THE SYSTEM ANALYSIS IN TASKS AIMED AT MINIMIZATION OF GEOECOLOGICAL RISKS AT COMPLEX GAS MAIN PIPELINES

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The methodology of application of the system analysis and the relevant mathematical models for optimization of gas flows in complex gas transportation systems (GTS) are considered taking into account the gas pipelines emissions' environmental impact. The proposed approach allows the researcher to estimate the level of geoecological risks at separate sections of pipelines and rank the GTS subsystems by this index. In turn, it permits to single out the pipeline sections sets, where the management solutions and measure have to be undertaken in order to decrease the level of geoecological risks. The stage of the system synthesis envisages the possibility of the geoecological risk assessment during operation of the whole system.

In the gas industry of the Russian Federation the gas transportation system (GTS) exerts the main impact on the environmental condition, which is caused by its large length - to the tune of 155 thou km, and by its capacity - over 44 mln kW. The most significant emissions of pollutants in the process of gas pipelines operation occur due to the so-called gas consumption for own needs. On the gas mains the main share of gas consumption for own needs includes the fuel gas used for compressor stations (CS), technological losses, including leakages on the linear part and during CS operation, emergency situations and other technological needs, including losses during repair of gas pipelines.

On the average, in the structure of gas consumption for own needs the fuel gas accounts for 80 percent, other technological needs - 8 percent and technological losses of gas - 12 percent. Furthermore it should be noted that in the total consumption of fuel-energy resources the share of natural gas is about 92 percent [1]. Figure 1 presents the dynamics of the fuel gas consumption in GTS, in percentage, by 1999. If this tendency keeps on, then with the planned gas production by 2020 amounting up to 590 bcm this index can exceed 50 bcm. Therefore the problems of reduction of the GTS energy intensity and, as a result, the decrease of negative impact on the environment, become of first priority.

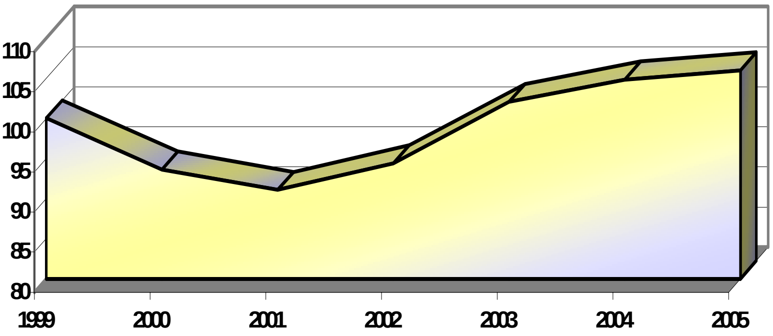

Figure 1. Dynamics of the fuel gas consumption in GTS, in percentage, by 1999

Among the most promising technological solutions, which allow the gas industry to improve the indices of the energy intensity of gas pipelines, are the increase of the working pressure, the use of internal smooth coating of pipes, application of high-efficiency gas producing units (GPU). For example, the use of pipes with internal smooth coating and high-efficiency GPU allows increasing the gas pipeline capacity up to 10 percent [2].

The optimization of the of gas pipeline parameters seems the most effective direction of energy saving on the basis of system approach. It implies the consideration of the gas pipeline as an element of GTS taking account of its technological, and technical and economic interrelations with other UGSS (unified gas supply system) objects. In fact, this implies the consideration of the gas transportation complex as a unified system and the formation of general scenarios of development and reconstruction.

Moreover an optimum distribution of gas flows in GTS allows a wider use of new technologies with the increased pressure and corresponding reduction of the overall power inputs [3].

The mathematical models, which allow the researcher to minimize the costs of gas transportation through complex gas transportation networks are very well studied [4]. However, in practical realizations the functionals, which, together with the technical and economic indices, take account of geoecological components, are very seldom considered. Of course, in terms of economy, expenditures for reduction of the geoecological risks are much less than overall power inputs. Nevertheless, the optimization of gas flows in the gas transport networks, subject to the economic assessment of the GTS environmental impact, will allow somebody to work out decisions on the geoecological risks management. This will enable to decrease the costs of direct gas losses occurring due to gas leakage during its transportation, storage and conducting repair works. In addition to the obvious economic damage from these losses, this approach allows the company to consider the reduction of indirect losses, connected with the possible trade in greenhouse gas emission quotas [5,6].

Let us examine the methodical approaches and mathematical models allowing to realize the above stated principles. Figure 2 shows the schematic aggregated diagram of the gas transportation system of the unified gas supply system.

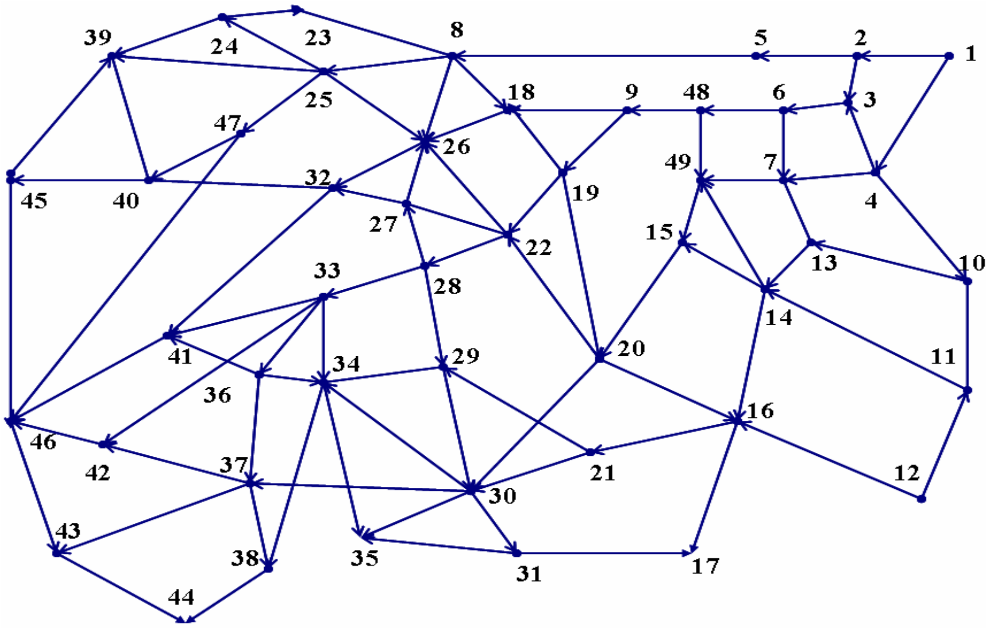

Figure 2. Schematic aggregated diagram of the gas transportation system

The degree of the system' aggregation is selected, on the basis of existing zones with different selling prices for natural gas, so that for the GTS sections this index at the entrance and at the exit would be different.

With the currently existing approaches the planned gas flows are calculated by the maximization of the functional:

$$F = \sum_{i=1}^{n} Q_i \cdot v_i \to \min \qquad (1)$$

where Q_i - flow along the i arc,

v_i - weight of the i arc.

The optimization of the functional is carried out with limitations:

$$Q_i <= M_i, \qquad (2)$$

where Mi - the maximum output of the gas pipeline section.

And for each unit the equality from Kirchhoff's law is applied:

$$\sum_{i \in j} \pm Q_i \pm S_j = 0 \qquad (3)$$

where S_j – gas supply (+) or consumption (-) in the j-unit of the system.

The weight of the i -arc for this task is determined from the ratio

$$v_i = T_i , \qquad (4)$$

where Ti - specific expenditures for gas transportation, including depreciation and tax allocations, return of investments.

Actually the issue in question is the calculation of annual gas flows at all sections of the gas transportation system subject to minimization of transportation costs and the fulfillment of commitments regarding gas supplies to users. Value T_i, in turn, is function of gas flow Q_i, therefore, the optimization of functional (1) is carried out iteratively. The methods of construction and optimization of gas flows in complex gas transportation systems and gas-distribution networks are well studied for different classes of tasks [2, 7, 8]. Therefore, we won’t dwell on them and come to the formation of the functional for optimization of gas flows taking account of ecological component.

For each section the economic component of the estimation of geo-ecological consequences includes:

- determination of the volumes of probable gas emissions in accidents and leakage on the basis of statistical models;
- determination of the volumes gas release during the planned repair works on the basis of optimization of schedules of their conducting;
- determination of the volumes of gas consumed for the fuel needs on the basis of minimization power inputs at compressor stations.

The mathematical models, which allow evaluation of specific economic losses from environmental impact for all enumerated tasks are represented in the paper [9]. Thus, the weight of arcs in minimized functional (1) is determined from the ratio:

$$v_i = T_i + E_i \ , \qquad (5)$$

where E_i - the economic component of environmental impact during the year in the *i*-section of the gas transportation system.

Let us explain the above said on a simple numerical example (Fig.3).

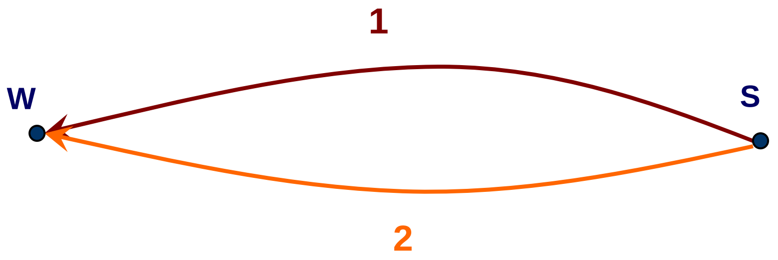

Figure 3. Example of the GTS scheme for calculation of gas flows

Let us assume that the annual production in node S amounts to 400 bcm. Accordingly, the annual consumption in node W will be equal to 400 bcm. (gas consumption for its own needs is tied to node W).

The additional data, necessary for conducting the calculation are represented in Table 1.

Table 1

Data necessary for conducting the calculation

№ of arc	Length of arc, km	Maximum capacity, bcm/yr	Specific expenditures (T) \$/(100 km* thou. m^3)	Ecological component (E) \$/(100 km* thou. m^3)	Flow, variant 1, bcm/yr	Flow, variant 2, bcm/yr
1	200	210	2	0,25	210	170
2	210	230	2	0,10	190	230

Let variant 1 be understood as the calculation of the gas flow without taking account of the ecological component, and variant 2, accordingly, as the calculation with ecological component. Then for variant 1 we have:

weight of the 1-st arc $v_i = 2*200/100 = 4.00$ \$/thou m^3

weight of the 2-nd arc $v_i = 2*210/100 = 4.20$ \$/thou m^3

Conducting the optimization with account of limitations for the maximum capacity of the arc (section of gas pipeline) we receive the gas flows (Table 1).

For variant 2 we have:

weight of the 1-st arc $v_i = 2*200/100 + 0.25*200/100 = 4.50$ \$/ thou m^3

weight of the 2-nd arc $v_i = 2*210/100 + 0.10*210/100 = 4.41$ \$/ thou m^3

The results of optimization with account of limitations for the maximum capacity of the arc (section of gas pipeline), subject to the ecological component, are shown in Table 1.

Thus, from the obtained results of the calculation it is obvious that in variant 1 completely loaded was the first section of the system, and in variant 2 - the second. The presented simple example shows that consideration of the ecological component can to a significant degree influence the redistribution of gas flows.

As applied to the considered system (Fig. 2) practical calculations have been carried out, their results are shown in Table 2.

Table 2

Results of the optimal redistribution of gas flows

Number of section	Number of nodes	Gas flow, mln m^3 without taking account of the ecological component	Gas flow, mln m^3 taking account of the ecological component	Risk level
1	**2**	**3**	**4**	**5**
1	1 - 2	510600	519016	**L**
2	2 - 3	423000	421842	**M**
3	4 -3	2700	1844	**H**
4	1 - 4	49700	41284	**H**
5	2 - 5	72000	81574	**L**
6	3 - 6	397700	395686	**M**
7	4 -7	13080	11062	**H**
8	6 - 7	92300	84972	**H**
9	4 - 10	21620	16079	**H**
10	10 - 11	11020	6328	**H**
11	10 -13	2000	1150	**H**
12	11 -14	5170	4100	**H**
13	12 -11	5750	9371	**L**
14	7 -13	18650	16137	**H**
15	5 - 8	184500	194074	**L**
16	6 - 48	281600	286914	**M**
17	7 - 49	73730	66896	**H**
18	13 - 14	9750	6388	**H**
19	14 - 15	5500	3836	**H**
20	12 - 16	61150	57529	**H**
21	9 - 18	23700	23740	**M**
22	9 -19	220300	216806	**M**
23	15 - 20	70130	69596	**M**
24	20 - 16	5040	3183	**H**
25	16 - 17	26100	29848	**L**
26	8 - 23	21400	23241	**L**
27	8 -25	119920	115274	**H**
28	8 -26	25080	37458	**L**
29	8 - 18	0	0	**

30	18 - 26	6570	5578	**H**
31	19 -18	8370	7538	**H**
32	19 - 22	200990	200541	**M**
33	19 - 20	4640	2626	**H**
34	20 - 22	13090	9671	**H**
35	16 - 21	73710	62520	**H**
36	20 - 30	43040	45768	**L**
37	21 - 29	21630	17402	**H**
38	21 - 30	38280	31318	**H**
39	31 - 17	25040	21292	**H**
40	22 - 26	22300	16330	**H**
41	22 - 27	23200	26054	**L**
42	22 - 28	166380	165628	**M**
43	24 - 23	4500	2659	**H**
44	25 - 24	17000	14020	**H**
45	25 - 26	3220	2516	**H**
46	27 - 26	9130	4418	**H**
47	28 - 27	10630	3063	**H**
48	28 - 29	23090	20031	**H**
49	29 - 30	16120	17875	**L**
50	30 - 31	39640	32281	**H**
51	26 - 32	0	0	**
52	27 - 32	13100	13099	**M**
53	28 - 33	120960	130834	**L**
54	29 - 34	25200	16158	**H**
55	30 - 35	22500	27558	**L**
56	30 - 37	20300	20174	**M**
57	33 - 34	3000	6275	**L**
58	33 - 36	52300	52299	**M**
59	34 - 35	4000	2553	**H**
60	36 - 34	6870	5004	**H**
61	34 - 38	33410	27172	**H**
62	36 - 37	36030	42268	**L**
63	37 - 38	5320	11558	**L**
64	24 - 39	8000	6861	**H**
65	25 - 47	94400	93439	**M**
66	32 - 41	7400	7031	**H**
67	33 - 41	14200	20802	**L**
68	36 - 41	16100	11727	**H**
69	33 - 42	45060	45059	**M**
70	37 - 42	20300	20174	**M**
71	37 - 43	28910	28910	**M**
72	38 - 44	13630	13630	**M**
73	43 - 44	32070	32070	**M**
74	40 - 39	10310	11462	**L**
75	40 - 45	33710	31965	**H**
76	41 - 46	14600	16459	**L**
77	42 - 46	63360	63233	**M**
78	46 - 43	3560	3560	**M**
79	45 - 39	1990	1978	**M**
80	45 - 46	19420	17688	**H**

81	14 - 16	30120	28156	H
82	47 - 40	57120	56159	M
83	47 - 46	26080	26080	M
84	48 - 9	252600	249146	M
85	48 - 49	11500	20268	L
86	14 - 49	2500	1696	H
87	49 - 15	88230	89360	M
88	30 - 34	14000	13948	M
89	31 - 35	3900	289	H
90	32 - 40	0	367	L
Functional F *		**2110**	**2090**	**M**

* the value of functional F is determined from ratio (1), the gas flows correspond to values in columns 4 and 5 of the table, weights of the GTS sections are calculated by formula (5).
** - the section is on the repair.

The value of the geoecological risk level in Table 2 is determined in the range: "low" (L), "medium" (M) and "high" (H). The estimation of risk levels is conducted on the basis of the change in the gas flow value for each section. In case of significant increase of gas flow, as a result of optimization taking account of the ecological component, relative to the analogous value, calculated without its account, it is assumed, that in this section the level of the geoecological risk is "low". In this case the consequences from environmental impact of operating gas pipeline, as compared with other sections, will be lower. These consequences are estimated in value terms per volume unit of gas transmitted through the GTS section.

Similarly, in case of significant decrease of gas flow of gas (column 4, Table 2) as compared with its value without taking account of the ecological component (column 3, Table 2), the level of the geoecological risk is evaluated as "high". For the remaining sections the level of risks is defined as "medium". In the given calculations the range of the "medium" level of geoecological risks in the section is accepted as 1.5% of the gas flow value, calculated without taking account of the geoecological component.

The obtained results allow us to distinguish sections, where geoecological risks are relatively small. Risk levels for such sections in Table 2 are highlighted with green color. At the same time, the carried out calculations allow to reveal sections with increased (compared with the average value for the whole system) level of environmental impact of trunk gas pipelines emissions (in Table 2 these sections are highlighted with red color).

Thus, for each unfavorable GTS section from the cited list it is expedient to envisage measures allowing to decrease the geoecological risks. Furthermore, the proposed approach allows us to estimate the total geoecological risks both for the entire GTS system and individual subsystems (corridors, gas pipelines belonging to separate companies, etc.). Table 2 contains the obtained weighted average estimation of geoecological risk for the entire gas transportation system, which shows that the environmental impact of the GTS system's emissions thus far are at the average admissible level (functional F).

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