Comparing pipelines made of different materials for replacement of old on-site pipelines of Kinel pumping-filtration plant

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Abstract. The article focuses on the pumping-filtering plan (PFP) in the town of Kinel and describes the pipes of various diameters made of modern materials. The authors compare characteristics of pipelines produced by four different manufacturers to choose pipeline materials which are most suitable for this particular pumping-filtering plan. The comparative analysis of the pipeline materials makes it also possible to decide on several options for use in reconstruction. The authors further consider characteristics of materials from which pipelines for water supply and heating systems are made. They describe metallic materials (steel, copper, zinc, stainless steel) and polymers (polyethylene, polyvinyl chloride, polypropylene and fiberglass). In the end the researchers share their experience and explain how water supply pipelines made of different materials operate in normal working conditions.

1. Introduction
Pumping-filtering plant (PFP) of Kinel town was built in 1972 and has been in operation ever since. During all this period, PFP facilities, pipelines and technological equipment made of metal have been subject to changes, that is they have been suffering from severe corrosion [1]. As a result, major repairs of pipelines and equipment are required.

2. Relevance
Kinel pumping-filtration plant as well as many other water treatment facilities was built in the second half of the last century. Its water supply on-site utilities were made of steel pipes. Nowadays these steel pipes are almost 100% worn down and ripe for replacement.

3. Problem specification
To choose pipeline materials suitable for the replacement of old water supply on-site utilities the authors suggest comparing modern pipeline materials produced by different manufactures.

4. Research Theory
To deliberately select the material and strength class of pipes for water pipelines, it is necessary to take into account climatic conditions, technical and economic calculations, corrosion aggressiveness of
soils and transported water. It is also important to consider the pipeline reliability and its operating period [1].

One of the most important characteristics of pipes is the ring stiffness parameter (nominal stiffness, SN) usually measured as the allowable force per unit of surface, N/m². There are 4 classes of stiffness:

- 2500 N/m² used for sheath laying and for 'pipe-in-pipe' method;
- 5000 N/m² for light loads (when laying is performed in mixed soils at a depth of 3 m) and with a load comparable to the load from a 60-ton truck;
- 10 000 N/m² for heavy loads (when laying is performed in mixed soils at a depth of 4 m) and with a load comparable to the load from a 60-ton truck with moderate padding;
- over 10 000 N/m² for special applications in areas with heavy mechanical loads, such as runways.

To select the most suitable option it is necessary to consider more characteristics. The pipes should be hard, structurally sound at coupling places and capable to maintain constant internal power pressure (that is water pressure). These pipes must also be resistant to corrosion processes to prevent pipeline choking and extend their operating life [2]. Pipes service life is another principal characteristic.

Environmental friendliness is also an important factor which should be taken into account due to the fact that the pipelines will pump water for drinking purposes. This water quality is subject to All Union State Standard (GOST) 51232-98 [3]. According to the requirements of SanPiN 2.1.4.1074-01 [4], the content of chemical compounds in water intended for drinking and household needs should not exceed concentrations specified in these specification documents. It all means that only pipes with a quality certificate satisfy the requirements mentioned above.

Taking into account all these characteristics and requirements, the authors selected five pipeline materials for further analyses. Along with that they also stress the fact that at the moment there is no material remaining in its original state when in contact with water. This makes the selection process even more complex [5]. Let us characterize these materials.

4.1. Steel
When exposed to water, the surface of steel pipes suffer corrosion. Steel oxidation products, in their turn, pollute water and significantly worsen its quality. For that reason, such steel pipes are no longer used in modern water supply systems. They are replaced by plastic pipes [6].

4.2. Zinc
Zinc-coated pipes are protected from corrosion, but lime suspended sedimentation dissolved in water lead to the formation of an oxide layer on the pipelines inner walls. Because of this, zinc-coated pipes can only be used in pure water with no extraneous substances [6].

4.3. Copper
Copper pipes are successfully used in autonomous engineering systems of country houses. But experts recommend using copper pipes only in heating systems Water in copper water pipes is saturated with copper ions that can further destroy all beneficial microflora [7].

4.4. Stainless steel
Stainless steel contain chrome That prevents corrosion of the material. There are two forms of chrome: Chrome-3 and Chrome-6. Chrome-3 performs an indispensable function in the human body. Chrome-6 is toxic and carcinogenic. Stainless steel water pipes are durable. Experts state that the material from which the pipes are made meets most sanitary and hygienic standards [8].

4.5. Polymers
Polymers include various ABS plastics, PVC, polycarbonate, polyethylene, polystyrene, PTFE, artificial rubber, composite mixtures with reinforced elements of carbon fiber, fiberglass, glass-fibre mat, metal and so on. Unlike traditional building materials, the desired technical characteristics of
polymers are set during the process of their production. Depending on the specific requirements, synthetic materials can have different strength, flexibility, colour, transparency, resistance to temperature impact, etc. The only thing that experts fear is the possibility that in the course of time, water biological parameters may deteriorate due to the penetration of organic substances used in the production of plastic pipes [9].

Based on the above, the authors conclude that plastic pipes are the best option in comparison with pipes made of other materials.

5. Investigation
The next step is to compare the types of plastic pipes and their characteristics.

1. Polyethylene pipes are characterized by increased strength while remaining elastic and flexible at the same time. They can endure the freezing of water (up to -20 °C) in water supply systems. These pipes are connected by diffusion welding, crimping and dismountable fittings. HDPE pipes are resistant to mechanical shocks and are used when increased ring stiffness is required (e.g. under the roadway). Drawbacks These pipes are characterized by instability under UV rays influence. Besides, they require the use of a special installation technology and cannot be used for the installation of fire extinguishing systems [10].

2. PVC pipes, in their turn, can successfully resist chemical reagents as well as mold and bacteria growth. They are easy to install and look aesthetically pleasing. PVC pipes are connected by gluing, by rubber-seals or by means of sockets. They are characterized by low weight and resistance to rust. At the same time, such pipes are not expensive and can be successfully used for 40-50 years. This material other drawbacks are its poor plastic properties and instability to UV-rays. These pipes are also difficult to dispose of, because they cannot be burned because of the release of chlorine during combustion process. For pressure systems it is possible to use pipes from non-plasticized polyvinyl chloride, i.e. from such a polymer that does not contain plasticizers and has exceptionally high strength [11].

3. Polypropylene pipes are a cheaper analogue of polyethylene pipes. Physic-chemical and thermal properties of these types of polymer pipes are very similar, but the installation of polypropylene water pipe is simplified by the availability of a variety of fittings, valves, adapters and other elements of installation. Polypropylene pipes are connected by welding, thus forming a monolithic connection that prevents leakage. These pipes main weakness lies in their sunlight and atmospheric air sensibility. They easily suffer from mechanical damage, either [12].

4. fiberglass pipes are made of composite materials, which are composed of various types of resin and reinforced with different types of reinforcement. Pipes can be manufactured while applying diverse technologies. fiberglass pipes advantages are as follows: light weight even if massive, the material is resistant to corrosion and to the effects of various acids. Pipes made of this material can be placed in any soils. Their installation is quite simple and usually includes the socket connection with double or triple seal. Therefore, the reliability of the joint does not require welding of its parts. The pipes can withstand high temperature changes, e.g. from -65 to +150 degrees Celsius. They also have their weaknesses and drawbacks. They include low crack resistance if the load is oriented across the fibers [13].

General characteristics of plastic pipes made of different polymers: no corrosion, resistance to chemical compounds, no formations on the walls, 50-year durability, non-toxic; strength, combined with elasticity, resistance to pressure difference, low thermal conductivity, ease of installation. Plastic pipes have such drawbacks as: all polymers are highly flammable, wear out rapidly under the influence of UV rays, their elasticity and strength are reduced when heated, they have a high linear expansion at temperature fluctuations [14].

When choosing pipes suppliers, it is necessary to check all technical characteristics of the materials they use for their products manufacture as well as the cost of pipes and the time this supplier is on the market [15].
The first company analysed in this research is LLC "PolyplasticPovolzhje". The company first appeared in 1989, when the Italian-Russian company "Italsovmont" was created. At that time, they produced metal structures. Since 2009, they have completely switched to the production of water pipelines and gas pipelines PE pipes. This company offers a wide range of products. LLC "PolyplasticPovolzhje" supplies high-quality raw materials, modern production technologies and state certificates (GOST compliable certificates) for all products [16].

Advantages of water pipes produced by this company are as follows: their more than 50-year guaranteed life; a high degree of resistance to corrosion when in direct contact with water or with other chemicals; light weight (4 times less than their concrete and metal analogues); ease of transportation; PE drinking pipe connected by butt welding, which requires much less time and effort compared to metal analogues; their installation is as fast as possible because of the application of welded fittings, also called electrofusion; butt joints do not require any additional sealing materials; plastic water pipes can be used several times, it does not entail additional costs for the works; PE pipes environmental friendliness due to the possibility of their processing and recycling; it is possible to use the so-called "drawing" for laying these water pipes; polyethylene pipes for water supply possess high elasticity, such a pipeline is not damaged by hydraulic shocks; the surface inside these pipes is completely smooth and prevents any harmful formations, resulting in leaning and deterioration of the hydraulic parameters of the water supply system; the fluid inside the pipes does not change its temperature due to low thermal conductivity, it completely excludes the formation of condensate water on the surface. The cost of pipes DU 630 mm ranges from 11721 to 26769 roubles.

The second company under investigation is LLC "Volgatekhstroy". It is one of the leading suppliers of polymer pipelines in Samara, Ulyanovsk, Orenburg and other regions. Its product range is constantly increasing. The company can make any reinforcement according to drawings of the client. Any volume of production is made within the shortest possible time. One of the advantages of this company is the minimum price policy in concern to raw materials. The company possess its own laboratories [17]. Profiled parts, fittings and welding equipment can be purchased together with a set of PE water pipes. The company "Volgatechstroy" also has all the quality certificates according to GOST (Russian National Standards). The cost of Du 630 mm pipe varies from 6 578 to 14 729 roubles.

The third company is LLC "Gazplast". Since 1996 this company is one of the leading producers of polyethylene pipes and fittings with a diameter of 25-800 mm for gasification, water supply and sewerage of PE 80 and PE 100 classes in Kazan and the Republic of Tatarstan. The company production is certified and meets all quality requirements imposed to water, sewerage and gas pipes. The latest equipment from Germany and Italy is used for the production of polyethylene pipes [18]. At the moment they have more than 1000 different products and manufacture articles in stock. All products have quality certificates. LLC "Gazplast" produces 20 – 800 mm in diameter polyethylene pipes for water supply systems according to GOST 18599-2001. Such pipes are used for transporting water (including water for domestic drinking water supply) at temperatures from 0° to + 40°, as well as other liquid and gaseous substances to which polyethylene is chemically resistant. The cost of pipes with a diameter of 630 mm is 5 750 - 12 875 roubles.

The fourth company in our research is "Promtekhkomplekt". They supply high-density polyethylene (HDP) pipes that meet the current GOST 18599-2001 and international standards ISO 4427-1:2007 and ISO 4427-2:2007. The company get certified products directly from the 5 largest manufacturers [19]. The PE pipes they supply are made from granules of primary polymer, which guarantee the uniformity of the composition and its chemical purity. These factors determine the following qualities of pressure pipes: operating temperature range: from -50 to +40 0C; internal pressure up to 10 MPa; light weight (900 kg/m³); minimal thermal expansion.

Low-pressure polyethylene is produced in pressure chambers at a temperature of about 150 0C and a pressure of up to 20 atmospheres. This determines the special structure of molecular chains and
significant differences in these polyethylene pipes characteristics as compared to other types of polyethylene. The cost of DN 630 pipes is within the range of 5 060 – 11 330 roubles. Table 1 presents a comparison of building costs for 1 r.m. (running metre) of polyethylene DN 630 mm pipeline.

**Table 1. Building costs for 1 r.m. (running metre) of polyethylene DN 630 mm pipeline.**

|                        | LLC "PolyplasticPovolzhje" | LLC "Volgatekhstroy" | LLC "Gazplast" | "Promtekkomplekt" |
|------------------------|-----------------------------|----------------------|---------------|-------------------|
| **Polyethylene pipes** | PROTECT GOST 18599-2001 with a protective shell, which can be laid without replacing the backfill soil, D630*57.2 mm | Polyethylene pipes 100 SDR 11 with blue strip, made of polyethylene at low pressure according to GOST 18599-2001, D630*57.2 mm | Polyethylene pipes for water supply systems, GOST 18599-2001, with a blue stripe, D630 mm | High-density polyethylene pipes, corresponding to the current GOST 18599-2001 and international standards ISO 4427-1:2007 & ISO 4427-2:2007, D630*57.2 mm |
| **Standards**          | GOST 18599-2001             | GOST 18599-2001      | GOST 18599-2001 | GOST 18599-2001   |
| Nominal diameter, mm   | 600                         | 600                  | 600            | 600               |
| Inner diameter, mm     | 515.6                       | 515.6                | 515.6          | 515.6             |
| Cross-section of open flow area, mm² | 208687.04              | 208687.04            | 208687.04      | 208687.04         |
| Expected service life, year | 50                          | 50                   | 50             | 50                |
| Operating pressure, (PN), Atms | 16                        | 16                   | 16             | 16                |
| **Pipeline material**  |                             |                      |               |                   |
| Price for 1 running meter of pipe, Rub | 26 769 (excl. VAT) | 14 729 (VAT included) | 12 875 (VAT included) | 11 330 (VAT included) |
| Total material costs for 1 r.m. of the pipeline, rub. | 26 769.00 | 14 729.00 | 12 875.00 | 11 330.00 |
| **Installation**       |                             |                      |               |                   |
| Laying (installation) of 1 r.m. of pipes, rub. | 380.66 | 380.66 | 380.66 | 380.66 |
|                                           |             |             |             |             |
|------------------------------------------|-------------|-------------|-------------|-------------|
| **Total Laying costs (installation) for 1 r.m. of pipes, rub.** | 380.66      | 380.66      | 380.66      | 380.66      |
| Trenching for 1 r.m. of the pipeline, m³ | 5.64        | 5.64        | 5.64        | 5.64        |
| Excavation price for 1 cubic meter of soil, rub. | 180.00      | 180.00      | 180.00      | 180.00      |
| **Excavation price for 1 r.m. of the pipeline, rub.** | 1 015.20    | 1 015.20    | 1 015.20    | 1 015.20    |
| **Total Trenching costs for 1 r.m. of the pipeline, rub.** | 1 015.20    | 1 015.20    | 1 015.20    | 1 015.20    |
| The volume of backfill (by hand) for 1 r.m. of the pipeline. | 0.10        | 0.10        | 0.10        | 0.10        |
| The price of filling 1 cubic meter (by hand), rub. | 650.00      | 650.00      | 650.00      | 650.00      |
| The cost of backfilling works (by hand) for 1 r.m. of the pipeline, rub. | 65          | 65          | 65          | 65          |
| The volume of backfill from barrow soils for 1 r.m. of the pipeline, m³ | 4.88        | 4.88        | 4.88        | 4.88        |
| The price of filling 1 cubic meter (by excavator), rub. | 100.00      | 100.00      | 100.00      | 100.00      |
| The cost of backfilling works (by excavator) for 1 r.m. of the pipeline, rub. | 488         | 488         | 488         | 488         |
| Soil compaction capacity for 1 r.m., m³ | 5.02        | 5.02        | 5.02        | 5.02        |
| Soil compaction price for 1 m³ of soil, rub. | 20.00       | 20.00       | 20.00       | 20.00       |
| Soil compaction price for 1 r.m. of the pipeline (additionally), rub. | 100.392     | 100.392     | 100.392     | 100.392     |
6. Practical significance
Many water treatment facilities (Kinel pumping-filtration plant, in particular) were built in the second half of the last century, with their on-site water supply networks made of steel pipes. Nowadays these steel pipes are almost 100% worn down [20]. In this research the authors compared modern pipeline materials produced by different manufactures which are suitable for the replacement of old water supply on-site utilities and produced a set of recommendations for using the most suitable option.

7. Conclusions
After a thorough analysis of polyethylene pipes supplied by four companies, it is possible to draw the following conclusions. LLC "Gazplast" company is a well-known reliable plastic pipes supplier which has been at the market long enough. During its work, the company has improved the technical performance of its products and introduced new manufacturing techniques. This company prices are second best in terms of availability among the suppliers, i.e. they range from 5 750 to 12 875 roubles. Taking all these arguments into account, the authors recommend that design engineers who will be involved in the project of Kinel pumping-filtration plant reconstruction should use pipes produced by LLC "Gazplast".

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