

On the need to account changes in hydraulic performance of worn-out metal water pipes

Oleg Aleksandrovich Prodous^{1,*}, Dmitry Ivanovich Shlychkov², and Aleksander Anatolyevich Shestakov²

¹INCO-Expert LLC, 37/1, Moskovskiy Prospect, office 1/14, lit. A, St. Petersburg, 190005, Russia

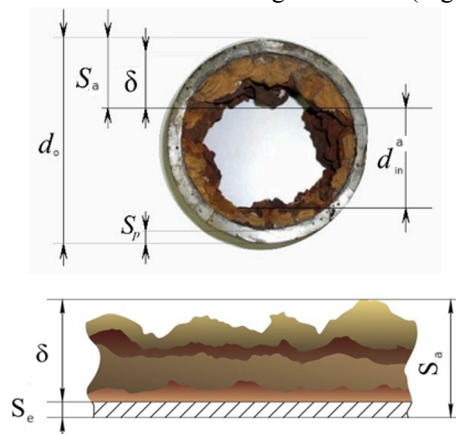
²Moscow State University of Civil Engineering, 26, Yaroslavskoye shosse, Moscow, 129337, Russia

Abstract. During the operation of metal water pipes made of steel and gray cast iron, a layer of internal deposits is formed, which changes the hydraulic potential of the pipes: the actual inner diameter, the actual speed of water movement and the actual pressure losses for resistance along the length (the actual hydraulic slope). These changes must be taken into account because the energy consumption of pumping units supplying drinking water to consumers located at a considerable distance from pumping units changes. A specific example shows how changing the hydraulic potential of worn pipes affects the energy consumption of pumping units that supply water to consumers.

Keywords: metal water pipes, hydraulic analysis, calculation dependencies, internal deposits, energy consumption of pumping units

1 Introduction

The hydraulic potential of metal pipes that changes during the operation of pipelines is calculated according to the well-known formulas given below (Fig. 1).



*Corresponding author: pro@enco.su

Fig. 1. Characteristics of steel pipes with internal deposits.

Notations in Fig. 1 are the following:

S_e is the estimated wall thickness of the pipe according to GOST for steel and cast-iron pipes, m (mm);

S_a is the actual wall thickness of the pipe with a layer of deposits δ_a , m (mm);

δ_a is the actual thickness of the deposit layer, mm,

$$\delta_a = S_a - S_e, \text{ mm (m)} \quad (1)$$

d_o is the outer diameter of the pipe according to GOST, mm (m);

d_{in}^a is the actual inner diameter of pipes with deposits δ_a , mm (m);

$$d_{in}^a = (d_o - 2S_e) - 2\delta_a, \text{ mm (m)} \quad (2)$$

The actual hydraulic potential of the pipes (d_{in}^a , Vf, if) is calculated according to the formulas: d_{in}^a according to formula (2); d_a – according to formula (3):

$$d_a = d_{in}^a - d_{re}, \text{ mm (m)} \quad (3)$$

where d_{re} is the reduced diameter of the pipes, determined by the formula (4) [1-3]:

$$d_{re} = \sqrt{d_{in}^2 - (d_{in} - 2\delta_a)^2}, \text{ mm (m)} \quad (4)$$

The actual average velocity of water movement in a pipe V_a with a layer of deposits δ_a , m/s, is determined by the formula:

$$V_a = \frac{4 \cdot q}{\pi \cdot (d_{in}^a)^2}, \text{ m/s} \quad (5)$$

where d_{in}^a is the actual inner diameter of the pipe with a layer of deposits δ_a , m;

q is the set flow rate, l/s (m^3/s).

The actual hydraulic slope of pipes i_a with a layer of deposits δ_a is calculated according to the formula of Professor F.A. Sheveleva, having the form [4, 5]:

$$i_a = 0.00107 \frac{V_a^2}{(d_{in}^a)^{1.3}}, \text{ mm/m (m/m)} \quad (6)$$

The form of formula (6) specified by the authors, taking into account the thickness of the layer of internal deposits δ_a , looks as follows [6]:

$$i_a = 0.00107 \frac{V_a^2}{[(d_o - 2S_e) - 2\delta_a]^{1.3}}, \text{ mm/m (m/m)} \quad (7)$$

The energy consumption of pumping units N_{dv} transporting water through new and worn pipes is determined by the formula [7, 8]:

$$N_{dv}^{e(a)} = 10^6 \cdot i_{e(a)} \cdot \left(d_{in}^{e(a)}\right)^2 \cdot V_{e(a)} \cdot \frac{0.00808}{\eta}, \text{ kWh} \quad (8)$$

where $i_{e(a)}$ is the estimated (actual) hydraulic slope of the pipes, determined by formulas (6)-(7), mm/m;

$d_{in}^{e(a)}$ is the estimated (e) (actually measured) inner diameter of pipes (a) with a layer of deposits δ_a (Fig. 1) according to GOST, m;

$V_{e(a)}$ is the the estimated (actual) speed of water movement in new (e) and worn (a) pipes, m/s;

η is the efficiency of the pumping unit. For practical calculations, $\eta=0.7$ is assumed [8].

2 Materials and methods

Accounting for the actual hydraulic characteristics of worn-out metal water pipes is the basis for predicting the residual service life of pipelines with internal deposits and making a decision whether their reconstruction projects are required [9-11].

A quantitative assessment of the hydraulic efficiency of the operating worn-out metal water supply networks is carried out according to the dimensionless coefficient of their operation efficiency, determined by the formula (9) [12, 13]:

$$K_{ef} = \frac{N_{dv}^e}{N_{dv}^a} = \frac{\left(d_{in}^e\right)^2 \cdot V_e \cdot i_e}{\left(d_{in}^{(a)}\right)^2 \cdot V_a \cdot i_a}, \quad (9)$$

where $N_{dv}^{e(a)}$ is the estimated (actual) energy consumption of the pumping unit, kWh;

$d_{in}^{e(a)}$ is the estimated (actual) inner diameter of pipes, m;

$V_{e(a)}$ is the estimated (actual) water velocity, m/s;

$i_{e(a)}$ is the calculated hydraulic slope for new pipes (e) and actual hydraulic slope for worn pipes (a), mm/m.

An example is given below confirming that a change (increase) in the hydraulic characteristics of worn steel water pipes leads to an increase in the energy consumption of pumps and ensures that such changes must be taken into account to improve the accuracy of hydraulic analysis of worn metal water pipes.

3 Results

3.1 Problem conditions

Compare the hydraulic potential of new steel electric welded pipes with an outer diameter $d_o=426$ mm (wall thickness $Sp=7.0$ mm) transporting drinking water $q=134$ l/s (0.134 m³/s) with the characteristics of worn pipes of the same diameter with a layer thickness of internal deposits $\delta_a=14$ mm (0.014 m).

Let us build $i_{e(a)} = f(\delta_a)$ vs. $N_{dv}^{e(a)} = f(\delta_a)$ graphs.

3.2 Solution

The method of hydraulic calculation of worn metal water pipes is described in detail in the scientific publication [8]. To analyze and compare the calculated and actual hydraulic characteristics of new and worn pipes for the conditions of the given example, Table 1 presents the hydraulic potential of the compared pipes at different thicknesses of the inner deposit layer in the range of δ_f values=0, 5, 10, 15, 20 mm.

In Table 2, according to the formula (8), the energy consumption of pumping units for the conditions of the problem are calculated.

Table 1. Hydraulic potential of new and worn pipes with a diameter of $d_o=426$ mm.

Actual thickness of deposits δ_a , mm	Measuring the characteristics of the pipes being compared						
	new			worn out			
	d_{in}^e , m	V_e , m/s	i_e , mm/m	d_{in}^a , m	V_a , m/s	i_a , mm/m	K_{ef}
0	412	1.01	0.001099	---	---	---	1
5	---	---	---	0.402	1.06	0.00125	0.88
10	---	---	---	0.392	1.11	0.001419	0.79
15	---	---	---	0.382	1.17	0.00163	0.68
20	---	---	---	0.372	1.23	0.001865	0.59
Percentage of discrepancy in the characteristics of pipes with a diameter of $d_h = 426$ mm, at different thickness δ_a , %							
0	---	---	---	0	---	---	1
5	---	---	---	2.43	4.72	12.08	12.0
10	---	---	---	4.85	9.01	22.55	21.0
15	---	---	---	7.28	9.90	32.58	32.0
20	---	---	---	9.71	17.89	41.07	41.0

Table 2. Energy consumption of pumping units with different thickness of internal deposits in a pipe with a diameter of $d_o = 426$ mm.

Actual thickness of the layer of internal deposits δ_a	Actual energy consumption of the pumping unit for the conditions of the problem (formula (8)), N_{dv}^a kWh				
0	2.174	---	---	---	---
5	---	2.471	---	---	---
10	---	---	2.70	---	---
15	---	---	---	3.21	---
20	---	---	---	---	3.66

According to Table 2, graphs of dependence are plotted in Fig. 2

$$N_{dv}^{e(a)} = f(\delta_{e(a)}, V_{e(a)})$$

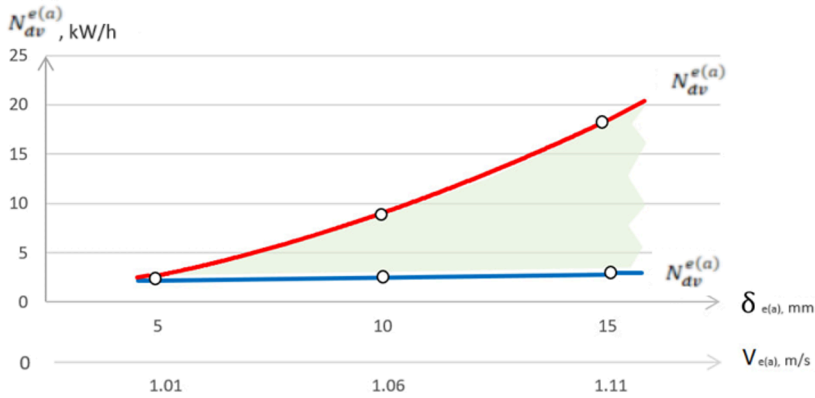


Fig. 2. Dependency graph $N_{dv}^{e(a)} = f(\delta_{e(a)}, V_{e(a)})$

4 Discussion

Analysis of the characteristics of the compared pipes (Tables 1-3) and the graphs in Fig. 2 and 3 confirm that it is required to consider changes in the hydraulic potential characteristics of steel and cast-iron water pipes (d_{in}^a, V_a, i_a) during their operation. The purpose of such accounting is to create operating conditions for worn-out metal water pipes, in which the energy consumption of pumping and power equipment will have rational and reasonable levels. This requires:

- at least once a year, monitoring changes in the actual thickness of the layer of internal deposits in steel and cast-iron water pipes made of gray cast iron [14-16];
- quantifying the efficiency of the operation of metal water pipes using their operation efficiency coefficient K_{ef} (formula (9));
- according to K_{ef} , making an expert quantitative assessment of the efficiency of water supply operation using the recommendations published in the monograph [8, 17];
- predicting the characteristics of the hydraulic potential of pipes that change during the operation of metal water pipes (d_{in}^a, V_a, i_a) allows network operators to provide financial resources in advance for the development of reconstruction projects of metal networks and replace with new ones).

5 Conclusion

Thus, the energy consumption of pumping units supplying water to consumers can also be determined by the actual thickness of the deposit layer δ_f measured using a thickness gauge as part a portable flow meter or other controls [18].

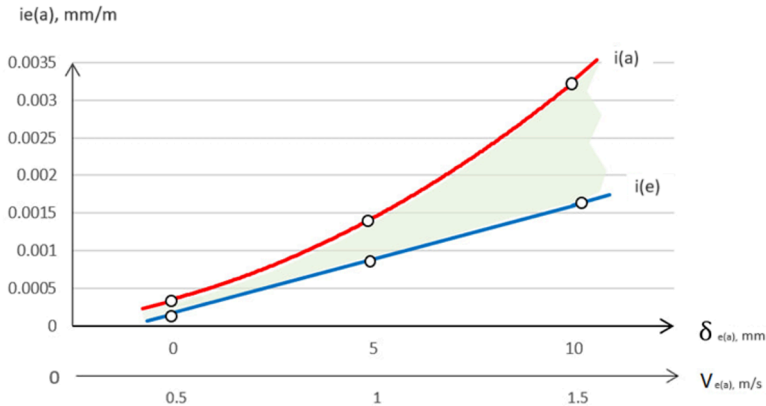


Fig. 3. Dependency graph $i_{e(a)} = f(\delta_{e(a)}, V_{e(a)})$

Table 3. Design characteristics of the hydraulic potential of new pipes with a diameter of 426 mm.

Estimated diameter of the new pipes, d_{in}^e , m	Hydraulic characteristics of pipes	
	Estimated speed V_e , m/s (formula (5))	Calculated hydraulic slope of pipes, i_e , mm/m (formula (6))
0.412	0.5	0.000847
0.412	1.0	0.003388
0.412	1.5	0.007623
0.412	2.0	0.01355
0.412	2.5	0.021176

According to Table 3, Figure 3 shows $i_{e(a)} = f(\delta_{e(a)}, V_{e(a)})$ dependence graphs, and according to Table 2, Figure 2 shows $N_{dv}^{e(a)} = f(\delta_{e(a)}, V_{e(a)})$ dependence graphs confirming the need to take into account changes in the hydraulic characteristics of worn metal water pipes that change the energy consumption of pumping units.

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