# CALCULATION OF HYDRAUDYNAMIC PARAMETERS OF PIPELINES REPAIRED WITHOUT TRENCHING USING POLYETHYLEN PIPES

V. Agapchev, M. Fattakhov

Ufa State Petroleum Technological University

*The paper describes features of hydraulic frictions calculation for pipelines repaired using polyethylene pipes. Effective formulas are given to determine the hydraulic friction coefficient for various zones of fluid flow in a pipeline.*

## INTRODUCTION

The choice of a conventional method for pipeline repair depends on the degree of pipeline failure which may result in disturbing hermetic conditions or may not. If hermetic conditions are preserved, the pipeline is considered as consisting of several sections in accordance with surface topography and technical feasibility of pulling a plastic pipe through these sections; if hermetic conditions are disturbed, the ends of sections are determined by locating holes on pipeline surface. Both ends of these sections are opened and bobbins are cut out. One end of the section is flanged and then capped with a flange equipped with a lubricator for a cable and an inlet for pumping in water or injecting compressed air to push a plug with a cable attached towards the other end of the section under repair.

A section of plastic pipes with a head is pulled through the pipeline by means of a winch or a tractor. Depending on the working pressure in the pipeline the interpipe annular space may be filled with grouting mortars (cement – clay or clay – cement). The main physical and chemical properties of grouting mortars are setting time, solidification time, shearing stress, mortar density and mechanical properties of cement stone. The setting time of these mortars is about 10 min. The interpipe annular space is grouted using equipment for mortar mixing and injecting used for well construction. Air is completely forced out of the interpipe annular space using a gel plug ahead of the mortar stream so that no air caps are formed in upper bends of pipeline profiles.

Finally, the sections of plastic pipes on repaired parts of the pipeline are flanges and covered with a shell jacket made of steel pipe and the interpipe annular space is grouted as mentioned before.

But this classic scheme doesn’t work in repairing underwater parts of pipelines with holes. A hole makes it impossible to push a plug with a cable through a pipeline because of a pressure drop which takes place after the plug has passed this hole.

We suggest using a new method for pulling a cable through a pipeline section with a hole. This is achieved by using a system having two plugs (Fig. 1) [1].

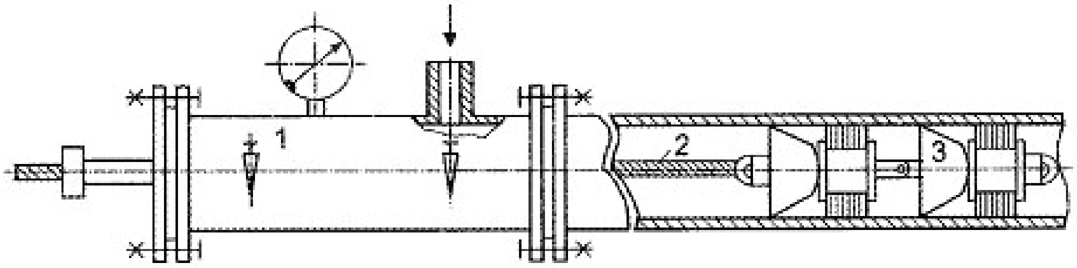

Fig. 1. Pulling a drawing-in cable

1 – working space; 2 – a cable; 3 – a cleaning device

One of the plugs with a non-return valve, a locking device and a junction element is pushed through by means of the working fluid thus pulling a cable through the pipeline. After the plug has passed a hole the working pressure in the pipeline drops bringing the plug to a stop with interlocking to prevent backward motion.

Then the second plug is set to motion in the same way from the other end of the section under repair. The first plug that has been locked serves to pass the air and fluid forced out by the second plug. Then the junction element of the second plug interacts with that of the first plug.

On assessing the results of the two plugs’ junction the mode of the two plugs withdrawal is chosen, i.e. using the first or second end of the section. Thus it becomes possible to pull a cable through a non-hermetic pipeline with subsequent pulling a plastic pipeline through this section.

This technology was used in Bashkortostan on the Belaya River for Kuraskovo – Thermoelectric Plant-3 gas pipeline repair, with an underwater section with holes being 750 m long, inner diameters 219 and 273 mm and working pressure 0,6 MPa.

## METHOD DESCRIPTION

Wide use of polymer pipes for systems collecting and transporting oil, gas and oil products requires investigating their hydraulic design [2, 3, 4]. Conventional methods don’t take into account the characteristic properties of hydrocarbon product piped using polymer pipelines [5, 6]. Moreover these methods as a rule are developed for pumping water having certain temperature [5].

Some authors [5, 7] state that representing a fluid flow as having two independent regions – a laminar underlay and the pipeline flow core - is to a certain degree arbitrary for their interaction is rather substantial.

Under such conditions there isn’t much ground to consider a laminar underlay as a distinct flow region having parameters different from those of other regions of pipeline flow. Some authors state that based on certain assumptions it’s more consistent to consider a turbulent flow as a single layer of fluid flow with parameters that can be rather accurately described knowing the distribution of total tangential stresses of friction depending on the distance from the walls of the pipeline to its centre and its relationship with the law of hydraulic resistance.

The value of tangential stresses in fluid layer is represented by the relation:

$$\tau = \tau_0 \cdot \frac{R(y)}{R_0}, \tag{1}$$

where τ is tangential stress of friction in a fluid flow layer at the distance y from the pipeline wall; $\tau_0$ is tangential stress of friction on the pipeline wall; R(y) is a hydraulic radius corresponding to a fluid flow layer having the specified velocity; $R_0$ is a hydraulic radius of the pipeline.

The formula (1) shows that if $R(y) = R_0$ (infinitesimal distance from the wall) $\tau=\tau_0$. At infinitesimal distance from the flow axis when $R(y) \rightarrow 0$ the value of τ becomes minimal.

Assuming that flow velocity at different distances from the pipeline wall is a function of total tangential stresses of friction τ, we can write down that:

$$\frac{V}{V_{\max}} = \left( \frac{R_V}{R_{V\max}} \right)^m, \tag{2}$$

where V is flow velocity at the distance y from the pipeline wall, $R_v$ is a hydraulic radius corresponding to the location of a point with velocity V; $V_{max}$ is maximum flow velocity along the axis of fluid flow; $R_{Vmax}$ is a hydraulic radius corresponding to the location of a point with maximum velocity.

Processing the experimental data obtained by Nikuradze, I. who studied the distribution of local velocities on the cross-section of pressure flow in smooth circular cylinder pipes in the range of Reynolds numbers from $4 \cdot 10^3$ to $3{,}2 \cdot 10^6$. The results obtained using the equation

$$\frac{V}{V_{\max}} = \left( \frac{R_V}{R_{V\max}} \right)^{\sqrt{\lambda}}, \tag{3}$$

agree well with the experimental data obtained by professor Shevelev F.A. who studied the distribution of local velocities for new circular cylinder steel and cast iron pipes with diameters from 16 to 301 mm [5]. Velocity profiles in a 301 mm diameter pipeline, $\lambda = 0{,}020279$, are given in Figure 2. It's clearly seen that the experimental data agree well with the firm line obtained using the equation (3).

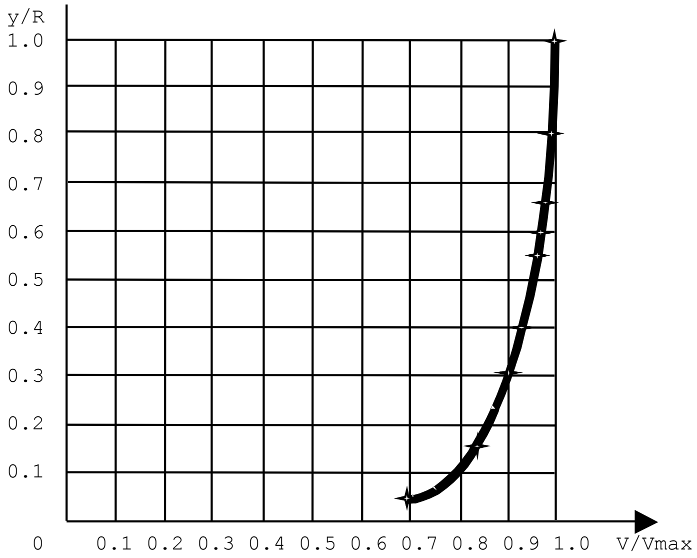

***Fig. 2***

**Comparison of the calculated data using the formula $\frac{V}{V_{max}} = (\frac{R_v}{R_{vmax}})\sqrt{\lambda}$ and the experimental data obtained by Shevelev, F.A.**

**__________ calculated**

**✧ experimental**

Though for pipes with small diameters (16 mm) deviations are more appreciable being within the experimental error due to disturbances affected by a Pitot tube used to measure local velocities.

The equation (3) shows a unique relationship to estimate a hydraulic resistance coefficient along a pipeline:

$$\lambda = \frac{\lg^2\left(\frac{V}{V_{\max}}\right)}{\lg^2\left(\frac{R_V}{R_{V\max}}\right)}, \tag{4}$$

The equation (4) includes two complicated parameters $\frac{V}{V_{\max}}$ and $\frac{R_V}{R_{V\max}}$. To solve design problems of pipeline systems and determine hydraulic parameters of fluid flows in these systems some authors using the concept of mean velocity $V_{mean}$ suggest that λ can be determined using the relationship:

$$\lambda = \frac{\lg^2\left(\frac{V_{mean}}{V_{\max}}\right)}{\lg^2\left(\frac{R_{Vmean}}{R_{V\max}}\right)}, \tag{5}$$

where $V_{mean} = \frac{4Q}{\pi d^2}$ is mean flow velocity; Q is volume flow; D is a pipeline diameter.

The parameter $\frac{R_{Vmean}}{R_{V\max}}$ shows the location of a point having mean velocity $V_{mean}$.

At present there are no unique relationships to describe the $\frac{V_{mean}}{V_{\max}}$ ratio and no formula to assess the location of a point having mean velocity. Based on experimental data obtained by various authors, it may be stated that the mean flow velocity point is located in the range from 0,1d to 0,155 d (where d is a pipe diameter) [5].

To design pipeline systems and to calculate their hydraulic parameters it is recommended to use Kolbruk-White formula to calculate the λ coefficient:

$$\frac{1}{\lambda} = -2\lg\left(\frac{K_{eq}}{3.7d} + \frac{2.51}{\mathrm{Re}\sqrt{\lambda}}\right), \tag{6}$$

where $K_{eq}$ is a coefficient of equivalent roughness with uniform granularity.

For hydraulically smooth pipes if the influence of $K_{eq}$ is excluded the equation (6) gives Prandtl formula.

$$\frac{1}{\lambda} = 2\lg(\mathrm{Re}\sqrt{\lambda}) + 0.8, \tag{7}$$

$K_{eq}$ is a parameter to be studied separately, for different types of plastics have different roughness. It's obvious that this parameter also depends on the technology used in pipe fabrication. The coefficient of equivalent roughness can be determined only experimentally using the relation common to the whole region of turbulent flow, i. e. using hydraulic experiments. The character of this parameter can be further investigated from the point of view of physical roughness of the inner surface of plastic pipelines based on the state standard GOST 2789 "Surface Roughness" [7]. Thus, engineers working for "VNII VODGEO" Institute, Leningrad Institute of Railway Engineers developed the following relation for $K_{eq}$:

$$K_{eq} = 2 \cdot r_a^{1,33}, \tag{8}$$

where $r_a$ is mean arithmetic deviation of the profile of the inner surface of a pipe from the mean line showing the height of unevenness.

The influence on $K_{eq}$ value affected by such parameters as height of unevenness for ten points on investigated surface, the greatest height of unevenness, mean spacing of unevenness for tops having the greatest height, mean spacing of unevenness, is not more than 5 % for low and high pressure polyethylene pipes, polyvinyl chloride and chlorinated polyvinyl chloride pipes having diameters from 25 to 400 mm [5]. In accordance with the work [4], the value of equivalent uniform grained roughness coefficient for polymer pipes such as low and high pressure polyethylene pipes, polyvinyl chloride and chlorinated polyvinyl chloride pipes as well as for multilayer metal-polymer pipes produced by various firms such as "Virsbo", "Oventrop", "Rehau", "Freatek", "George Fisher", "Henco" averages 0,02 mm.

Using the formulas (6) and (7) presupposes determining the beginning of turbulence resistance region boundary. To do it we use the relation developed by Altshul, A.D. for determining $\mathrm{Re}_{sq}$ – a Reynolds number corresponding to the beginning of this region.

$$\mathrm{Re}\,sq = \frac{500 \cdot d}{K_{eq}}, \tag{9}$$

The author of the work [5] suggests using a coefficient $B_n$ ranging from 1 to 2 to show flow regime change from laminar to turbulence resistance region. The value of $B_n$ is determined using the formula:

$$b_n = 1 + \frac{\lg \mathrm{Re}\,act}{\lg \mathrm{Re}}, \tag{10}$$

where $\mathrm{Re}_{act} = V_{mean} \cdot d/v$ is an actual Reynolds number; v is a kinetic coefficient of piped fluid viscosity.

If $\mathrm{Re}_{act} > \mathrm{Re}_{sq}$ , we assume that $\mathrm{Re}_{act} = \mathrm{Re}_{sq}$ because a pipe works in the square region of resistances, in this case $B_n$ equals 2.

Approximating the formula (6) enabled the author [5] to obtain the following formula to determine λ in the transient region of hydraulic resistances.

$$\lambda = \frac{\left[ \frac{b_n}{2} + \frac{1.312(2 - b_n) \cdot \lg\left( \frac{3.7d}{K_{eq}} \right)}{\lg \mathrm{Re}\,act - 1} \right]^2}{\lg^2\left( \frac{3.7d}{K_{eq}} \right)}, \tag{11}$$

While designing plastic pipes working in the square region of hydraulic resistance it's recommended to use Prandtl formula for rough pipes.

$$\lambda = \frac{0.25}{\lg^2\left( \frac{3.7d}{K_{eq}} \right)}, \tag{12}$$

The work [5] contains experimental data to test the relations (3) and (11). The experiments were performed using a rectangular cross-section (36 x 75 mm) acrylic plastic pipe and a laser Doppler velocity meter (LDVM). Using LDVMs enables measuring local velocities without disturbing the fluid flow which is preferential as compared to other methods, e. g. a Pitot tube. As follows from Figure 3, maximum error doesn't exceed 12 % which is quite admissible for hydraulic calculations.

What makes using the formulas (6), (7), (11) and (12) a matter of principle is the fact that these formulas are used for fluid models of more viscous, as compared to water, systems, such as oil and oil products. It requires a more detailed study of piped product viscous characteristics and their dependence on the temperature factor [10, 11].

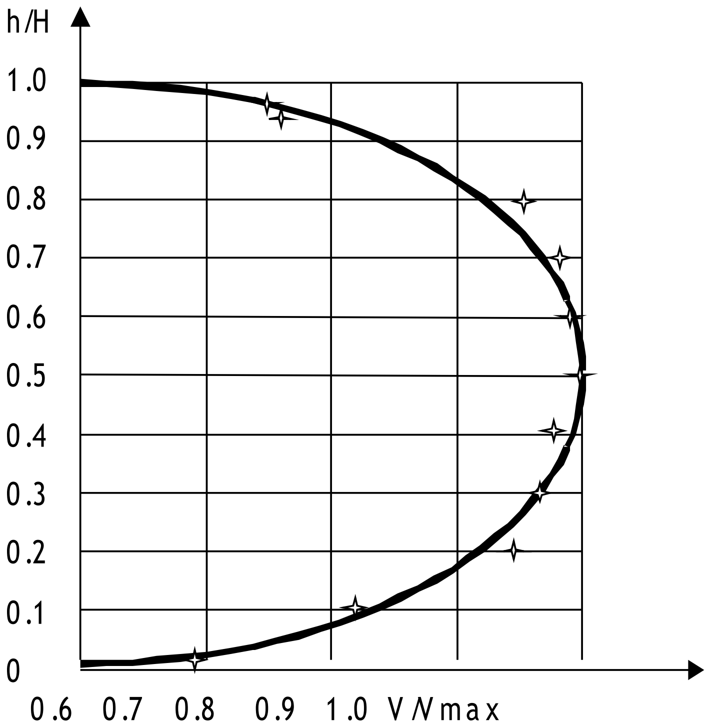

*Fig. 3*

**Comparison of calculated data using the formula $V/V_{max} = (Rv/Rv_{max})^{?\lambda}$ and the experimental data obtained using LDVM. Local flow velocities in a rectangular cross-section pipe**

**_________ calculated**

As follows from hydrodynamic parameters calculations of pipelines with inner plastic pipe sections, plastic pipe pulling results in a volume flow drop. At the same time increase of the $d/d_o$ ratio ($d_0$ and d corresponding to inner diameters of metal and plastic pipes) results in the $Q/Q_o$ ratio increase($Q_o$ and Q corresponding to volume flows of metal and plastic pipes). In the laminar flow region a volume flow drop is 20-25 % higher as compared to the transient region. As follows from these calculations, for the laminar flow region $Q/Q_o \sim (d/d_o)^4$ and for the transient region $Q/Q_o \sim (d/d_o)^{2{,}714}$. Nevertheless, in the hydraulic friction zone of turbulence resistance with $Q/Q_o \sim \{\lambda_0/\lambda \cdot$

$(d/d_o)^5\}^{1/2}$ plastic pipe roughness as compared to metal pipes decrease results in pipeline volume flow increase (Fig.4). This agrees with the effects given in [9].

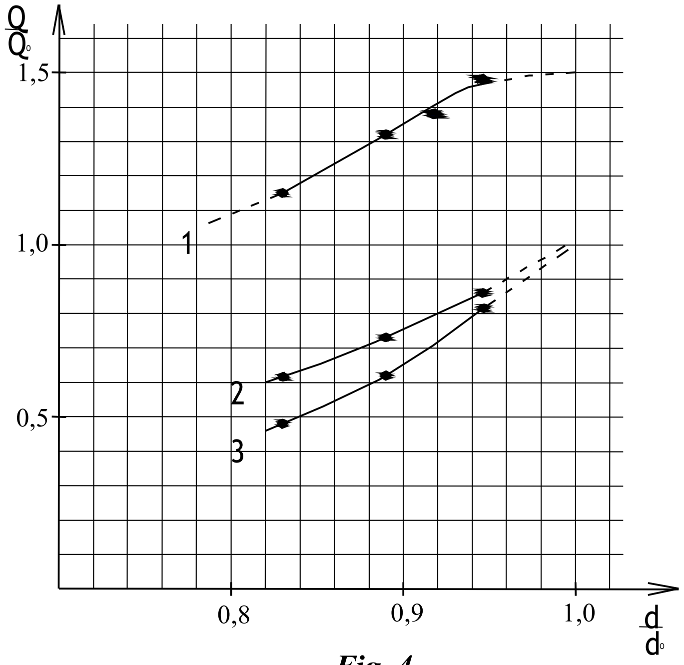

*Fig. 4.*

**Dependence of Q/Q$_0$ change on d/d$_0$ for various zones of hydraulic friction**
**1 - turbulence resistance region zone**
**2 - transient zone**
**3 - laminar zone**

## CONCLUSION

Significant change of piped fluid volume flow studied in the real change interval for the $(d/d_o)$ ratio in pipeline systems requires detailed verification of hydraulic parameters change during pipeline operation.

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