

Investigating the Possibility of using Fiberglass Reinforced Polyethylene Pipe for the Transportation of Natural Gas

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Abstract

Background/Objectives: Historically the most applied pipe material for gas transportation is steel, but polyethylene and fiberglass are also used. The purpose of this article is to present the results of a comprehensive study of the possibility to use composite pipes. **Methods:** A multivariate experiment to refine the method for calculation of reinforced polyethylene pipes consisting of three layers was carried out using pipe samples specially prepared in the laboratory; the economic effect of composite pipes introduction during the construction of gas pipelines instead of traditional steel was analyzed on the basis of the calculation of net present value and profitability index using the industrial data for offshoot pipeline construction. **Findings/Improvements:** The literature and statistical data analysis shows an increase in the length of composite pipelines over the last 10 years and their defect-free; a classification of multilayer pipes offered by various manufacturers was first developed and proposed and a diagram of product characteristics is presented; advantages and disadvantages of using these pipes for hydrocarbon transport streams are shown. According to the laboratory experiment the regression coefficients for mathematical model of a composite pipe were obtained for the first time and the assumption of the joint participation of polyethylene and a reinforcing frame to ensure overall pipe strength was confirmed, as well as the method of calculating the critical pressure for a classical composite pipe was proposed and conclusions about the nature of the pipe wall destruction were represented. The profitability index of the project, built of composite materials, compared to the project, built of traditional materials, shows a higher efficiency of the former by 34%, which enables to reduce the costs of social projects without reducing investment totally. **Application:** The investigation results can be used in creating the methodological and regulatory base for the implementation of multi-layer composite pipes of different designs in the oil and gas industry.

Keywords: Fiberglass, Gas Transportation, Natural Gas, Polyethylene Pipes, Reinforced Pipes

Introduction

Historically, steel is the construction material most widely used for pipelines, which provides a balance of price, availability, maintainability and safety. However, steel pipelines have a number of limitations, such as corrosion resistance, relatively high weight and costs for construction. According to Alberta province (Canada) report on the pipeline for the period from 1 January 1990 to 31

December 2012¹ there were 9,024 accidents because of internal corrosion in pipelines, which made 54.8% of the total number of accidents on all pipes, including transportation of crude oil, natural gas, water, multiphase flows and other liquids and gases (Figure 1). Totally 64.9% of emergency situations were identified due to corrosion problems, which include exploding fracture and leak.

Today polyethylene, aluminum, fiberglass and composite pipes are increasingly applied as the alternative to

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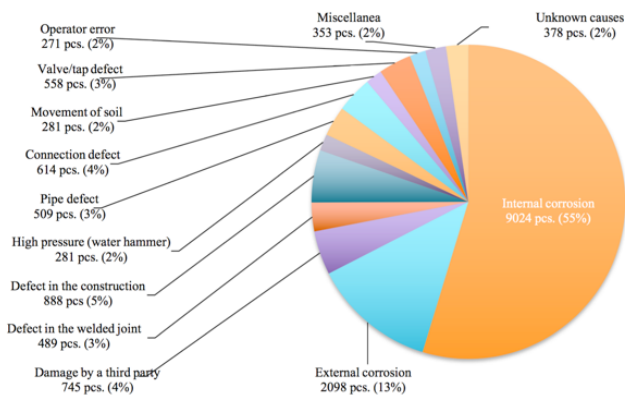


Figure 1. The number of pipeline accidents in Alberta province, Canada for the period from 1 January 1990 to 31 December 2012, classified according to their causes.

steel pipes not only for the delivery of natural gas, but also for other liquids and gases²⁻⁴. Composites based on glass fibers have not been used on pipes with large flow rates and pressures in any significant quantities. In the Russian oil and gas industry such pipes are not known yet, but they arose the interest. There are a number of different resins and reinforced fiber materials used in composite pipes. E-glass, S-glass, aramid (known as KEVLAR™ of DuPont company) and carbon/graphite are most often used as fibers⁵. Among the pipe manufacture technologies, there are three main methods for fiberglass pipes production: Simple filament-wound⁶, contact molding⁷ and centrifugal molding⁸.

In the production activity of one of the operators in Texas there are 326 km of steel pipes, 520 km of fiberglass pipes and 130 km of composite pipes. In Australia, the leading oil company in 2013 built a pipeline, the first of its kind in this territory with a length of 170 km and a diameter of 101.6 mm (4 inches) for piping liquid hydrocarbons from the field in the Cooper basin in Queensland province to a processing plant in the southern part of the continent⁹. North Fork gas pipeline project on the Kenai Peninsula near Anchor Point, Alaska, United States is a pipe with a diameter of 114.3 mm and a length of 12 km. The first gas was transported in the pipeline on March 31, 2011^{10,11}.

As a result, the analysis shows a growing interest in composite pipes of various designs in many countries for the transport of liquid and gaseous hydrocarbons. In view of the increasing number of manufacturers of pipes and variation of their products today there is no general classification, calculation methods, besides in the Russian

Federation there is no regulatory framework for the design and construction of pipelines of composites.

In industry and in some scientific studies their own symbols are used, which leads to misunderstandings in the discussions. The same materials have different names at the request of the author exploring this issue. First, we should start with the introduction of clear technical terms. Figure 2 provides a classification, which is divided into two broad categories according to stiffness.

Corrosion resistance—to influence of such corrosive substances as humid carbon dioxide and sodium chloride—is one of the main advantages of fiber reinforced composite material and important means of reducing operating costs. Composite Reinforced Line Pipe (CRLP) has the inner sealant layer that is a polyethylene core, which is not subject to conventional electrochemical corrosion typical of oil and gas pipes. It is covered or wrapped with a composite shell, metal cord or steel plates, which increases strength and protects the inner layer. Currently Western companies produce composite pipes of nominal diameter from 25 to 200 mm (1 to 8 inches) and nominal operating pressure to 22.4 MPa (3250 psi).

A unique feature of these composite pipes is the possibility of supplying them in a total length of 6 km in coils¹². The flexibility of these pipes with a certain combination of materials may be greater than any other common materials in industry—leading pipe producers selected such a composition of materials that can withstand large deformations without strength losses. Flexible multilayer pipes can be delivered to the track in the coils of great length, which can significantly reduce the cost of docking lashes in the construction of pipelines.

A comparison of data of the Alberta Energy Regulator (Canada) reports in 2005 and 2012^{1,13}, (Figure 3) as of 31

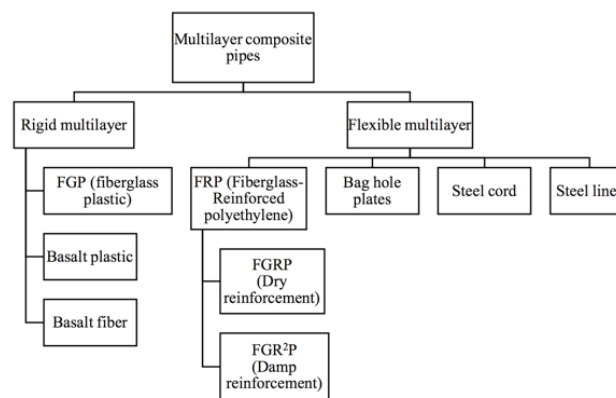


Figure 2. Multilayer composite pipes classification.

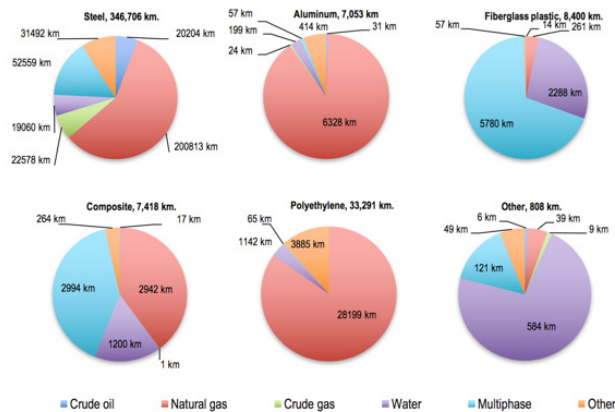


Figure 3. The length of the pipeline in Alberta province, Canada, as of December 31, 2012, classified by material and type of pumped product.

December 2012 demonstrated a significant increase in interest namely to composite pipes—the length of composite pipes increased by 5.77 times (from 1095 km to 7418 km), including the length of pipe for the transport of only natural gas which increased by 2331 km or 381%. This certainly indicates a growing interest in composite pipes.

This type of pipe was mainly used for the transportation of water, multiphase fluids and gas. It is worth noting that composite pipes for gas transportation rank second in total length (2942 km) and are only slightly inferior to the length of composite pipes used for the transportation of multiphase flows (2994 km), mainly at the field of development and production of hydrocarbons.

To achieve these goals, the authors conducted a scientific research on the issue of using the composite pipelines in various projects. To better visualize the state of the market of composite pipes Figure 4 presents a graph of dependency on pressure and the diameter of the pipe by major foreign manufacturers.

There are also many questions relating to the pipeline mechanics of composite materials. For example, the questions about the effect of bending and other types of pressures in the pipe body when winding and transporting, as well as how these pressures are close to critical have not been studied. Methods for calculating reinforced pipes are often unreasonable and use large safety factors. It is believed that when using high strength materials to reinforce polyethylene pipes, reinforcing system accepts 90-95% of the total pressure and the polymer layers are

stressed insignificantly because of an insignificant system deformation¹⁴. In this case the outer layer, making the structural integrity, is generally not taken into account in calculations^{15,16}. This leads to the overrun of expensive material and lowers the cost effectiveness of such materials and therefore limits their application.

Fiberglass reinforced polyethylene pipes can be referred to composite one as they consist of several layers. The study considered their classic design, which consists of three components:

- Inner sealant polyethylene layer;
- Reinforcing frame made of high-strength threads;
- Outer layer made of high-temperature copolymer.

The samples in which a cross-linked PE-X polyethylene was used as the inner layer were prepared for laboratory tests. Reinforcement was made by Kevlar® fibers in a quantity of 36 pieces, the density of 3300 dtex, the tensile strength of each fiber of 670 N. The structural layer of the high-temperature copolymer was applied to protect the reinforcement carcass from mechanical damage and is sealed with the inner polyethylene to provide structural integrity.

As it is well known, polymers' strength is characterized by temperature-time dependency, thus limiting the value of internal pressure, at which the plastic pipe wall destruction occurs, differs, depending on the designed operational lifetime. In the study the internal pressure required for polyethylene work for 50 years was taken as critical.

Critical pressure of reinforcing frame was calculated from the known formula:

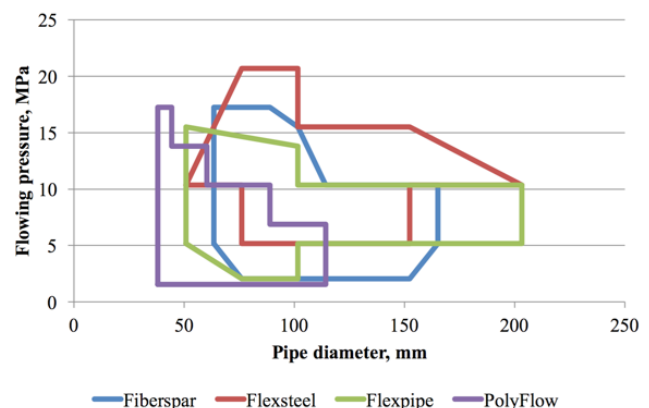


Figure 4. Classification of composite pipes manufacturers.

$$P_{crit}^{reinf} = \frac{2 \times N \times R \times \sin(\varphi) \times tg(\varphi)}{\pi \times D^2},$$

Where N is the number of threads laid in two directions:

R is tensile strength reinforcement thread;

the angle of reinforcing thread placement depending on pipe axis;

D is an outer diameter of inner polyethylene pipe.

Calculation of the polyethylene layer was carried out according to the formula:

$$\lg(t) = A + \frac{D}{T} \times \lg(\sigma) + \frac{B}{T} + C \times \lg(\sigma),$$

Where A, B, C, D are empirical coefficients in the polymer dependence according to the standard curve in the All-Union State Standard 52134-2003;

Pressure in polyethylene;

T – Environment temperature.

Tension in polyethylene was found according to Strength Theory 4:

$$\sigma_{str}^{IV} = \sqrt{\sigma_m^2 + \sigma_t^2} - \sigma_n,$$

Where P is inner pressure:

D – Outer pipe diameter;

σ_t : – Circumferential stresses;

σ_m : – Meridional stresses;

S – Wall thickness.

As a result, the wall thickness stress is calculated by:

$$\sigma_{str}^{IV} = \frac{\sqrt{3}}{4} P_{crit}^{PEX} \times SDR.$$

Substituting $t = 43$ h (50 years) in the left side of the equation 1 where $\lg(438000) = 5.64147$ and considering equation 2:

$$5.641474111 = a + \frac{D}{T} \lg\left(\frac{\sqrt{3} P_{crit}^{PEX} \times D}{4 \times s}\right) + \frac{B}{T} + C \times \lg\left(\frac{\sqrt{3} P_{crit}^{PEX} \times D}{4 \times s}\right).$$

By elementary transformations, we obtain:

$$\lg(P) = \frac{T \times (5.641474111 - A)}{C \times T + D}$$

$$P_{crit}^{PEX} = \frac{s \times 4 \times 10^{\frac{T(5.641474111 - A) - B}{D + C \times T}}}{\sqrt{3} \times D_{int}}$$

We add the obtained critical pressures for polyethylene layer and a reinforcing frame and introduce the regression polyethylene strength and reinforcing frame coefficients, as well as coefficient, considering the material type of the outer layer:

$$P_{crit}^{gen} = k_1 \frac{s \times 4 \times 10^{\frac{T(5.641474111 - A) - B}{D + C \times T}}}{\sqrt{3} \times D_{int}} + k_2 \frac{2 \times N \times R \times \sin(\varphi) \times tg(\varphi)}{\pi \times D^2} \varepsilon$$

Considering the conditions of the carried out study when $T = 293^\circ\text{K}$ and for cross-linked PE-X polyethylene used in this work, we obtain:

$$P_{crit}^{gen} = k_1 \frac{21.99176 \times s}{D} + k_2 \frac{2 \times N \times R \times \sin(\varphi) \times tg(\varphi)}{\pi \times D^2} \varepsilon.$$

The plan of three-factor two-level experiment is presented in Table 1.

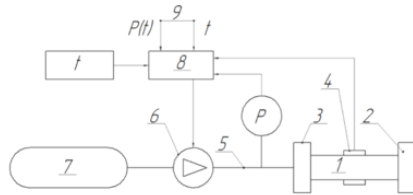
The study was conducted in several steps for each of the samples according to the scheme shown in Figure 5 at a constant fluid temperature of 20°C .

The linear size of the samples was taken in accordance with the All-Union State Standard GOST 24157-80, "Determination of Resistance under Constant Internal Pressure Method" as making no less than (excluding fittings):

- For a nominal diameter of 90 mm-520 mm;
- For a diameter of 110 mm-580 mm.

Table 1. The experiment plan

			Levels			
Factors	The mandrel diameter		90 mm		110 mm	
	Winding angle		54°44'	65	54°44'	65
	Outer layer	PERT	1	2	5	6
		M604TB	3	4	7	8



1 – Test specimen; 2,3 – Pipe fittings; 4 – Strain measurement; 5 – Communications; 6 – Pump; 7 – Expansion tank; 8 – Secondary converter controller; 9 – Experiment programming; P – Manometer; t – Timer.

Figure 5. Test unit scheme.

Sample 1 using fittings 2 and 3 was sealed and connected to the hydraulic testing system. With the help of the controller 8 the stage pressure and dwell time was set, upon the expiration of which the pressure was increased to the next planned value. Increasing the pressure was made by pump 6 according to the schedule shown in Figure 5. The moment of depressurization the sample is taken into account by P pressure gauge with transferring the value to the controller and tagging the actual time exposure t at the current stage.

The idea of conducting the experiment was in supporting a sample at a certain initial pressure with a consistent gradual increase in pressure and holding at this pressure for a particular time. Depressurization of the sample between different stages was not made; the test was carried out before the sample destruction.

In the end of the study during the inspection of samples 3 main types of failure were found out which were identified and presented in Figure 7.

The destruction of the first type takes place in samples with the elevated angle of reinforcing thread placement, regardless of diameter. The destruction of the second type occurs with twisting that is typical for samples with equilibrium reinforcement. On samples with the outer epoxy

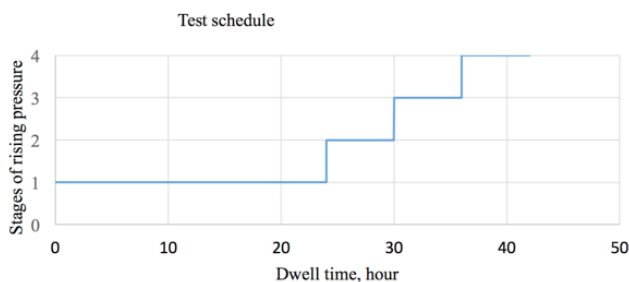


Figure 6. Pressure-time curve in stages.



a – destruction along the forming tube, b – destruction along the line of reinforced fibers laying, c – extensive damage with complete destruction of the reinforced layer

Figure 7. Different types of sample seal failures.

surface the 3rd type destructions are recorded, which, unlike the first two occur in polyethylene on a large surface and simultaneously destroy the reinforcing frame in the damaged area along the entire damaged part of polyethylene.

It is important to note that after the application of the experimental data to the theoretical model, it turned out that for samples with an elevated angle of placement (φ : φ) there is no relationship between the type of damage and the excess of the tensile strength along the pipeline axis or in the circumferential direction. At the longitudinal destruction of the pipe with an elevated angle of installation and a nominal diameter of 90 the ultimate axial strength limit was exceeded in the reinforcing frame and for the pipe with an elevated installation angle and a nominal diameter of 110 at excess of annular stress limit of reinforcing frame was observed with the same nature of the destruction. Thus while the data processing it was revealed that the outer coat type does not affect this process.

Table 2 presents a summary test report. The large number of articles indicates that the inner polyethylene layer almost completely transmits stress to the reinforcing frame, but during the experiment the samples were supported at the initial phase for a considerable time. Furthermore, sample №1 was separately maintained at 35 bar pressure close to the critical pressure of the whole structure for 66 hours, then kept tightness for a certain time at a critical pressure equal to 40 bar. According to All-Union State Standard calculations, a polyethylene pipe with the original diameter and wall thickness without the reinforcing layer at a pressure of 35 bar is destroyed almost instantly, and the separately reinforcing layer at a pressure of 26 bar. However, the final outcome of 40 bar coincides with the theoretical assumption that the inner polyethylene may contribute to the overall strength of the structure according to the proposed model.

Having processed data of the experiment by the method of least squares to find k_1 , k_2 and ϵ , the k_l and

Table 2. Summary test report

Name	Sample number	Pressure 1, bar	Estimated time, h	Actual time, h
90-STD*	1	15	12	12
		20	6	6
		25	6	6
		30	6	6
		35	6	66
		40	6	6
90i-STD	2	35	24	18
90-E	3	20	24	24
		25	6	6
		30	6	40 min
90i-E	4	15	24	24
		20	6	6
		25	6	1 hour 20 min
110-STD	5	25	24	24
		35	6	6
110i-STD	6	35	24	24
		40	6	6
		45	6	6
110-E	7	20	24	24
		25	6	6
110i-E	8	15	24	24
		20	6	6
		25	6	6
		30	6	20 min

Note: *The structure code is formed in the following way: the nominal diameter of pipe, hyphen, outer layer type. STD means a factory polyethylene coating. E is an epoxy resin layer. The “i” index next to the nominal diameter denotes an elevated winding angle compared to the equilibrium one.

k_2 coefficients were close to 1 and were equaled, and $\varepsilon = 0.598$ for M604TB and $\varepsilon = 0.9989$ for the PERT are assumed to be 0.6 and 1 respectively.

The experimental results coincide with the theoretical model with an accuracy of no more than 7 percent (Table 3, Figure 8). The error is caused by a large pitch of increasing the pressure during the test and can be significantly reduced in subsequent trials by reducing the pitch.

For the particular case, when cross-linked PE-X polyethylene is used as the inner layer and $T = 293^\circ\text{K}$ after applying coefficients:

$$P_{\text{crit}}^{\text{gen}} = \frac{21.99176 \times s}{D}$$

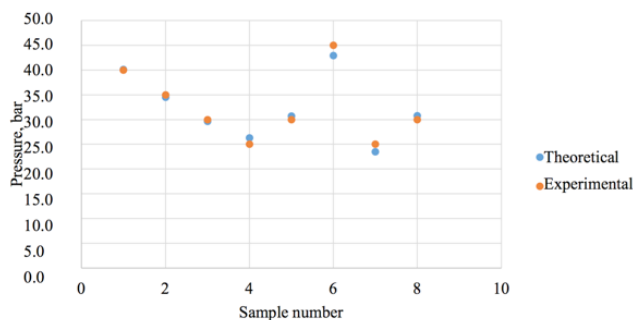
$$+ \frac{2 \times N \times R \times \sin(\varphi) \times \text{tg}(\varphi)}{\pi \times D^2} \varepsilon,$$

Where $\varepsilon = 0.6$ for M604TB and $\varepsilon = 1$ for PERT.

In most Russian regions mainline gas infrastructure development occurs at the expense of Gazprom, but the work related to pipe branches of gas distribution pipelines rests on the budget of a particular region. The budget is usually set from the gas tariffs, which are strictly limited and they are not enough to cover all expenses for gasification. Alexey Miller, Chairman of the Management Committee of Gazprom PJSC said that currently the main gas pipelines do not work at full capacity, less than 9 bil-

Table 3. Results of the theoretical model and the experiment

№	Sample code	Pressure, bar		Accuracy, %
		Theory	Experiment	
1	90-STD	40.1	40	0.24
2	90i-STD	34.51	35	1.43
3	90-E	29.65	30	1.18
4	90i-E	26.31	25	4.97
5	110-STD	30.68	30	2.21
6	110i-STD	42.89	45	4.92
7	110-E	23.49	25	6.41
8	110i-E	30.8	30	2.59

**Figure 8.** The theoretical values of critical pressure compared to the experimental values.

lion cubic meters of gas is supplied to the regions, this is less than 27% of the potential capacity. This is due to the fact that the gas distribution pipelines are not communicated to all consumers.

“In the region there is no place in which it would be possible to connect a few thousand consumers immediately after building a pipeline with a length of 10-15 km. Remote small towns remain non-gasified. Their gasification is loss-making, but it should be done. Not everything is measured by money. Quality of people’s life is more important”, Andrey Kislov, CEO of Gazprom Mezhhregiongaz Samara LLC, stated¹⁷.

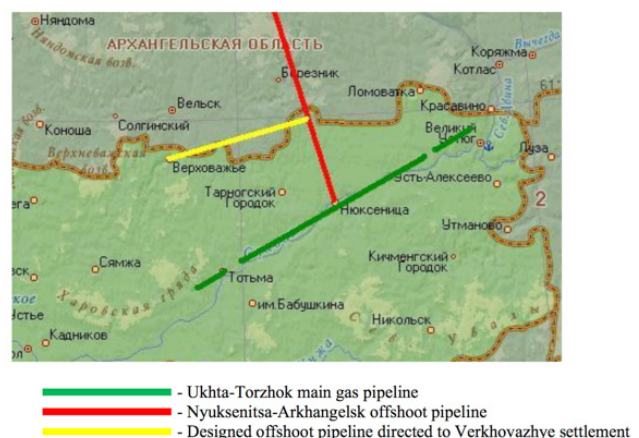
Two projects were compared to determine the effectiveness of applying the considered composite pipes:

- Traditional high pressure steel offshoot pipeline, built in 2007 on the territory of Vologda and Arkhangelsk regions;

- The similar offshoot pipeline built of the considered fiberglass reinforced polyethylene pipes under the same conditions of construction.

The real estimate for the construction of the gas offshoot pipeline, built in 2007 on the territory of Vologda and Arkhangelsk regions (Figure 9) was used in the first option of a steel gas pipeline. We analyzed the main indicators excluded calculations not related to this project and used the basic cost data for the construction of steel pipeline option. According to official sources, the inflation rate since the beginning of 2007 and currently amounts to 123.58%.

For the second option (a composite pipe) the project cost data, namely the cost of material and the costs for the construction of linear composite pipeline, were taken from public sources of NOV (National Oilwell Varco, United States). To compare the cost-effectiveness

**Figure 9.** Location map of designed offshoot pipeline to Verkhovazhye settlement on Vologda Region map.

of projects we identified the main technical and economic indicators and made the analysis according to them. An offshoot pipeline to the settlement was calculated based on the nominal diameter of pipes $D_n = 200$ mm, the length 56 km, the operating pressure in the pipeline of 7.4 MPa.

Below there are the calculations in which the benchmark data presented in Table 3 are used. The income was calculated not on the basis of the gas transportation tariff, but on the basis of the wholesale gas price multiplied by the pipeline performance. The calculation did not consider the works which should be carried out regardless of the type of material used in construction, for example, preparation of the construction site and the construction of building bases.

The criterion of the project successfulness under these conditions was considered the ratio of profitability indexes of the construction option using composite materials to the construction option with traditional materials. As a result of economic calculation, taking into account all the assumptions, this type of construction can be regarded as applicable when providing this criterion by more than 25%. The analysis was performed by standard methods of evaluating dynamic efficiency with the calculation of NPV (Net Present Value) on the basis of constant income for 50 years.

Revenue comes from the beginning of the operation after the construction is completed (1 year). According to the order of the Federal Tariff Service of Russia the gas price per thousand cubic meters is assumed to be 3.331 rubles. In the first year and the subsequent years the revenue will amount approximately to 134.906 million rubles.

The main calculation indicators affecting the project and operating costs are presented below. The main argument against the composite pipe is its higher cost compared to that of the steel pipe. However, the high processability of the material and the ease of working with it allow bearing lower costs for delivery and installation of the linear part of fiberglass reinforced polyethylene.

According to the calculation results, the cost of materials of the steel pipeline amounted to 353.66 million rubles, its construction cost – 656.81 million rubles yet, the total – 1010.47 million rubles. The cost of materials for a composite pipe according to calculations amounted to 505.23 million rubles and for the construction – 303.14 million rubles, the total is 808.37 million rubles. Indeed, compared with the steel pipes, the composite ones can significantly reduce the cost of pipeline construction. This is due to a significant decrease in a number of joints – a

composite pipe is supplied in coils to the track, each of which contains up to 1 kilometer of pipe, depending on the diameter, in addition the delivery of the steel pipe to the track is performed in segments of 12 m and they are welded directly at the track. Furthermore, at the construction stage, the cost of the composite pipe per meter is greatly reduced and becomes less than the cost of the steel pipe per meter. In conclusion, the period of the pipeline operation will also bring a significant economic benefit, as composite pipes can significantly reduce the cost of the pipeline operation compared with steel ones. They do not require the construction and exploitation of ECP systems, corrosion monitoring and in-line inspection. All these specifications are taken into account in justifying the use of fiberglass reinforced polyethylene pipes.

Capital investments in the construction of an offshoot pipeline for two options are shown in Table 4.

Depreciation expense for new fixed assets is accepted in accordance with the Resolution of the Government of the Russian Federation. In these projects, depreciation expense is calculated for the entire period of operation with the information about expenses of each sub-object within one operation object. The working service is 50 years.

Operating expenses include the following components:

- Material costs which include electric energy, maintenance of the pipeline;
- The cost of labor and social needs;
- Other costs.

Repair and maintenance service includes routine inspections and repairs at the pipeline track, maintenance and material support. According to statements of leading US manufacturers of composite pipes for the gas transportation, reducing costs of repairs and maintenance when using modern materials can be up to 4 times.

Outflows take into account the following calculation indicators:

- Investments;
- Operating costs (excluding depreciation);
- Depreciation;
- Taxable income.

Investments are attracted in the construction period. The total investment sum of 1805.45 million rubles is for the construction of pipelines of steel pipes and 1406.54 million rubles for the construction of composite pipe.

Table 4. Initial data for calculation

Index	UM	Value	
		Traditional materials	Composite pipeline
Investments	mln rub.	1805.45	1406.54
Building time	months	12	12
Term of the facility operation	years	50	50
Flow efficiency	mln m ³ /year	40.5	40.5
Gas transportation cost	rub/1000m ³	3331	3331
Interest rate on risk-free investments	%	10	10
Risk premium	%	1	1
Operating costs (excluding depreciation)	mln rub/year	4.256	12.453
Depreciation	years	50	50

The entire amount of the investment is the own resources of Gazprom PJSC and the involvement of credit is not required.

Operating costs are all annual costs for the performance of the pipeline constructed and put into operation.

In the context of the pipeline construction, whose working service is 50 years, the use of static methods cannot provide an impartial picture for the visual comparison of two projects.

Dynamic indicators are calculated using discounting. Net present value (integral economic effect) is the present value coming in at the project start time that is expected after the reimbursement of invested capital and receiving annual interest equal to the investor's required return. Net present value is the sum of the discounted cash flow. If the NPV value is positive, the investment project is considered cost-effective, which demonstrates the feasibility of financing and project implementation.

According to the calculation results, the exacted NPV is negative. The NPV value for the steel gas pipeline was 844 million rubles and for composite ones amounted to 406 million rubles. It means, as it was stated above, that the project rates of return are not provided, but the construction is necessary in view of its high social significance.

Profitability index of discounted investments is the ratio of the sum of the discounted cash flow elements from operating activity to the absolute value of the discounted sum of the cash flow elements from operating activity. Its value is equal to the ratio of NPV, increased by one, to accumulated discounted volume of investments.

In the research the profitability index was calculated using the formula:

$$PI = 1 + \frac{NPV}{\sum_{i=0}^T \frac{K_t}{(1 + E_H)^t}}$$

The result of calculation was as follows: The profitability index of the steel pipe amounted to 0.53, while the profitability index of the composite pipe was 0.71. It should be compared with "1" and in case it is less than unity ($PI < 1$), the project is not considered cost-effective. Based on the study, it may be concluded that the project is not compensated in both cases, but as the pipeline construction will yet be completed, it makes sense to build it from materials with a higher profitability index, provided that in both cases the profitability index will be less than unity. By relating the profitability index of the project built from composite materials to the project built from traditional materials, we obtain the effectiveness of the first one by more than 34%, at the same time, in these conditions the savings could reach more than 400 million rubles and there were cases in international practice when economic effect was \$45 million while using composite pipes¹⁸.

Positive findings will serve as an impetus for a widespread use of composite pipes, but the above mentioned problems must be solved comprehensively, as they follow one another and a solution of one of them does not solve all the others.

The main disadvantages of composite materials, as it was indicated above, is the need of connecting them in the

field environment, which may cause difficulties because stalks have a multilayer structure and the joint should take place in the manner providing a reliable connection of all layers. From the viewpoint of equipment, the cost of such jointing is greater than for single-component materials, such as steel or polyethylene.

The use of composite pipes for hydrocarbon transportation can provide many advantages. The main advantage of fiberglass reinforced polyethylene pipe is that it can be a worthy substitute for the steel pipe, which is traditionally considered as the basis for the high-pressure oil and gas transportation.

The analysis of a large amount of literature and the information provided above leads to the following findings:

- The amount of material needed for composite pipes compared to plastic ones is several times lower;
- In comparison with steel pipes, composite pipes can significantly reduce the cost of pipeline construction and its maintenance;
- Given a sufficiently high working pressure of some types of pipes, adjusting the nominal pressure of the pipe is possible by changing the construction, which will manage the project material consumption;
- The creation of typical joints for pipes of the same diameter with different pressures will help reduce the uniqueness level of each separate joint, which will reduce their cost and accelerate the performance of work to join pipe sections;
- Working out of an accurate method of engineering calculation of the pipe allows bringing a composite pipe to the new level, as the absence of such methods prevents the creation of a full-fledged standard for the universal application of composite pipes.

The main conclusion drawn from the results of the experiment is that when calculating the tensile strength of fiberglass reinforced polyethylene pipes, it is necessary to consider not only the strength of the reinforcing frame, but also the strength of the inner polyethylene layer, wherein:

- The critical internal pressure of polyethylene should be considered as the pressure at which the long-term durability is ensured for a period of 50 years (438 000 hours);

- Regression coefficients have been obtained by OLS. The k_1 and k_2 values were close to one, therefore $k_1 = k_2 = 1$, ε is 0.6 or 1 depending on the outer coating;
- As seen from the experiment based on sample №1 there is no sharp loss of pressures in the polyethylene after a few hours of testing;
- For pipes with an elevated angle of fiberglass winding and a nominal diameter of 90 the fracture occurs due to exceeding the axial tensile strength and for the pipes with an elevated angle of fiberglass winding and a nominal diameter of 110 due to exceeding the girth tensile strength, regardless of the type of external coatings.

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