

# Improving the efficiency of heat supply systems for infrastructure facilities by optimizing the pipeline subsystem according to technical and economic indicators

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**Abstract.** The fuel economy, which provides acceptance, storage, preparation and supply of the necessary amount of fuel oil for its combustion in boiler furnaces, is one of the energy-intensive technological subsystems of thermal power plants and boiler houses. The design of new technological pipelines and the modernization of existing pipeline systems for transporting fuel oil involves hydraulic calculations. Generally accepted in practice is the hydraulic calculation of pipeline lines based on the flow continuity equation and the Bernoulli equation for a real viscous liquid, which takes into account the pressure loss due to friction and to overcome local pipeline resistances. With this approach, hydraulic calculation is a multi-variant task, since there are an infinite number of combinations of parameters pipeline diameter - pressure drop, which are not equal from both economic and technical points of view. Research of literature sources has shown the feasibility of conducting hydraulic calculation of pipe-wire lines on technical and economic indicators. As a criterion for optimization of technological pipelines, the total annual costs for the creation and operation of the pipeline, which are a linear superposition of capital and operational costs, are proposed. The paper offers calculation relations for determining the optimal diameter of the pipeline from the condition of minimum total annual costs for its creation and operation, taking into account current prices and tariffs for the pipeline and electricity, pipeline tracing, conditions of its operation, as well as the properties of the transported medium. On the example of a hydraulic installation for pumping fuel oil, computational experiments were performed to assess the influence of the pipeline diameter on its technical and economic indicators and determine the optimal parameters of the fuel oil pipeline.

## 1. Introduction

An important constituent in providing of the vital activity for the infrastructure objects is their on-time, regular and efficient supply with electric power and heat.

The sources of heat supply for the objects of infrastructure are heat power plants (HPP) and boiler plants representing interrelated complex of means providing transformation of the chemical energy of the fuel into the heat energy with its further delivery to a customer [1].

One of the kinds of the liquid power-containing fuel is black oil fuel (mazut) produced as a result of oil refining. According to GOST 10585-99 the following ranks of the fuel oil are defined in a de-



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pendence of its viscosity: bunker fuel F5 and F12, fuel oil M40 and M100. Bunker oils are referred to the light fuels class, fuel oil of M40 rank is referred to the class of light fuels while fuel oil of M100 rank is considered as heavy oil fuel.

Fuel oil at HPP and boiler plants are utilized as the main fuel (if it is impossible to supply natural gas) as a reserve supply or emergency supply of the fuel in case of the restrictions or loss of the gas supply.

One of the power-consuming technological sub-systems of HPP and boiler plants is their fuel oil enterprise providing take-over, storage, preparation and supply of the required amount of the fuel oil for its combustion in the boiler furnaces [1, 2]. Fuel oil enterprise is a complex of buildings, reservoirs for taking-over and storage of the fuel oil, equipment for its thermal and mechanical treatment (vapor satellites, stationary heaters, filters), as well as fuel oil pumping facilities, connected with fuel oil lines interconnected with hydraulic pipe-lines. The latter ones are characterized by significant extension and branching, complicated spatial configuration, presence of a great number of local resistances (stoop and control valves, strainers, offsets, tee fittings, etc.).

Operating costs for the maintenance of the fuel oil enterprise comprising of more than 9% of the boiler's load involves electric power cost required for the driving of pumps for dispensing of the fuel oil over the fuel line, driving of circulating pumps used for heating of the fuel oil in the reservoirs during its storage, driving of equipment applied for the drain operations, for heating of the fuel oil in the heaters and for spraying of the oils in the boiler's furnace burners [1, 3].

When designing and building of the new HPP and boiler houses as well while modernizing of the fuel oil enterprises for the operating heat-generating objects it is necessary to account for the capital expenditures invested for erecting of the buildings utilized at the fuel oil enterprise and fuel oil lines. In its turn, expenditures for the development of HPP and boilers fuel oil lines are associated with their lengths and diameters, the adopted scheme of supply of the liquid fuel to the boilers and they are determined basing on the listed prices for the pipe-lines, stop and regulating valves, and adapter fitting.

According to the Power Energy strategy of Russian federation up to 2030, non-realized potential of organizational and technological energy savings for the moment of its development was of about 40 % of the total amount of internal power consumption, while the ratio of electric power engineering was estimated as 13 – 15 %. A part of this reserve could be recovered by the employment of the fuel oil enterprises.

One of the ways to increase power efficiency of the HPP and boilers at the fuel oil enterprises is a decrease of the heat and electric power expenditures for auxiliaries due to incorporation of the innovative power-saving technologies, equipment for their realization as well as organization of the optimal operation modes for the machinery and equipment at the fuel oil enterprises [3, 4].

Measures directed for the increase of efficiency in the use of heat energy consumed for the maintenance of the fuel oil enterprises are well known and they are presented in the disciplinary literature [1 - 6].

Reduction of electric power expenditures for driving of the pump stations is achieved due to a decrease of pressure produced by the pump that is equal to the pressure losses during fuel oil pipe-line transportation. It is facilitated by the choice of the optimal parameters of the pipe-line (diameter, extension, spatial configuration), the use of stop and regulating valves with a less hydraulic resistance, improvement of the fuel oil operative and rheological parameters by using of its heating and applying of additives [2, 5, 7].

Losses of pressure in the pipe-line (implying a required pressure that should provide the pump) are most sensitive to the changes in the pipe-line diameter. Thus, according to Gagen-Poiseuille formula [7], in a laminar flow of the Newton fluid with invariable volume flow rate in the channel with circular cross-section an increase of the pipe-line diameter by two times results in a reduction of the pressure fall at the pipe ends by four times. This provides a decrease of the power consumed by the pump by four times as well. Other ways for reduction of the energy output for the process of the fuel oil transportation by the fuel oil line (reduction of the local hydraulic resistance, decrease of the fuel oil

viscosity by its heating and the use of additives) result in a less considerable reduction of power inputs for the fuel oil transportation.

Thus, the problem of increase of utilization efficiency of the heat energy consumed for maintenance of the fuel oil enterprise represents complex, multiple-choice techno-economic task and one of the most important stage in it is the performance of hydraulic calculations for the fuel oil lines applying additional indicators for the economical estimations of the proposed variants.

In the common case hydrodynamic computation of the pressure pipe-lines is performed numerically basing on the continuity equation and Navier-Stokes equation, in addition with the equations of convective thermal conductivity and the state of the moving medium [8], that provides certain difficulties.

However, using the assumptions on isothermal, stationary and incompressible flow of the moving medium the initial task is reduced to the performance of hydraulic calculations according to the equation of the flow continuity and Bernoulli equation for the real viscous liquid which takes into account pressure losses due to the friction and surmounting of the local resistances in a pipe-line. This approach is realized as a common one both in the native and foreign practical implementations while performing hydraulic computations for the technological pipe-lines and it encompasses solution of three practical problems: determination of the pipe-line diameter, determination of the pressure fall in the pipe-line and estimation of its capacity [1, 7, 9].

Hydraulic calculations for the complicated pipe-lines with the branchings, rings, parts with different diameter and so on are performed using graph theory techniques and electro-hydraulic analogy [1, 10].

Capabilities for numerical simulation of the pipe-line systems with a complex structure make it possible to consider heat-mass exchange, chemical and biochemical processes proceeding in the pipe-line systems as interrelated ones, to simulate operation modes and to choose their optimal construction and operative parameters [11-14].

One of the problems in the routine hydraulic calculations is the task of determination of the pipe-line diameter and pressure losses within the line of predetermined layout under invariable volume flow rate [1, 7, 9].

With such approach hydraulic calculation is a multi-variant task since there is an infinite set of parameters combinations of the pipe-line diameter – pressure fall thus enabling the pumping of transported fluid with a pre-defined fluid flow rate. One should note that the variants are of unequal value both from economical and technical viewpoints.

For example, on the one hand when the pipe-line diameter decreases its cost and steel intensity are reduced (implying capital costs) but under defined fluid flow rate and, as a result, the losses of pressure for its transportation in the pipe-line grow. In order to provide a greater pressure in the pipe-line more powerful hydraulic pump is required to be mounted and this result in a higher electric power consumption. Hence, reduction of the capital costs for the development of the pipe-line system by a decrease of its diameter results in a rise of cost price of the pump assembly and in an increase of expenditures for the employment of the pipe-line system.

On the other hand, fluid transportation over more expensive pipe-line made from the tubes with a diameter more than the nominal one requires less than electric power cost for the driving of pump assembly.

Consequently, the choice of the pipe-line diameter should be justified as from the technical as from economical point of view. Obviously, there exists some optimal diameter of the pipe-line that corresponds to the minimal total of expenses for construction of the technological pipe-line and pumping of the fluid.

In order to solve this problem of optimization it was proposed a great number of techno-economical criteria different from each other by their complexity, a greater detail and the number of the accounted economic and technological indicators. However, a common issue for all of the criteria is the account of the maintenance charges associated with the expenses for the electric power con-

sumption in order to drive the pump (expenses for the pressure fall) and capital costs due to the pipe-line cost [15, 16].

As an example, it should be noted the works [17–20], where indicator of the aggregate discounted costs is applied as a criterion of optimization. In [21–23] optimization of the pipe-line parameters by the electric power expenditure consumed for the pump driving is presented. When performing optimization of parameters for the cryogenic pipe-lines as optimization criteria authors of [24, 25] used loss power of hydraulic and thermal losses. The use of a study technique for the parameters space made it possible to find Pareto-optimum solution. To minimize material costs for the air-ducts of ventilation systems authors of [26–28] used dynamic programming allowing to sequentially determine optimal diameters of the parts in the ventilation systems for the given values of pressure and airflow consumption. The choice of the optimal diameter for the pipe-line was proposed in [29] for centralized heat supply network consisting of the offsets and rings with the use of graphs theory and minimization of the costs.

Thus, computation of the fuel oil diameter and losses of pressure in the pipe-line utilizing techno-economic indexes is an actual problem directed at the reduction of the costs for the development and employment of the fuel oil line and increase of the power efficiency for the fuel oil enterprises of HPPs and boiler-houses.

## 2. Theory of the work

Let us use the total annual costs  $F$ , rubl./year for the development and operation of the fuel oil line as a criterion of techno-economic optimization which prove to be a linear superposition of the capital  $C$ , rubl., and operational  $O$ , rubl., costs [15, 16]

$$F = C + O. \quad (1)$$

Capital costs  $C$ , rubl./year can be presented in the first approximation as the expenditures for the fuel oil line development which are proportional to its overall dimensions (diameter and length), list price and related to one-year operation of the fuel oil line

$$K = f_{mp}(D)L, \quad (2)$$

where  $L$  – is a total line of the fuel oil line (it involves the length of all its horizontal and vertical parts), m;  $f_{mp}(D)$  – is a regression equation approximating the price list data on the cost of pipe-line in a dependence of its diameter. The value of  $f_{mp}(D)$  represents the price of 1 running meter of the pipe-line with a diameter  $D$  and thickness of the pipe wall  $\delta$ , mm.

Linear dependence for the approximating function  $f_{mp}(D)$  is recommended in [30]

$$f_{mp}(D) = aD, \quad (3)$$

where  $a$  – is a regression coefficient, rubl./m<sup>2</sup>;  $D$  – is the pipe-line diameter, m.

With the account of (3) the capital costs in (2) can be represented as

$$K = S_D D, \quad (4)$$

where  $S_D$  – are cost per unit, rubl./m

$$S_D = aL. \quad (5)$$

Operating costs  $O$ , rubl./year, for operating of the fuel oil line during a year represent expenditures for transportation of the fuel oil over the pipe-line and they are proportional to the amount of the electric power amount consumed by the pump during its annual operation and tariff price of 1 kilowatt-hour of the electric power

$$\mathfrak{D} = \tau_g N_{el} c_{el} \tau_c, \quad (E = O) \quad (6)$$

where  $N_{el}$  – is the electric engine power in the drive of the pump, kW;  $c_{el}$  – is tariff (price) for 1 kW·hr of electric power;  $\tau_g$  – is the number of the workdays per year, hr.;  $\tau_c$  – is the operating period of the fuel oil line per day, hr.

The power of electric motor in the pump drive is

$$N = K_3 \frac{Q \Delta P}{1000 \eta}, \quad (7)$$

where  $K_3$  is a power reserve coefficient for electric motor;  $Q$  – is a volume flow rate of fuel oil, m<sup>3</sup>/s;  $\Delta P$  is a pressure provided by the pump, Pa;  $\eta$  – is the efficiency of the pump (considering mechanical efficiency, leakages through the gaps and gaskets of the pump, wear and co on).

With the account of (7) maintenance charges in the form of (6) can be represented as

$$E = S_p \Delta P, \quad (8)$$

where  $S_p$  are costs per unit in order to produce a unit of pressure, rubl./kPa

$$S_p = \frac{\tau_g K_3 Q c_{el} \tau_c}{\eta}. \quad (9)$$

With the account of expenses (4) and (9) criterion of optimization expressed as in (1) takes the form of [31]

$$F = S_p \Delta P + S_D D. \quad (10)$$

In the criterion (10) pressure  $\Delta P$ , produced by the pump, represents losses of pressure in the fuel oil line that depends on the line topology and length, the type and number of the local resistances, volumetric rate of the fuel oil flow and its properties as well as on the line diameter [1, 7, 9]. Thus, criterion of technical and economic assessment (TEA) (10) accounts for the current price and tariff values related to the lines and electric power, parameters of the fuel oil line, conditions for the transmission of the fuel oil, its properties and meets all the requirements related to the optimization criteria: it measures the efficiency of the system; it can be quantified; it has clear physical sense and quite completely represents the most significant features of the process.

The problem of techno-economical optimization for the fuel oil line with a specified topology is to find such values of  $D$  and  $\Delta P$ , that criterion of TEA (10) attains its minimum value for the specified flow rate value of the fuel oil  $Q$ , which, in turn, also depends on  $D$  and  $\Delta P$  [31]:

$$F(\Delta P, D) = S_p \Delta P + S_D D \xrightarrow{\Delta P, D} \min \quad ;(11)$$

$$Q(\Delta P, D) = \text{const.} \quad (12)$$

Thus, we get a problem of constrained minimization for the criterion (11) in the presence of the constraint (constraint equation) in the form of (12). To solve the problem in the forms of (11) and (12) it is necessary to reduce it to the task of search for the unconditional extremum.

Constrain equation (12) should connect losses of pressure  $\Delta P$ , diameter of the pipe-line and the flow rate of the fuel oil in the explicit form.

Let us present the link between  $\Delta P$  and  $D$  in the form of equation [7, 9].

$$\Delta P = \Delta P_{lin} + \Delta P_{mc} \pm \Delta P_{gs}, \quad (13)$$

where  $\Delta P_{lin}$  are losses of pressure over the length of the pipe-line, Pa;  $\Delta P_{mc}$  – are losses of pressure due to the presence of local resistances, Pa;  $\Delta P_{gc}$  are hydrostatic losses of pressure due to the changes connected with the ascent (descent) of the fuel oil, Pa.

Losses of pressure along the pipe-line length can be determined by Darsi-Weisbach formula.

$$\Delta P_{lin} = \lambda \frac{L_g + L_v}{D} \cdot \frac{g^2 \rho}{2}, \quad (14)$$

where  $\lambda$  is friction coefficient;  $L_g, L_v$  is the length of horizontal and vertical parts of the pipe-line, m;  $g$  – is the average speed of the fuel oil transmission in the pipe-line, m/s;  $\rho$  is the density of the fuel oil, kg/m<sup>3</sup>;  $D$  is the diameter of the pipe-line, m.

Losses of pressure due to the presence of the local hydrodynamic resistances and be determined by Weisbach formula.

$$\Delta P_{mc} = \sum \xi_{mc} \frac{g^2 \rho}{2}, \quad (15)$$

where  $\xi_{mc}$  is a coefficient of the local resistance.

Hydrostatic losses of pressure are determined by the formula

$$\Delta P_{gc} = \pm \rho g L_v, \quad (16)$$

where  $g$  is the acceleration of gravity, m/s<sup>2</sup>.

With the account of (14) – (16) one gets.

$$\Delta P = \lambda \frac{L_g + L_v}{D} \cdot \frac{g^2 \rho}{2} + \sum \xi_{mc} \frac{g^2 \rho}{2} \pm \rho g L_v, \quad (17)$$

Equation (17) does not include the value of the volume flow rate  $Q$  in the explicit form. In order to reduce this equation to the form of (12), let us present the average speed of the fuel oil transmission in the pipe-line using its diameter  $D$ :

$$g = \frac{4Q}{\pi D^2}. \quad (18)$$

In the laminar flow mode of the fuel oil the value of the friction coefficient  $\lambda$  depends on the value of Reynolds number  $Re$ .

$$\lambda = \frac{64}{Re}, \quad (19)$$

That is determined as

$$Re = \frac{g D \rho}{\mu}, \quad (20)$$

where  $\mu$  is a dynamic viscosity of the fuel oil, Pa·s.

Taking into account (18) – (20) equation (17) takes the form of

$$\Delta P = \frac{8\rho Q^2}{\pi^2 D^4} \left( \frac{16\mu\pi}{\rho Q} (L_g + L_v) + \sum \xi_{mc} \right) \pm \rho g L_v. \quad (21)$$



Constrain equation (21) allows determination of the optimal values of  $D$  and  $\Delta P$ , when optimization criterion (1) attains its minimum value for the specified volume flow rate of the fuel oil  $Q$ . The necessary condition for minimization of criterion (1) takes the form of [30, 31].

$$\frac{dF}{dD} = S_P \frac{d\Delta P}{dD} + S_D = 0. \quad (22)$$

Solution of equation (22) is just the optimal value of the fuel oil pipe-line diameter which is then used for the determination of the optimal pressure losses in accordance to the equation (21).

Differentiating (21) by the diameter  $D$ , we obtain.

$$\frac{d\Delta P}{dD} = -\frac{32\rho Q^2}{\pi^2 D^5} \left( \frac{16\mu\pi}{\rho Q} (L_g + L_v) + \sum \xi_{mc} \right). \quad (23)$$

Substituting (23) into (22), we obtain the equation.

$$-\frac{32\rho Q^2}{\pi^2 D^5} \left( \frac{16\mu\pi}{\rho Q} (L_g + L_v) + \sum \xi_{mc} \right) S_P + S_D = 0. \quad (24)$$

Solving equation (24) relative to  $D$  and excluding complex roots we obtain the optimal values of the fuel oil line diameter [30].

$$D^* = 2 \left[ \frac{\rho Q^2}{\pi^2} \left( \frac{16\mu\pi}{\rho Q} (L_g + L_v) + \sum \xi_{mc} \right) \frac{S_P}{S_D} \right]^{0,2}. \quad (25)$$

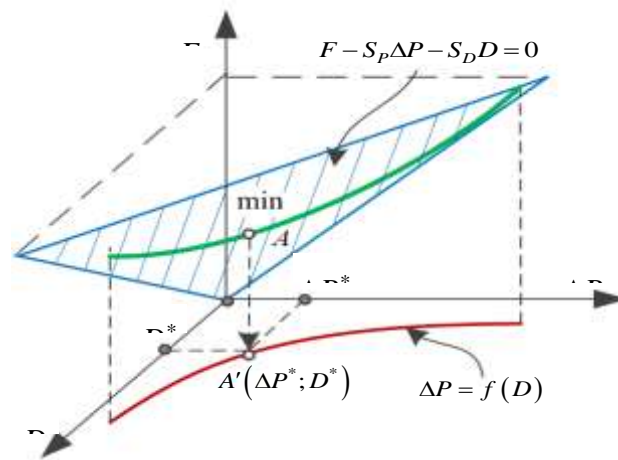
Substitution of solution (25) into constrain equation (21) makes it possible to determine the optimal value of the pressure losses in the pipe-line [30].

$$\Delta P^* = \frac{1}{2} \left[ \frac{\rho Q^2}{\pi^2} \left( \frac{16\mu\pi}{\rho Q} (L_g + L_v) + \sum \xi_{mc} \right) \left( \frac{S_D}{S_P} \right)^4 \right]^{0,2} \pm \rho g L_v. \quad (26)$$

Substitution of the optimal values of  $\Delta P^*$  and  $D^*$  into the optimization criterion (1) enables to calculate the minimal value of the total expenses for the development of the fuel oil line with the specified topology and fuel oil transmission by this line with the specified volume flow rate and the corresponding properties.

Geometric interpretation of the problem for optimization of the technological pipe-line is presented in Figure 1. The plane of objective function (1) is presented here in the space of  $(F; \Delta P; D)$ , constrain equation (13) for  $Q = \text{const}$  and the curve formed by cross-section of the plane (1) with cylindrical surface and base of a cylinder (13).

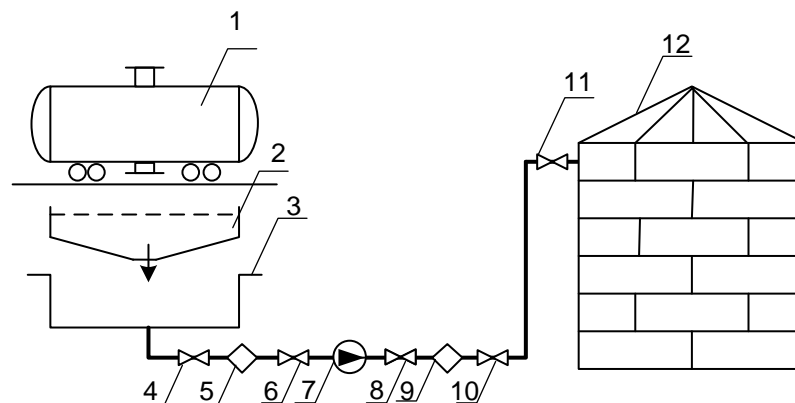
Pont  $A'$  with coordinates  $(\Delta P^*; D^*)$  is a projection of the point  $A(F_{\min}; \Delta P^*; D^*)$  for the minimal value of optimization criterion (in this point both conditions of (11) and (12) are executed at one and the same time, i.e. a constrained extremum of optimization (1) is attained.



**Figure 1.** Graphical interpretation of the optimization.

### 3. Computational experiment and discussion of results

The discussed technique for optimization of the fuel oil line parameters by the techno-economical indexes can be illustrated in the computational experiment basing on example of the fuel oil enterprise of HPP intended for transmission of the fuel oil with the grade M100 (Figure 2).



**Figure 2.** Scheme of the fuel oil enterprise with a terrestrial fuel oil storage reservoir: 1 – railroad tank; 2 – drain tray; 3 – receiver tank; 4, 6, 8, 10, 11 – valve; 5 – coarse filter; 7 – pump; 9 – fine filter; 12 – fuel oil storage reservoir.

Let us use the data presented in [1] as raw data for the computing experiment. Freight turnover of the furnace fuel oil with a grade M100 for HPP is of 34560 tons/year. Delivery of the fuel oil is executed one time per ten-day period by railroad transport in 32 tanks each of 60 m<sup>3</sup> in volume. Unloading of the fuel oil from the tanks is performed by a simultaneous drain at the double-sided dock for 8 hours. In this case the mass flow rate of the fuel oil is of 33,33 kg/s (120000 kg/hr/).

While the unloading drain from the tanks 1 the fuel oil is emptied spontaneously into the receiver tank (3) by the drain trays 2 (see Figure 2). From this receiver tank fuel oil is supplied to the rough filter and fine filter 5 and 9, respectively with the help of the pump 7, and then to the overland tank 12 of the fuel oil reservoir. A decrease of the fuel oil viscosity is obtained due to its heating up to 80 °C. To do this, the drain trays are equipped with the steam pipe-lines all over their length while the receiver tanks and the fuel oil reservoir are provided with the surface-type steam pipe heaters



To calculate the fuel oil density  $\rho$ , kg/m<sup>3</sup>, and its kinematic viscosity  $\nu$ , m<sup>2</sup>/s, in a dependence on the temperature  $t$ , °C, empiric equations were applied [1]:

$$\rho = [0,881 - 0,00304(t - 68)] \cdot 10^3; \quad (27)$$

$$\nu = \left[ \frac{7,17 \cdot 10^9}{10^{(t+273)^{3,745}}} - 0,8 \right] \cdot 10^{-6}. \quad (28)$$

Calculations of the dynamic viscosity of the fuel oil  $\mu$ , Pa·s, were performed according to [7]

$$\mu = \nu \rho. \quad (29)$$

At the temperature of  $t = 80$  °C physical properties of the furnace fuel oil M100, calculated by the formulas (27) – (29), are equal to:  $\rho = 844,52$  kg/m<sup>3</sup>,  $\nu = 114,31 \cdot 10^{-6}$  m<sup>2</sup>/s,  $\mu = 0,096$  Pa·s. Volume flow rate of the fuel oil in this case is of  $Q = 0,039$  m<sup>3</sup>/s (142,093 m<sup>3</sup>/hr).

The fuel oil line consists of the horizontal and vertical parts and their total length is of  $L_g = 102$  m and  $L_v = 11$  m, respectively. This fuel oil line is characterized by the local resistances and their values are presented in Table 1.

In accordance with the recommendations [1] we used a steel seamless hot deformed tube in compliance with GOST 8732-78 as a tube for production of the fuel oil pipe-line. According to the open Internet-resources for the average wholesale and retail trade price of 70000 rubles/ton the relationship between the price of 1 running meter of the tube and its inner diameter  $D$ , m, was obtained by the form of the regression equation (3).

$$f_{mp}(D) = 28728D. \quad (30)$$

Relationship (30) is true for the tubes produced in accordance with GOST 8732-78 with the wall thickness of 16 mm and outside diameter from 108 mm to 426 mm.

The computing experiment included the assessment of dependence of the fuel oil line diameter on its techno-economical parameters and determination of the optimal diameter of the fuel oil line for the pumping of the furnace fuel oil of M100 grade in the flow amount rate of  $Q = 0,039$  m<sup>3</sup>/s.

**Table 1.** Values of the coefficients of local resistances [1, 9].

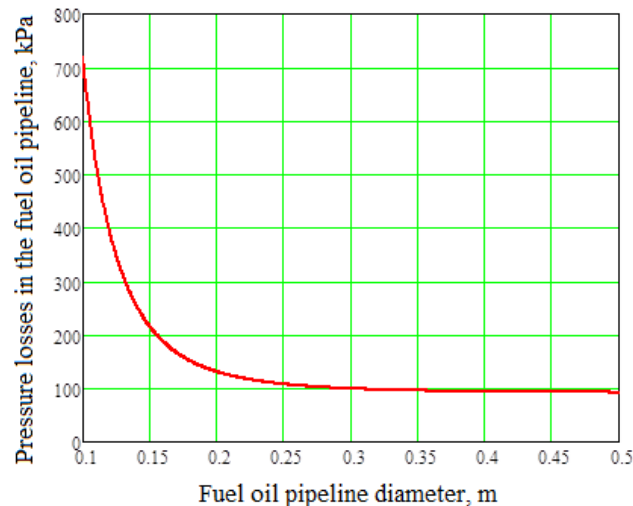
Local resistance	Value	Quantity
Input to the pipe	0.5	1
Valve	2	5
Pipe bend (turning at 90°)	1.3	3
Sudden bottleneck	0.64	3
Sudden expansion	0.64	3
Filter	8	2
Output from the pipe	1	1

During performance of the computing experiment the value of diameter of the fuel oil line was varied within the interval of 0,1 to 0,5 m with the following calculations of techno-economical indexes.

Capital cost per unit according to the formula (5) will be  $S_D = 3,246 \cdot 10^6$  rubl./m. Power reserve coefficient for the electric motor and coefficient of efficiency for the pump drive are considered as  $K_s = 1,2$  and  $\eta = 0,8$ , respectively. Operating period of the fuel oil line per day equal to the duration of the fuel oil drain from 32 tanks is equal to  $\tau_c = 8$  hours. The number of the active days per year

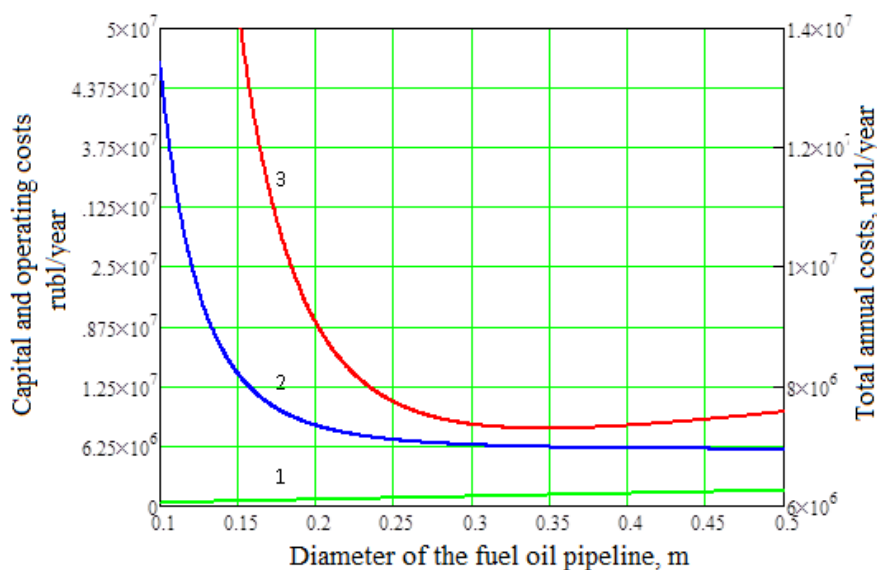
supposing fuel oil delivery one time per ten-day period is of  $\tau_2 = 36,5$  days. Tariff price for the electric power supply of 1 kW·hr. (for Voronezh region, January 2020) is of  $c_{el} = 3,74$ , rubl./kW·hr. Therefore, operational cost per unit according to (9) are equal to  $S_p = 64,657$  rubl./Pa.

Dependence of the pressure losses  $\Delta P$  in the fuel oil line with the specified topology (see Figure 2) on its diameter  $D$  calculated by (21) is presented in Figure 3.



**Figure 3.** Dependence of the pressure losses in the fuel pipeline on its diameter.

The dependences of the capital, operational and the total annual expenses on the diameter of the fuel oil line calculated according to the formulas (4), (8) and (10), respectively, are presented in Figure 4. As it follows from the figure 4, an increase of fuel oil line diameter results in the increase of the capital costs (curve 1) for its development and simultaneous decrease of the operating costs (curve 2) connected with the transit of the fuel oil from the receiver tank to the storage reservoir of the fuel oil. An extreme character of the curve 3 indicates at the presence of the value of pipe-line diameter that provides the development and employment of the fuel oil line with the minimal total annual expenses. Calculations in accordance with (17) and (18) provide the optimal values of the diameter of the fuel oil line  $D^* = 0.347$  m and losses of pressure in the fuel oil line (i.e. the pressure produced by the pump)  $\Delta P^* = 9.549 \cdot 10^4$  Pa, when the total annual expenses for the maintenance and employment of the fuel oil line become minimal ones  $F^* = 7.299 \cdot 10^6$  rubl./year.



**Figure 4.** Dependence of the capital (1), operating (2) and total annual costs (3) for the development and operation of the fuel oil pipeline on its diameter.

The calculated optimal value of the fuel oil line diameter should be correlated by the pipe grades according to GOST 8732-78 “Seamless hot-deformed steel tubes; Pipe grades” with the following refinement of the capital, operational and total annual expenses.

The considered technique for optimization of the fuel oil line at the HPP enterprise by its techno-economical indexes can be added, in case of necessity, by the check-up calculations of the fuel oil line and its separate elements for the endurance, durability and vibrations in accordance with the corresponding regulative documents.

#### 4. Conclusions

1. Computational relationships are proposed for the determination of the optimal diameter of the fuel oil line at the HPP and boiler house enterprises in terms of the condition for minimization of the total annual expenditures for its development and employment with the account of the current prices and tariffs for the pipe-line and electric power, fuel oil line layout, conditions of its operation as well as the properties of the furnace fuel oil.

2. Computing experiment was performed in order to assess the effect of the fuel oil line diameter on the techno-economical indexes of the setup for the transmission of the furnace fuel oil, grade M100 from the receiver tank to the overland reservoir of the fuel oil storage for the given value of the fuel oil consumption. An increase of diameter for the fuel oil line was found to reduce the operational costs for the transmission of the fuel oil and at the simultaneous increase of the capital expenditures for its development.

3. An optimal value of the diameter for the pipe-line of the fuel oil enterprise was found thus providing the minimum of the total annual costs for the development and employment of the fuel oil line intended for the transmission of the furnace fuel oil from the receiver tank to the overland reservoir of the fuel oil storage at the specified value of the fuel oil consumption.

#### References

- [1] Nazmeev Yu G 2002 Fuel oil facilities of TPPs (Moscow: MEI Publishing House) p 612
- [2] Zaedinov A V 2018 Features of using fuel oil as a backup fuel *Young Scientist* **47** pp 37-39

- [3] Shamsutdinov E V 2011 Algorithm for the development and assessment of the efficiency of using energy-saving measures for fuel oil farms of TPPs and large boiler houses *Modern Problems of Science and Education* **2** p 19
- [4] Zvereva E R 2007 Improving the technical and economic indicators of fuel oil farms *Proceedings of Higher Educational Institutions. Energy Problems* **11(12)** pp 12-8
- [5] Mutugullina I A 2012 Ways to solve problems when using fuel oil *Kazan Technological University Bulletin* **10** pp 369-71
- [6] Olimpiev V V, Mikheev N I, Molochnikov V M, Kususyomov A N and Zanko F S 2005 Energy-saving technology of storage and heating of fuel oil in fuel oil facilities of TPPs of boiler-houses *Bulletin of the Russian Academy of Sciences. Energy* **1** pp 119-38
- [7] Einstein V G et al 2019 Processes and devices of chemical technology. General course. In two books. Book 1: The Textbook (SPb.: Lan) p 916
- [8] Popov D N, Panaiotti S S and Ryabinin M V 2014 Hydromechanics (M.: Publishing house of MSTU named after N E Bauman) p 317
- [9] Mirkin A Z and Usinsh V V 1991 Pipeline Systems (Moscow: Chemistry) p 256
- [10] Kutepov A M, Iashalkin V P, Panov M Ya and Kvasov I S 1996 Mathematical modeling of flow distribution in transport hydraulic systems with variable structure **350(5)** pp 653-4
- [11] Novitsky N N and Mikhailovsky E A 2012 Object Oriented Hydraulic Circuit Modeling *ISTU Bulletin* **7** pp 170-6
- [12] Novitsky N N et al 2015 *Power Pipeline Systems: Methodological and Applied Problems of Mathematical Modeling* (Novosibirsk: Nauka) p 475
- [13] Seleznev V E, Aleshin V V and Pryalov S N 2014 Mathematical modeling of pipeline networks and canal systems: methods, models and algorithms (Moscow; Berlin: Direct-Media) p 694
- [14] Kolesnikov S V, Kudinov I V, Eremin A V and Branfileva A N 2014 Using computer models to design complex piping systems *Energy. News of Higher Educational Institutions and Energy Associations of The CIS* **5** pp 72-83
- [15] Vasilenko A I and Fedosenko A A 2018 Technical and economic optimization of air ducts *Don's Engineering Gazette* **1**
- [16] Hlebnikov A, Siirde A and Paist A 2007 Basics of optimal design of district heating pipelines diameters and design examples of Estonian old non-optimised district heating networks *Doctoral school of energy and geotechnology: 4th International Symposium "Topical problems of education in the field of electrical and power engineering"* (Tallinn: Tallinn University of Technology, Faculty of Power Engineering; Elektriavam) pp 149-53
- [17] Gusev Yu M, Gafarov R R and Danilin O E 2008 Optimization of the operation of a section of the main oil pipeline based on a genetic algorithm *USATU Bulletin. Management, VTiI* **11(1)** pp 43-52
- [18] Samarin O D 2011 Technical and economic optimization of the diameters of heat pipes of water heating systems *Heat Supply News* **5** pp 42-4
- [19] Gagarin V G 2009 Methods of economic analysis of increasing the level of thermal protection of building envelopes. Part 1 *ABOK* **1** pp 10-6
- [20] Savastienok A Ya 2006 Optimization of pipeline engineering networks of hydraulic calculation *Energy. News of Higher Educational Institutions and Energy Associations of The CIS* **4** pp 67-72
- [21] Shabanov V A and Bondarenko O V 2012 Objective functions and optimization criteria for oil pumping through oil pipelines with a privately-controlled electric drive of main pumps *Oil and Gas Business* **4** pp 10-7

- [22] Evlakhov S K 2007 Methodological prerequisites for the study of problems of optimal flow control in the network of main oil pipelines *Oil, Gas and Business* **1-2** pp 28-30
- [23] Golyanov A I, Mikhailov A V, Nechval A M and Golyanov A A 1998 Selection of a rational mode of operation of the main pipeline *Transportation and Storage of Petroleum Products* **10** pp 16-8
- [24] Zaitsev A V and Logvinenko E V 2014 Cryogenic pipeline optimization *Omsk Scientific Bulletin* **3(133)** pp 164-8
- [25] Zaitsev A V and Logvinenko E V 2015 Solution of the cryogenic pipeline optimization problem using the Pareto-optimal solution search method *MAX Bulletin* **2** pp 55-60
- [26] Shaganov A Yu 2013 Optimization of material consumption for air ducts of ventilation systems using dynamic programming in a spreadsheet system *Bulletin of the Priazovsky State Technical University. Series: Engineering Sciences* **26** pp 128-36
- [27] Seleznev V E, Aleshin V V and Klishin G S 2005 Methods and technologies for numerical modeling of gas pipeline systems (M: KomKniga) p 327
- [28] Huei-Jiunn Chen 2003 Process exhaust duct system design using dynamic programming methods *Journal of the Chinese Institute of Engineers* **26(2)** pp 155-64
- [29] Jakub M 2018 Selecting optimal pipeline diameters for a district heating network comprising branches and rings, using graph theory and cost minimization (2018) *Journal of Power Technologies* **98(1)** pp 30-44
- [30] Khvostov A A, Magomedov M G, Zhuravlev A A, Shipilova E A, Semenikhin O A and Nikitchenko A A 2020 Optimization of technological pipeline parameters according to technical and economic indicators *Vestnik VSUIT* **82(1)** pp 34-46 DOI: <http://doi.org/10.20914/2310-1202-2020-1-34-46>
- [31] Ivanov A V, Sinyukov V V, Ryazhskikh V I, Khvostov A A and Zhuravlev A A 2017 Statement of the problem of optimization of pipeline networks for general purpose ground service facilities *Modern Methods of Applied Mathematics, Control Theory and Computer Technology* pp 180-3

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