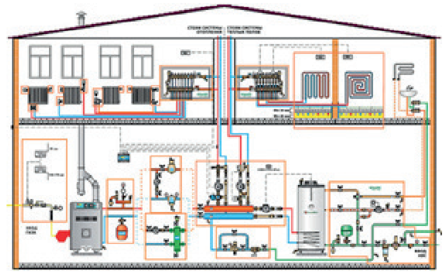

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# CAUSES AND CONSEQUENCES OF CHANGES IN THE VALUES OF HYDRAULIC CHARACTERISTICS OF METAL WATER SUPPLY AND SANITATION NETWORKS DURING THEIR OPERATION

***Purpose:*** *It consists in carrying out a comparative analysis of the values of the characteristics of the hydraulic potential of metal pipelines used in assessing the energy consumption of pumping units installed on pipelines with different thickness of the layer of internal deposits.*
***Methods:*** *The reasons for changing the values of hydraulic characteristics of metal pipelines during their operation are developed in tabular form. A concrete example shows the change in the values of the characteristics of the hydraulic potential of pipes with different thickness of the layer of internal deposits included in the calculated dependence for determining the actual energy consumption of pumping units.*
***Results:*** *It is proposed to develop for the entire range of manufactured steel pipes and pipes made of gray cast iron, a scale of maximum permissible values of the thickness of the layer of internal deposits, according to which a decision should be made to continue or stop the operation of pipe wires.*
***Conclusion:*** *To recommend, based on the hydraulic calculation of the characteristics of the hydraulic potential of pipes for the given example, minimizing the use of steel and cast iron pipes made of gray cast iron in projects of water supply and drainage networks. When operating metal pipelines, take into account the dynamics of changes in the energy consumption of pumping units with different thickness of the layer of internal deposits.*

***Цель работы:*** *Заключается в проведении сравнительного анализа значений характеристик гидравлического потенциала металлических трубопроводов, используемых при оценке энергопотребления насосных агрегатов, установленных на трубопроводах с разной толщиной слоя внутренних отложений.*
***Методы:*** *Разработаны в табличной форме причины изменения значений гидравлических характеристик металлических трубопроводов в процессе их эксплуатации. На конкретном примере показано изменение значений характеристик гидравлического потенциала труб с разной толщиной слоя внутренних отложений, входящих в расчетную зависимость для определения фактического энергопотребления насосных агрегатов.*
***Результаты и обсуждение:*** *Предложено разработать для всего сортамента выпускаемых стальных труб и труб из серого чугуна шкалу предельно-допустимых значений толщины слоя внутренних отложений, по которой должно приниматься решение о продолжении или остановке эксплуатации трубопроводов.*
***Заключение:*** *Рекомендовать на основе гидравлического расчета характеристик гидравлического потенциала труб для приведенного примера минимизирование использования в проектах сетей водоснабжения и водоотведения стальных и чугунных труб из серого чугуна. Учитывать при эксплуатации металлических трубопроводов динамику изменения энергопотребления насосных агрегатов при разной толщине слоя внутренних отложений.*

**Keywords:** *hydraulic calculation, metal networks of water supply and sanitation, characteristics of hydraulic potential, energy consumption of pumps, internal deposits*

**Ключевые слова:** *гидравлический расчет, металлические сети водоснабжения и водоотведения, характеристики гидравлического потенциала, энергопотребление насосов, внутренние отложения*

### Introduction

During their operation life cycle, water supply networks made of metal pipes (gray cast iron), as well as drainage networks made of any type of material, are subject to the formation of a layer of internal deposits on the pipe walls under certain conditions, which change the values of the characteristics of the hydraulic potential of the pipes (V, $d_{in}$, i) [1–6].

Figure 1 presents fragments of deposits on the inner surfaces of metal water supply and wastewater networks.

A layer of internal deposits on the walls of pipes causes consequences that change the values of the characteristics of the hydraulic potential of pipes and affect the duration of use of worn-out networks and the energy consumption of pumping units for pressure networks and collectors [1, 2].

Table 2 lists the causes and consequences of changes in the hydraulic characteristics of water supply and wastewater pipelines with internal deposits.

### Methods

Using a specific example (Fig. 1), we perform a hydraulic calculation and show changes in the values of the characteristics of the hydraulic potential of a pressure drainage collector made of cast iron pipes with a diameter $d_n$ of 0.404 m.

### Problem

A pressure cast iron collector with a diameter $d_n$ of 0.404 m (GOST 9583-75) and a wall thickness $S_p$ of 12.5 mm (0.0125 m) pumps wastewater flow q of 140 l/s (0.14 $m^3$/s). The thickness of the layer of internal deposits σ is 25 mm (0.025 m).

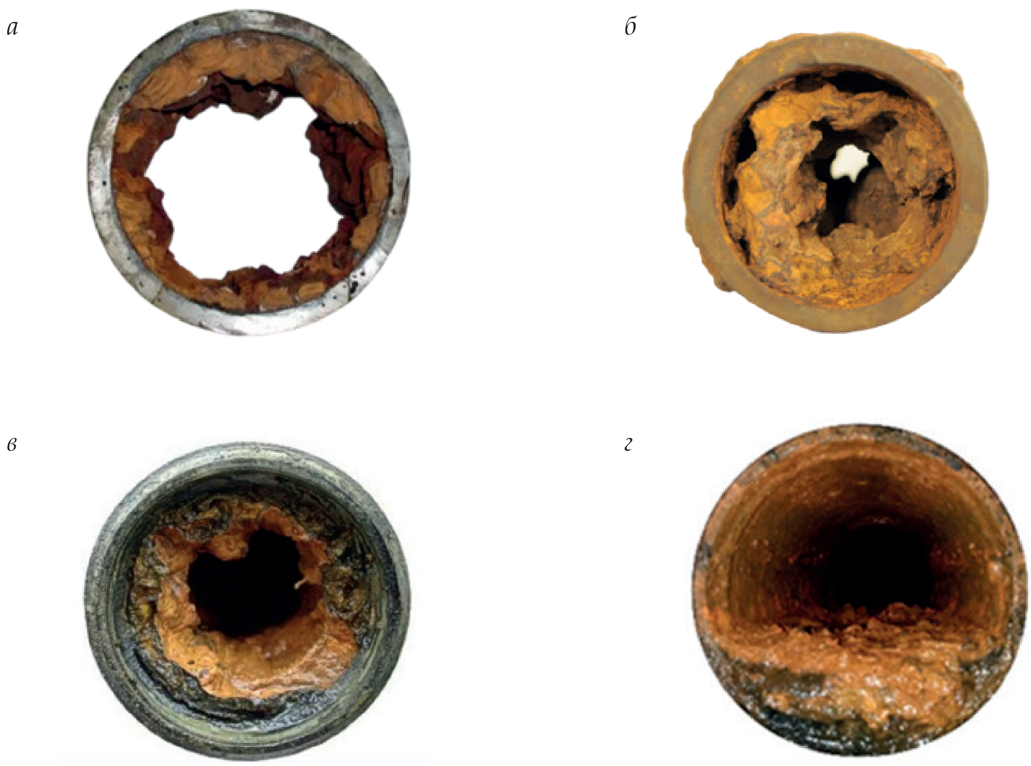


Fig. 1. Fragments of internal deposits on the walls of metal pipes:
a,b – Pressure drainage networks; c,d – gravity drainage networks


Fig. 2. Causes and consequences of changes in the hydraulic characteristics of water supply and wastewater pipelines

We calculate and compare the values of the actual characteristics of the hydraulic potential of pipes $d_{\text{in}}^{\text{a}}$, $V_{\text{a}}$, and $i_{\text{a}}$ and new cast iron pipes with a diameter $d_n$ of 0.429 m. Here, we present the change in the energy consumption of the pumping unit $N_{\text{dv}}^{\text{a}}$ for the given conditions of the problem.

**Solution**

1. Accounting for the actual internal diameter, we calculate the average flow velocity $V_n$ for new cast iron pipes and pipes with a deposit layer thickness σ of 25 mm as follows:

$$V_{\text{н}} = \frac{4 \cdot q}{\pi \cdot d_{\text{вн}}^2} = \frac{4 \cdot 0{,}14}{3{,}14 \cdot 0{,}379^2} = \frac{0{,}56}{0{,}4510} = 1{,}24$$

$$d_{\text{вн}} = d_{\text{н}} - 2S_{\text{р}} = 0{,}404 - 0{,}025 = 0{,}379$$

$$d_{\text{вн}}^{\text{ф}} = (d_{\text{н}} - 2S_{\text{р}}) - 2\sigma = (0{,}404 - 0{,}025) - 2 \cdot 0{,}025 = 0{,}379 - 0{,}05 = 0{,}329$$

$$V_{\text{ф}} = \frac{4 \cdot 0{,}14}{3{,}14 \cdot 0{,}329^2} = \frac{0{,}56}{0{,}3399} = 1{,}65$$

The values of the hydraulic slope are calculated for new cast iron pipes $d_n$ and for pipes with a layer of deposits σ of 0.025 m. The calculation was made using the following equations [9, 10]:

$$i_{\text{н(ф)}} = 0{,}00107 \frac{V_{\text{н(ф)}}^2}{[(d_{\text{н}} - 2S_{\text{р}}) - 2 \cdot \sigma]^{1{,}3}}, \text{ м/м;}$$

$$i_{н} = \frac{0{,}00107 \cdot 1{,}24^2}{[0{,}404 - 2 \cdot 0{,}0125]^{1{,}3}} = \frac{0{,}00165}{0{,}379^{1{,}3}} = \frac{0{,}00165}{0{,}2833} = 0{,}00582$$ , м/м;

$$i_{ф} = \frac{0{,}00107 \cdot 1{,}65^2}{[(0{,}404 - 2 \cdot 0{,}0125) - 2 \cdot 0{,}025]^{1{,}3}} = \frac{0{,}00291}{0{,}329^{1{,}3}} = \frac{0{,}00291}{0{,}2357} = 0{,}01234$$ , м/м.

The changes in the actual values of the hydraulic characteristics of cast iron pipes $d_{in}$ of 0.404 m with different thicknesses of the layer of internal deposits of 0 ÷ 30 mm (0 ÷ 0.03 m) are given in Table 1.

According to the authors, the operating efficiency of pressure and nonpressure water supply and wastewater pipelines ($K^*_{eff}$) should be assessed using the value of the dimensionless coefficient of the hydraulic efficiency of pipelines, which is the ratio of the energy consumption of pumping equipment installed in the new pipeline $N^{p}_{dv}$ to the value of energy consumption in the pipeline with the actual thickness of the deposit layer $\sigma_{a} - N^{ф}_{dv}$ or the ratio of the product of the values of the characteristics of the hydraulic potential of new pipes ($V_c$, $d^{c}_{in}$, and $i_c$) to the product of the values of the same characteristics for pipes with a specific thickness of the deposit layer $\sigma_a$ on their inner surface [11]:

$$К_{эф} = \frac{N^{р}_{дв}}{N^{ф}_{дв}} = \frac{V_{р} \cdot \left(d^{р}_{вн}\right)^2 \cdot i_{р}}{V_{ф} \cdot \left(d^{ф}_{вн}\right)^2 \cdot i_{ф}} \qquad (1)$$

where $N^{p}_{dv}$ is the rated value of the energy consumption of the pumping unit in the new pipeline (kW/h); $N^{a}_{dv}$ is the actual value of energy consumption of a pumping unit operating in a pipeline with a deposit layer thickness $\sigma_a$ (kW/h); $V_c$, $d^{c}_{in}$, and $i_c$ are the values of the calculated (certified) characteristics of the hydraulic potential of new pipes at the time of putting the pipeline into operation; and $V_a$, $d^{a}_{in}$, and $i_a$ are the values of the actual characteristics of the hydraulic potential of worn pipes with deposits at the time of assessment.

The limiting value of the layer thickness of internal deposits σ in Table 1 is presented in bold.

The analysis of the values of hydraulic characteristics presented in Table 1 revealed the following.

For the conditions of the given example, the values of the actual internal diameter of a pipe with internal deposits of different thicknesses decreased from a $d_{in}$ of 0.400 m (pipe without deposits) to a $d^{a}_{in}$ of 0.319 m (pipe with a layer of deposits σ = 0.03 m, i.e., by 15.83% or 1.19 times). This resulted in an increase in the flow speed from V = 1.24 m/s (in a new cast iron pipe) to $V_a$ = 2.47 m/s (in a pipe with a deposited layer of σ = 0.03 m), that is, by 49.8% or 1.99 times.

Under these conditions, in comparison with a new pipe, the values of the actual pressure loss due to resistance along the length (hydraulic slope) $i_a$ increased in the range $i_p$ = 0.00581 m/m ≤ $i_a$ ≤ 0.02883 m, that is, by 51.29% (pipe with a layer of deposits σ = 0.03 m) or by 4.96 times.

According to Table 1, a graph of the dependence $i_a$ = f(σ) is plotted in Figure 3, confirming that the smaller the value of the actual internal diameter $d^{a}_{in}$ in pipes with a deposited layer σ, the greater the value of the hydraulic slope $i_a$ and the greater the value of the actual flow velocity $V_a$. This was also confirmed by the values of the hydraulic efficiency coefficient of the pipeline $K_{eff}$, which, for the given example, characterized the influence of the layer thickness of internal deposits σ on the values of the pipeline hydraulic characteristics.

For the given example, we determined the limit value of σ, above which further operation of the pipeline is unacceptable—0.018 m (Table 1). That is, at $\sigma_a$ of 0.018 m, the pipeline must be decommissioned.

An expert assessment by specialists involved in the operation of water supply networks made of metal pipes recommends the following.

The decrease in the actual internal diameter of steel and cast iron pipes (made of gray cast iron) with internal deposits should not exceed 5% of the nominal internal diameter of the pipes; that is,

$$d^{a}_{in} \le d_{in} = (d_{н} - 2 \cdot S_{p}) - 2\,\sigma \le 5\,\%$$

For the example given, this corresponds to

$$d^{a}_{in} = d^{n}_{in} - 5\% = 0.379 - 0.01895 = 0.360 \text{ m}$$

Therefore, for the given example, the limiting value of the actual thickness of the deposit layer $\sigma_a$ should not exceed the value

$\sigma_a$ = 0.379 − 0.360 = 0.018 m (1.8 mm).

This is indicated in bold in Table 1.

Table 1

| Deposited layer thickness σ (m) | Actual average velocity $V_a$ (m/s) | Actual internal diameter of pipes with deposits $d_{in}^{a}$ (m) | Actual specific pressure loss 1000 $i_a$ | Pipeline hydraulic efficiency coefficient $K_{eff}^{*}$ |
|---|---|---|---|---|
| 0 | 1.24 | 0.379 | 5.81 | 1.0 |
| 0.005 | 1.31 | 0.369 | 6.71 | 0.87 |
| 0.01 | 1.38 | 0.359 | 7.72 | 0.76 |
| 0.018 | 1.52 | 0.343 | 9.94 | 0.58 |
| 0.02 | 0.55 | 0.339 | 10.49 | 0.56 |
| 0.03 | 2.47 | 0.319 | 28.83 | 0.14 |

In this case, the limiting value of the pipeline hydraulic efficiency coefficient $K_{eff}$ is as follows:

$$K_{eff} = \frac{0.00581 \cdot 0.379^2 \cdot 1.24}{0.00994 \cdot 0.343^2 \cdot 1.52} = \frac{0.001035}{0.001778} = 0.58$$

This proves that with a value $K_{eff}$ of 0.58, further operation of the pressure manifold with a diameter $d_n$ of 0.404 m is unacceptable.

For the conditions of the problem considered, we calculated the actual energy consumption of pumping equipment $N_{dv}^{a}$ installed on a pressure manifold with a diameter $d_n$ of 0.404 m and an internal deposit layer thickness $\sigma_a$ of 0.03 m (30 mm).

The methodology for calculating the energy consumption values of pumping and power equipment $N_{dv}^{a}$ has been presented in previous studies [2, 11].

The value of $N_{dv}^{a}$ for the conditions of the given example was calculated using the following equation [11, 12]:

$$N_{dv}^{p(a)} = 10^6 \cdot i_{p(a)} \cdot \left(d_{in}^{p(a)}\right)^2 \cdot V_{p(a)} \cdot \frac{0{,}00808}{\eta}, \text{ kW/h}, \quad (2)$$

where $N_{dv}^{p(a)}$ is the value of energy consumption of pumping equipment in the new (p) and worn-out (a) pipelines at the time of assessment (kW/h); $i_{p(a)}$, $d_{in}^{p(a)}$, and $V_{p(a)}$ are the values of the characteristics of the hydraulic potential of new (p) and worn-out (a) pipes with a deposited layer thickness σ; and $\eta$ is the pumping unit efficiency. For the calculations, the value $\eta$ was taken as 0.7.

Table 2 presents the energy consumption values of the pumping units installed in a new pipeline $N_{dv}^{p}$ and in a pipeline with different thicknesses of the layer of internal deposits $\sigma_a$.

The graph presented in Figure 4 for the given example confirms the change in energy consumption of the pumping units and shows that the greater the thickness of the deposit layer σ, the greater the energy consumption of the pumping units (Table 2). With a value of σ ≥ 0.018 m, the actual value of the energy consumption of the pumping units $N_{dv}^{a}$ installed in a pipeline with a diameter $d_n$ of 0.404 m increased sharply. This means that during the operation of pressure collectors made of cast iron pipes, the actual values of the layer thickness of internal deposits $\sigma_a$ must be controlled.

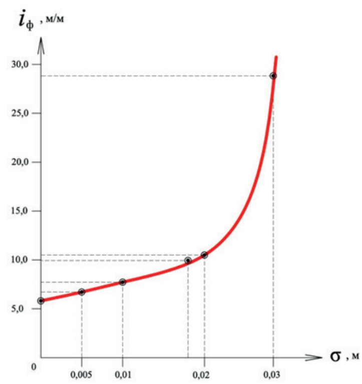


Fig. 3. Dependency graph $i_a = f(\sigma)$

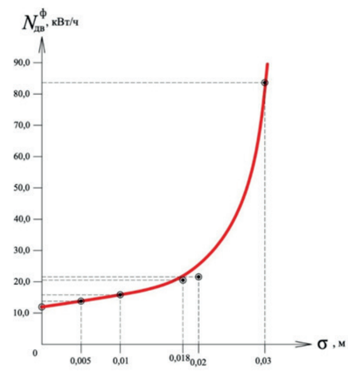


Fig. 4. Dependency graph $N_{dv}^{a} = f(\sigma_a)$

Table 2

Energy consumption of pumping units

| Actual inner diameter of pipes $d_{in}^{a}$ (m) | Actual thickness of the internal layer of deposits $\sigma_a$ (m) | Actual energy consumption of pumping units $N_{dv}^{a}$ (kW/h) |
|---|---|---|
| 0.379 | 0 | 11.94 |
| 0.369 | 0.005 | 13.81 |
| 0.359 | 0.010 | 15.84 |
| 0.343 | 0.018 | 20.51 |
| 0.339 | 0.020 | 21.56 |
| 0.319 | 0.030 | 83.62 |

**Conclusion**

The analysis of the graphs presented in Figs. 3 and 4 enables us to draw the following conclusions:

1. For the entire range of steel and cast iron pipes (from gray cast iron) produced following GOST, a scale of limit values of the permissible thickness of the layer of internal deposits σ must be developed to regulate the further operation of pipelines.

2. The use of steel and gray cast iron pipes when developing projects for water supply and wastewater networks should be minimized by law.

3. A method for monitoring the actual layer thickness of internal values $\sigma_a$ during the operation of pipelines made of metal pipes should be developed.

4. Based on the thickness of the deposited layer σ, a legislative method should be developed to justify the need for hydrodynamic (mechanical) cleaning of pressure water supply and drainage networks from metal pipes.

5. When selecting pumping units for metal water supply and sewerage networks, the dynamics of changes in the energy consumption of pumping units operating in pipelines with different thicknesses of the layer of internal deposits $\sigma_a$ should be considered.

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