traditional pipes made of cast iron and steel in many respects, including in terms of length, throughput, speed of construction and, especially, weight, durability.

Along with the valuable consumer properties of plastic pipes, modern requirements of scientific and technological progress even in the field of their production are more modern: the production of pipe products is highly productive, easily computer-controlled and environmentally friendly, since almost all waste can be recycled. Determination of the quality indicators of the pipeline - reliability and durability.

However, before proceeding to the consideration of the characteristic properties of plastic, we would like to indicate what types of pipes are replaced by polymeric materials and whether this process is not an alternative. In order to know what material the main pipelines of the housing and communal sector of a number of countries are made of, it is of particular importance to consider the structure of water supply networks by type of pipe material in most cities of the world in 1985-1990.

In a number of countries in Europe and Asia, a significant part of the water supply network is made of steel pipes. In other cities of the country - a similar

structure: the proportion of these pipes in volume is 20-65%. At the same time, in the largest cities of the world, the use of steel pipes does not exceed 7-10%, and most of the external water supply systems are made of durable, non-metallic materials, including plastic.

Let us note once again that the main quality of a steel pipe is characterized by its resistance to external influences, which ensures its versatility. It is used to transport hot and cold water, steam, gas, various liquid and dry products. If we do not take into account the reliability and durability that determine the economic efficiency of pipelines, then unlimited diameters and working pressures theoretically determine unlimited possibilities.

Indeed, the resistance of steel pipes to external influences is their main advantage. However, an analysis of working pressures shows that in about 30-50 percent of all systems, and in 95 percent of main pipelines and distribution gas pipelines, the working pressure does not exceed 0.6 MPa.

Unfortunately, pipelines made of traditional materials, especially steel, have two features: they are susceptible to corrosion destruction, and most often the inner surface of the pipelines corrodes in the transported medium and is filled with products. The latter leads to a decrease in the quality and damage to the transported fluid, which leads to a decrease in production.

Considering that these processes occur continuously in metal pipelines without reliable protective coatings, after 8-10 years the pipelines must be restored or repaired. However, this work is not done, and this continues to reduce the shadow-economic and environmental characteristics of these systems. According to reports from utility experts, the depreciation of water pipes is reduced by 50-60 percent, and in some places by up to 40 percent.

Great damage to the economy is caused by the fact that the inner surface of metal pipe basins is covered with corrosion products and sediments from the flood environment. Already in 5-10 years, such networks require an increase in energy consumption for pumping by 2-3 times. The cost of housing and communal services increases by 1.5-2 times due to the length of external engineering networks and internal sanitary pipelines of the housing stock, as well as the degree of their deterioration. This objective reality was realized in almost all developed countries in the 1960s, and they were only able to choose the right direction - the development of production and the widespread use of pipes made of polymeric materials.

Industrial production and use of plastic pipes began almost simultaneously in the early 50s of the 20th century in Europe, the USA and Japan. These pipes easily merged with the steel pipe market, since they weighed 3-5 times less, and most importantly, they did not rust.

The availability of copper and bronze, plastic and other non-metallic pipes, which have a durability that is 3-5 times longer than the service life of steel pipelines, stabilized the steel pipe market in the USA, Japan and Germany, and then led to its decline.

Plastic pipes are mainly used in the construction and overhaul of hot and cold water supply and heating systems in residential and public buildings. Plastic pipes are gradually penetrating the pipe market for water supply and heating pipes in Central European countries, competing with steel, copper and bronze pipes, with an average annual growth rate of 8%. The highest use of polymer materials in pipes is in Switzerland - 70 percent, Finland - 51 percent, Germany - 46 percent, Norway - 42 percent, Hungary - 32 percent, the Czech Republic and Slovakia - 28 percent, and Poland - 8 percent.

Since the first half of the 2000s, more and more metal pipes have been removed from water supply and heating systems. The most developing markets for plastic pipes are Turkey, Poland, the Czech Republic, England, Belgium, the Netherlands, etc.

The corrosion resistance of plastic pipes has determined their use in many technological processes in pipe-intensive industries, such as oil production, collection, transportation and processing, in addition to transporting corrosive media.

However, along with many positive properties, pipes made of polymeric materials have a quality that pipes made of other materials do not have: they are "alive", that is, they age over time. This quality is characteristic of almost all types of polymers, since they are in a "non-living" state and obey many laws of the living world. For example, the rate of their "aging" depends mainly on factors such as temperature and pressure. At the same time, as in a living organism, the aging process is accompanied by such phenomena as a decrease in elasticity, strength, an increase in fragility and a tendency to deform. The appearance of cracks, including micro-vertical ones, in the pipe wall leads to a decrease in the basic quality of plastic pipes, their resistance to aggressive environments.

A feature of pipes made of polymeric materials is called "light fragility". Defects that affect the reduction of the physical and mechanical properties of the pipeline can appear at any stage of production.

A pipeline made of polymeric materials is operated with strictly defined parameters, in particular temperature. Only when these conditions are met, the necessary reliability and durability of the plastic pipeline are ensured.

The mass use of plastic pipes often results in extensive preparatory work. Pipes made of polymeric materials are not as versatile as steel, so they are competitive only under certain conditions.

The economic efficiency of pipelines is largely based on the correct selection of material, design, high-quality installation and maintenance.

In modern times, plastic pipelines are designed to meet the basic needs of water supply, sewage, distribution gas pipelines and pipelines of domestic heating systems, low-pressure hydraulic transmissions.

II. THEORETICAL RESEARCH

In a number of countries around the world, studies have been conducted to study the pressure loss in plastic pipes, and

as a result of these studies, the value of the coefficient of friction - λ along the length of the pipe is expressed as follows.

$$i = \lambda \frac{\rho^2}{2gd} \quad (1)$$

Professor H. Tizon of the University of Belgium conducted a series of studies to study the coefficient of friction - λ and presented the results in tabular form. The experiments were carried out in polyethylene "Sopolex" pipes in laboratory and natural conditions.

Liquid release of polyethylene and metal pipes

H. Tizon's the following formula to compare knowledge

$$i = \frac{\lambda \rho^2}{d2g} \text{ and } \lambda = \frac{0.3164}{Re^{0.25}}$$

put in another form

$$i = 0,00054 \frac{\rho^{1.75}}{d^{1.25}}$$

When comparing H. Tizon's formula (1) with the Flemish formula

$$i = 0,00092 \frac{\rho^{1.75}}{d^{1.25}}$$

It was concluded that the liquid capacity of polyethylene pipes of the same diameter is 1.36 times higher than the liquid capacity of low-rough metal pipes.

A study of pressure losses in polyvinyl chloride and polyethylene pipes was conducted at a technical school in Zurich, and based on the results obtained, it was concluded that the Herman-Burbach formula used to calculate the pressure loss in smooth metal pipes was used to calculate the hydraulic resistance coefficient (friction λ).

$$\lambda = 0,00540 + \frac{0,322}{Re_r^{0.3}} \quad (2)$$

can be used. Here $Re_r^{0.3}$ - Reynolds is a number and belongs to the radius of the pipe. The formula (2) is true for the Reynolds number 10000 ÷ 950000. The following formula is proposed to determine the pressure loss [2,3,5]:

$$i = 0,0826\lambda \frac{Q^2}{d^5} \quad (3)$$

In Germany, H. Hruner conducted a study to study the pressure loss in polyvinyl chloride and polyethylene pipes, and concluded that to determine the pressure loss in such pipes Colbrug-White

$$\frac{1}{\sqrt{\lambda}} = -2 \lg \left(\frac{2,51}{Re \sqrt{\lambda}} + \frac{k}{3,71d} \right) \quad (4)$$

formula can be used. It can be accepted here $k = 0,0015$.

In the Czech Republic, Ph.dok. A.Polyanskiy and muh. A. Janus conducted experimental studies at small values of the Reynolds number to study the hydraulic resistance in polyvinyl chloride pipes with conventional transition diameters of 15.20, 25, and 32 mm. A. Polyan-skiy's own results for smooth pipes Yakoba and Erka

$$\lambda = 0,0072 + \frac{0,6104}{Re^{0.35}} + \frac{5,1 \cdot 10^{-6}}{d} Re^{0.108} \quad (5)$$

compared with the formulas and concluded that the value of the hydraulic resistance coefficient in polyvinyl chloride pipes is less than the result calculated by formula (5).

In the Institute of Hydraulics of the University of Padua (Italy) prof. A. Veroneza and K. Daten conducted experiments to study the pressure loss in rigid polyvinyl chloride (PVC) pipe. The experiments were performed on 80, 125 and 200 mm pipes. Based on these experiments, A. Veroneza and K. Daten proposed the following formulas for hydraulic calculations in polyvinyl chloride (PVC) pipe.

$$\lambda = \frac{0,18}{Re^{0.2}} \quad (6)$$

$$Q = K_2 D^{\frac{8}{3}} i^{\frac{5}{9}} \quad (7)$$

$$K_2 = 10,64 \left(\frac{\rho}{\mu} \right)^{\frac{1}{9}}$$

It is recommended to use these formulas in the range of $4 \text{eyn} 10^4 \div 10^6$ Reynolds number.

To approximate the value of the coefficient of hydraulic resistance in viniplast pipes, Shevelyev proposed the following formula:

$$\lambda = \frac{0,287}{Re^{0.226}} \quad (8)$$

Shortly afterwards, M. Ruzin proposed the following formula for calculating the coefficient of hydraulic resistance, regardless of the material of which the plastic pipes (viniplast or polyethylene) are made [2,3,4]:

$$\lambda = \frac{0,246}{Re^{0.22}} \quad (9)$$

Given the expression (9), it is recommended to use the following formula to calculate the pressure loss.

$$100i = 0,27 \frac{Q^{1.78}}{d^{4.78}} \quad (10)$$

Based on the results of experimental studies conducted in 1958, formulas were proposed to calculate the coefficient of hydraulic resistance in viniplast and polyethylene pipes:

$d = 15 \div 50$ mm for viniplast pipes

$$\lambda = 0.39 \frac{D^{0.10}}{Re^{0.25}} \quad (11)$$

or

$$\lambda = 0.04 \frac{D^{0.35}}{Q^{0.25}} \quad (12)$$

It is proposed to calculate the pressure loss in these pipes by the following formula:

$$100i = 0.032 \frac{Q^{1.75}}{D^{4.65}} \quad (13)$$

$d = 15 \div 60$ mm for polyethylene pipes

$$\lambda = \frac{0.287}{D^{0.20} Re^{0.25}} \quad (14)$$

or

$$\lambda = 0.03 \frac{D^{0.06}}{Q^{0.25}} \quad (15)$$

The following formula is proposed to calculate the pressure loss in polyethylene pipes with a diameter up to $D = 60$ mm:

$$100i = 0.024 \frac{Q^{1.75}}{D^{4.95}} \quad (16)$$

In subsequent studies, formulas (14), (15) and (16) were further improved, allowing the calculation of hydraulic resistance in polyethylene pipes with a diameter up to $d = 100$ mm. According to the normative documents used in the machine-building industry, the following formula has been proposed for the calculation of hydraulic resistance in viniplast pipes [4,6,7].

$$100i = 0.025 \frac{Q^{1.774}}{D^{4.774}} \quad (17)$$

III. EXPERIMENTAL RESEARCH

In accordance with the results obtained by the above-named researchers, the following formulas were proposed based on the results of experiments conducted on polyethylene pipes of different diameters 12mm, 14mm, 15.5mm, 20mm and 27 mm in the experimental device (Figure 1.) assembled by us:

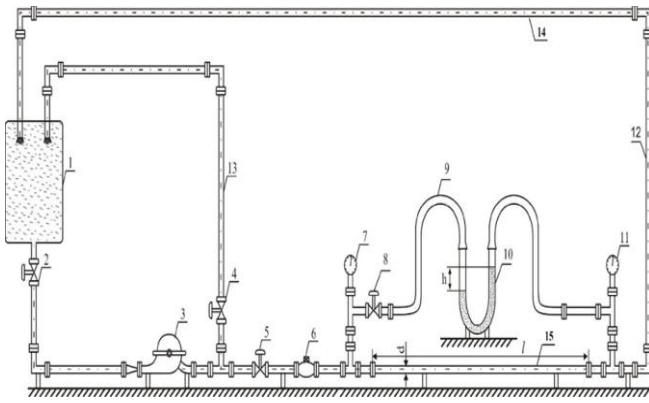


Fig. 1. Schematic of the experimental device.

Graphs were constructed according to the experimental values, and the following empirical expressions were obtained, which were used in practical calculations for the corresponding diameters and certain intervals of the Reynolds number. For $d = 12$ mm pipe $Re = 5100 \div 18500$ within limits

$$\lambda = \frac{0.254}{Re^{0.213}} \quad (18)$$

for $d = 20$ mm pipe $Re = 4000 \div 17000$ within limits

$$\lambda = \frac{0.338}{Re^{0.249}} \quad (19)$$

$d=27$ mm pipe $Re = 3600 \div 14500$ within limits

$$\lambda = \frac{0.404}{Re^{0.272}} \quad (20)$$

In general, these expressions can be written as follows:

$$\lambda = \frac{A}{Re^B} \quad (21)$$

Thus, in order to obtain a generalizing formula $A = f(d)$ and $B = f(d)$ dependencies were considered.

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Experiments conducted to study the hydraulic resistances in plastic pipes (polyethylene and vinyl) have shown that the resistances in these pipes are identical to the resistances in hydraulically smooth pipes.

To determine the value of the hydraulic slope i in plastic pipes, the formula proposed by F.A. Shevel'ev can be used.

$$i = 0,000685 \frac{\vartheta^{1,774}}{d^{1,226}} \quad (22)$$

Using formula (22), tables have been $i = f(Q, d)$ compiled, and through these tables, i and $H=iL$ can be determined.

In the case under consideration, the value of the specific resistance A can be calculated as follows.

$$A = \frac{i}{Q^2} = \frac{0,00111}{\vartheta^{0,226} d^{5,226}} \quad (23)$$

$\vartheta = 1,0 \frac{m}{sek}$ then expression (23) takes the following form:

$$A' = \frac{0,00111}{d^{5,226}} \quad (24)$$

$\vartheta \neq 1,0 \frac{m}{sek}$ It is advisable to calculate the specific resistance A as follows.

$$A = A' k_2 \quad (25)$$

where k_2 is the correction factor and is calculated by the following formula

$$k_2 = \frac{1}{\vartheta^{0,226}} \quad (26)$$

Due to the high corrosion resistance of plastic pipes, there is no chance of unevenness during their operation. Therefore, the reported table values can be used for both new and used pipes.

IV. RESULTS

1. Analysis of the existing literature shows that there is a need for experimental research of the new generation of non-metallic pipes and fittings produced. Thus, expressions that are not based on empirical results and are theoretically derived often do not yield results in solving practical problems. Therefore, our experimental research covers a topical issue.
2. The results of experimental research provide a basis for ensuring economic efficiency and energy savings in design and calculation work.
3. The expressions obtained for the calculation of linear hydraulic resistances are also suitable for compiling table estimates used in design work.
4. It is possible to carry out research of unexplored plastic pipes of different diameters in the assembled experimental device.

at Azerbaijan Technical University in experimental facilities assembled by us.

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