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IMPULSE TEMPERATURE INFLUENCE ON STRESS-CORROSION CRACKING OF BIG-DIAMETER GAS MAINS

INTRODUCTION

The big diameter gas main laid in areas with continental climate is a powerful source of heat in spite of moderate temperatures of operation (about 30^oC) [1]. Such a pipeline affects the adjoining ground creating a zone of heat influence up to 10 meters to all sides from the pipe. The effect is summed up if several pipelines are laid in one corridor. For example, triple pipe Urengoy corridor of 1420 mm gas pipelines at the "Polyana-Moskovo" section has 50 m zone of heat influence what is 5 times more than the former "hot" 1020 mm oil pipeline "Gurjev-Kujbyshev" had.

The ground state along big-diameter pipeline contour and the change of ground characteristics are determined by climate conditions, snow thawing and ground saturation with flood water, by dry and rainy seasons, etc.

Ground humidity depends on environmental factors, but it can also change around the gas mains due to industrial factors.

SOME REAL FACTS

In the zone of heat influence of a pipeline redistribution of humidity - temperature field of the ground takes place due to the influence of heat flow from the pipe towards the periphery and due to the thermomotivity force.

This effect is known and studied, up to the certain degree, for "hot" pipelines [2] where temperatures of operation are much higher. Migration flows in the zone of heat influence of "hot" pipelines lead to ground drying and prevail in the process of moisture redistribution.

More complicated processes take place around underground pipelines. Here exist 3 phenomena that are comparatively equal in their significance:

1. Underground big-diameter pipelines break ground hydraulic conditions and create barrage and drainage effects. As a result filtration movement of ground water either slows and creates water-encroached areas or, vice versa, drainage under the lower generating line of the pipe is created.

2. In the zone of non-isothermal pipelines heat influence migration flows are being developed caused by temperature influence. But the temperature pressure and gradients around the pipeline are not high, that is why the adjoining ground humidity decreases only partially. There is no full moisture migration. At some distance from the pipe an overmoistened ground ring is formed that accumulates moisture. This moisture returns back to the pipeline when gas temperature and temperature pressure decrease.

3. The most complicated processes take place in the ground surrounding the non-isothermal pipeline of big diameter. Practice of gas mains operation shows that due to

different causes temperature of gas while gas injection changes impulsely, that is changes by several degrees in several days or even during the day. As the gas pipeline is a quick-response system (as compared with oil pipeline) then the change of gas temperature is transmitted as if by "a wave-guide" (the term is proposed in [3]) to the initial segment of the pipeline (at 10…20 km distance or more) and causes impulse temperature change in the adjoining ground layer of 5…10 cm thickness.

Thus, alongside with the change of gas temperature, humidity of ground contacting with the pipe also changes. If gas temperature changes impulsely then the ground humidity also changes impulsely but with some time delay due to heat inertia of ground.

ONE OF STRESS-CORROSION CRACKING CAUSES

Let inspect impulse moisture movement as activating factor of stress-corrosion cracing.

As ground humidity changes not only in the course of time but along the pipe perimeter as well then anode and cathode zones are created on the pipe surface and electrochemical, biological and other processes of micro-corrosion elements are being activated that are developing by SCC-type (stress-corrosion cracking).

The analysis of stress-corrosion cracking [4] on the inspected sections of "Polyana-Moskovo" gas main showed that, under other equal conditions, zones of periodical water encroachment (coombs, gullies, gulches, etc.) are subjected to more intensive stress-corrosion. The authors [5] studying stress-corrosion cracking processes at high pH note that in these processes seasonal differences controlling the changes of ground electrolyte parameters play the important role.

For the formation of concentrated medium with high pH cathode potential should be rather high. But the potential range in which such type of SCC occurs is within natural potential of pipe steels corrosion and potential of regulated cathode protection (850mV Cu/SO_4). Seasonal changes cause differences of medium and potential parameters, thus creating the conditions that can cause SCC.

We should also note that seasonal and climate temperature differences begin at ground surface, so they are rather far from the pipe and because of high heat capacity and accumulating capacity of the ground can not always reach the pipe contour. The same may be said about atmospheric precipitation. But nevertheless researchers note the effect of the influence of seasonal humidity differences and of periodical water encroachment at SCC processes [4,5].

It's natural to suppose that differences of gas temperatures that cause differences of ground humidity on the pipe contour, have much greater effect on SCC development including the same very place which is the centre of corrosion cracking. In fact the process of corrosion cracking at the initial segments develops under the direct impulse temperature influence of a gas pipeline.

It correlates with the fact that no SCC is found at oil pipelines. Really, an oil pipeline, unlike a gas pipeline, has greater heat-hydraulic inertia which is enough for dampening not only vibration pressure changes but also impulse ones and for smoothing temperature differences as the liquid flows through the initial part of the pipeline. There is no impellent for corrosion fractures development because the pipe wall temperature is stable and the humidity of adjoining ground doesn't change.

Fracture researches show [3] that fracture development has 3 stages. At the 1st stage an intergranular fracture is formed under the influence of corrosive medium. At the 2nd stage the fracture cavity increases in size because of corrosion dissolution of its walls and mechanical tensile stress. The 3rd stage is the stage of final mechanical cracking. The authors attract attention to the possibility of reversible alternation of the 1st and 2nd stages in corrosion cracking development.

As we can see sign-variable migration flows, attendant to the impulse temperature influence of a pipeline at the adjacent ground, activate wavy corrosion processes and, as a result, discrete growth of SCC fractures.

Nowadays, humidity redistribution and breaking of the ground hydraulic condition are not taken into account to the full extent when pipeline stressed state, ground corrosion activity and cathode protection are calculated because the above mentioned processes are not still completely studied.

FULFILLMENT RESEARCH

Ground humidity evaluated by solving the inverse task of heat conductivity.

Taking into account the urgency of the topic under consideration there was performed an operation experiment and made researches of heat exchange at the gas main Urengoy-Novopskov (Polyana-Moskovo section). At the initial part, after the intercepting valve and at a 6 km distance from the compressor station, measuring points N 1 and 2 were mounted. They were equipped with temperature sensors mounted in the ground - resistance thermometers, 25 units in each section. Observations, dispatcher data processing, temperature measuring and temperature fields plotting in the mentioned gas pipe sections began on March 15, 2000 as the system monitoring.

Processing of experimental temperature fields of the initial part of 1420 mm gas pipeline and the use of method of stationary conditions change allowed to solve the inverse task of heat conductivity. The Fourier law of heat conductivity served the basis of this solution

$$q = \lambda \cdot \frac{\Delta t}{\Delta n} \cdot F,$$

where: q – is heat flow; λ – is ground heat conductivity; $\Delta t/\Delta n$ – is temperature gradient; F – is isothermal surface area.

The results obtained establish the fact of heat conductivity and ground humidity impulse change not only along the pipe contour but in the course of time as well (see Table 1). The dependence $\lambda=\lambda(W)$ for argillaceous ground was used for ground humidity evaluation.

During continuous observations impulse humidity change (0…40% and more) in the zone of pipeline outer surface contact with the ground was fixed synchronous to the temperature change of the gas flow.

Change of "ground-pipeline" heat exchange parameters (measuring point N2)

Table 1

Date	T_{gas}, °C	T_{hum}, °C	q, Wt/m°C	T_{ground}, °C			λ_{ground}, Вт/м³·°C			W, %		
				12-hour position	3-hour position	6-hour position	12-hour position	3-hour position	6-hour position	12-hour position	3-hour position	6-hour position
14.03.00												
15.03.00	30	3	142,0	30,5	29,0	30,5	0,579	0,398	0,579	1,7	0,0	1,7
24.03.00	30	0	147,0	31,5	31,0	32,0	0,733	0,827	0,942	4,6	6,6	9,2
29.03.00	30	6	144,0	30,0	30,0	31,0	0,923	1,076	1,076	8,7	13,7	13,7
07.04.00	30	0	146,0	26,6	27,6	28,5	0,780	1,723	1,723	5,6	40,0	40,0
10.04.00	30	2	154,0	25,7	25,7	25,7	0,493	0,411	0,735	0,3	0,0	4,0
11.04.00	30	0	157,0	25,7	25,7	25,7	0,503	0,419	0,749	0,4	0,0	4,9
12.04.00	30	3	160,0	26,0	26,0	25,5	0,552	0,448	0,897	1,2	0,0	8,1
13.04.00	30	3	162,6	26,0	26,0	26,0	0,561	0,456	0,810	1,4	0,0	6,2
14.04.00	30	4	165,4	26,0	26,0	26,0	0,571	0,464	0,824	1,6	0,0	6,5
18.04.00	30	4	168,0	26,6	27,1	29,0	0,477	0,618	0,897	0,0	1,0	5,6
19.04.00	30	14	167,0	25,6	25,7	28,0	0,506	0,657	0,936	0,4	2,2	9,1
20.04.00	30	3	166,0	25,6	25,7	28,0	0,503	0,653	0,930	0,4	2,1	8,9
21.04.00	30	1	165,0	24,8	26,1	27,1	0,561	0,725	1,321	1,4	4,5	24,6
25.04.00	30	10	162,0	28,0	28,0	29,4	0,865	0,982	1,300	5,0	7,5	16,0
27.04.00	30	19	157,0	27,6	28,0	29,0	1,257	1,100	1,467	21,5	14,6	34,8
28.04.00	30	12	155,5	27,6	28,0	29,0	1,245	1,453	1,090	21,0	35,8	14,2
29.04.00	30	4	154,0	26,6	26,6	27,6	1,501	2,301	1,918	38,8	40,0	40,0
15.05.00	28	5	140,0	26,1	26,1	27,1	0,981	1,365	2,242	10,2	27,4	>40,0
22.05.00	29	12	140,5	25,2	25,7	28,0	0,508	0,670	1,658	0,5	2,4	40,0
29.05.00	26	14	119,0	24,8	24,8	26,1	1,404	1,906	1,482	30,2	40,0	36,2
02.06.00	29	20	101,0	26,6	26,6	27,6	0,985	0,781	1,192	10,3	5,6	18,4
06.06.00	29	20	83,0	28,0	28,5	28,5	0,665	0,809	0,809	2,30	6,20	6,20

RESULTS

Fig. 1 presents the diagram of humidity change of the ground contacting with the pipe in "12, 3, 6-hour" positions in the direction of gas flow. The impulse character of the given parameter change is clearly seen. This parameter depends not only on climate but on industrial factors as well. For example, on April 7, 2000 there was a planned shut-down of one of compressor compartments. As a result the gas pipeline temperature at the gas main section "Polyana-Moskovo" decreased. Alongside with this the ground humidity increased sharply up to 40% at the lower generating line. When gas supply to the pipeline was resumed ground humidity decreased up to 0…10%.

Later on, at the beginning of April, because of snow thawing and drain formation in the pipeline area, humidity considerably increased, up to 36,5…40% and then to the full saturation, not only in "6-hour" position but along the pipe contour on the whole.

At the background of ground humidity increase around the pipe owing to the thaw water, we can observe more frequent humidity differences caused by impulse temperature changes due to technical causes. Redistribution of temperature along the pipe contour is a result of the changes of 3 factors at least. These factors are: gas

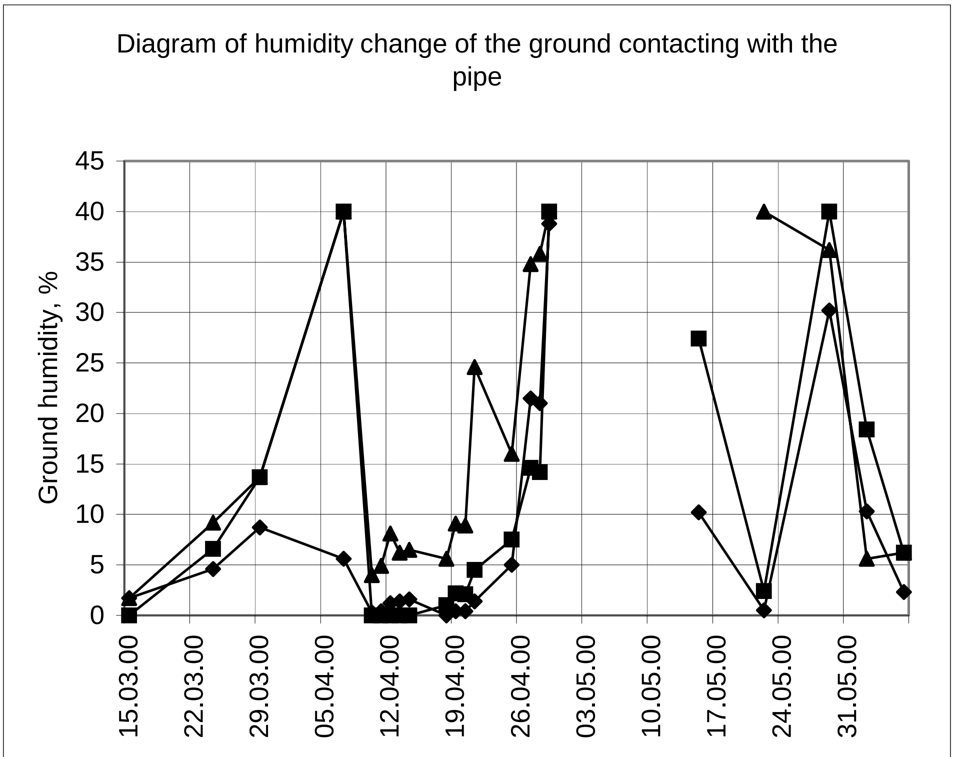
Diagram of humidity change of the ground contacting with the pipe
Ground humidity, %
45
40
35
30
25
20
15
10
5
0
15.03.00
22.03.00
29.03.00
05.04.00
12.04.00
19.04.00
26.04.00
03.05.00
10.05.00
17.05.00
24.05.00
31.05.00
12-hour position
3-hour position
6-hour position

Fig. 1

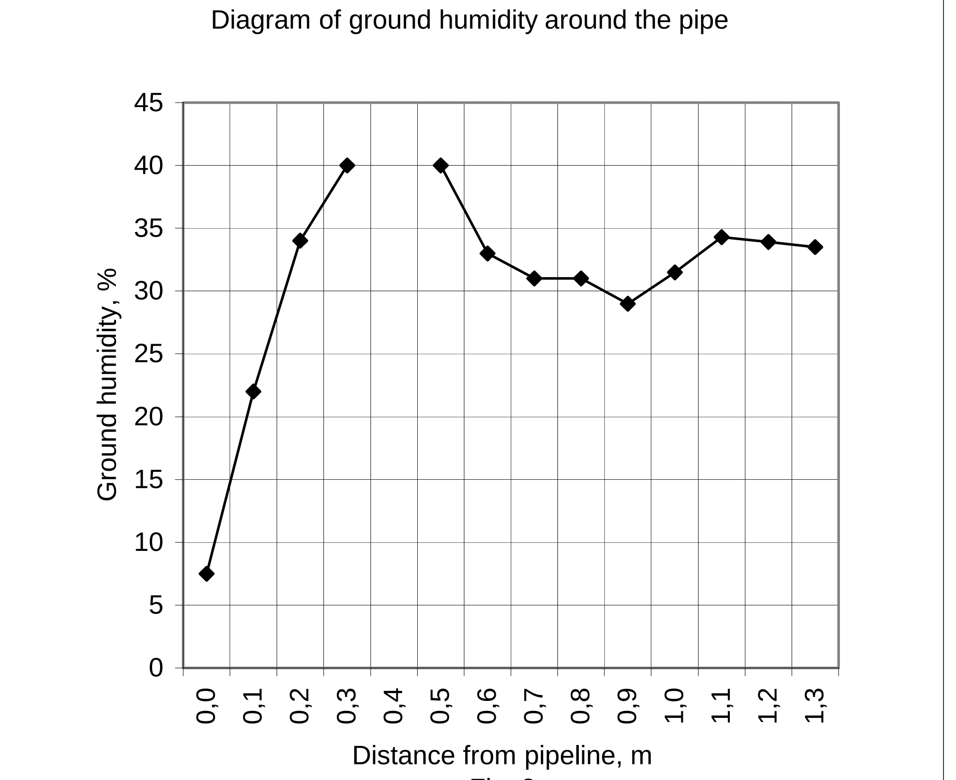
Diagram of ground humidity around the pipe
Ground humidity, %
45
40
35
30
25
20
15
10
5
0
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
1,1
1,2
1,3
Distance from pipeline, m

Fig. 2

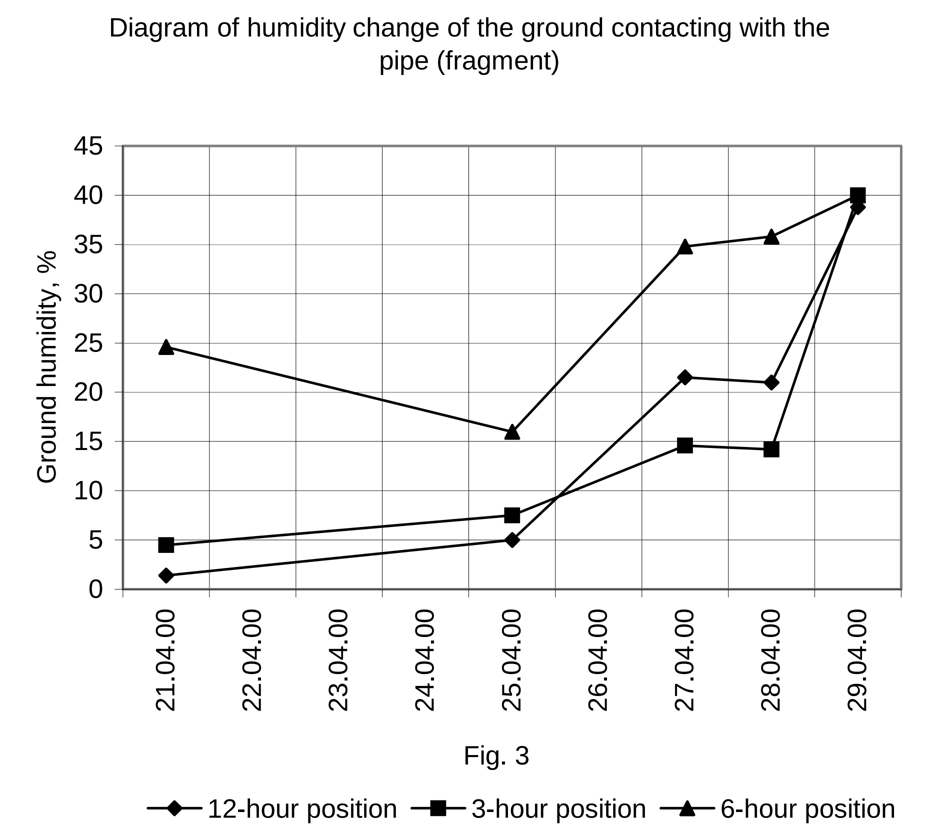
Diagram of humidity change of the ground contacting with the pipe (fragment)
Ground humidity, %
45
40
35
30
25
20
15
10
5
0
21.04.00
22.04.00
23.04.00
24.04.00
25.04.00
26.04.00
27.04.00
28.04.00
29.04.00
12-hour position
3-hour position
6-hour position

Fig. 3

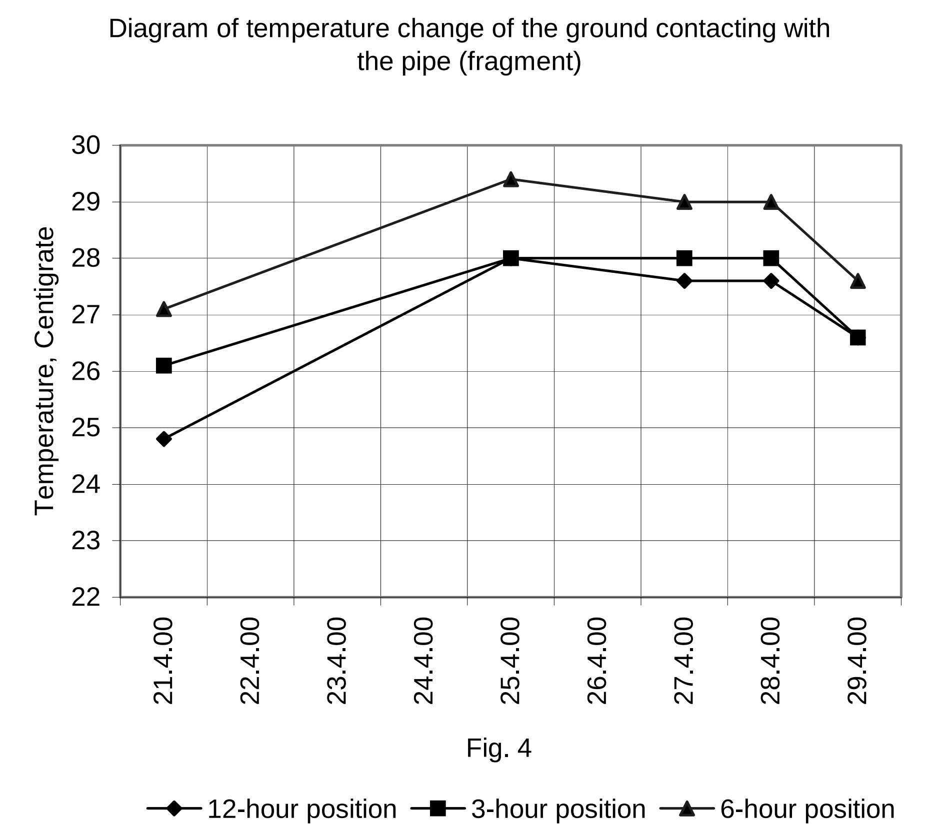
Diagram of temperature change of the ground contacting with the pipe (fragment)
Temperature, Centigrate
30
29
28
27
26
25
24
23
22
21.4.00
22.4.00
23.4.00
24.4.00
25.4.00
26.4.00
27.4.00
28.4.00
29.4.00
12-hour position
3-hour position
6-hour position

Fig. 4

temperature, air temperature and conditions of heat exchange on the ground surface (wind speed, precipitation, solar radiation, icing of coombs and gullies in autumn etc.).

It's interesting to study the temperature and humidity inter-influence (see fig. 3). The diagram shows humidity change along the pipe contour within one-week period of pipeline operation. Comparing these diagrams with temperature curves (fig. 4) we can see that they correlate with each other very well. During the first 4 days ground humidity around the pipe decreases alongside with temperature increase. On the contrary, during the next 2 days temperature decrease induces moisture inflow to the pipe (etc.).

It's necessary to note that such phenomena also occur in the ground when cross pipe between separate pipelines are opened or shutdown. The explanation of this is as follows: when the pipeline efficiency changes then heat loss into the environment increases or decreases proportionally what, in its turn, influences impulsely the contacting ground and its humidity.

As it is big-diameter gas pipelines that are exposed to failure caused by SCC then it is logical to compare these two facts (impulse changes of temperature and humidity in the zone of its maximum accumulation (in "5…7-hour" positions) and corrosion cracking also in the same positions) and then to find out connection between them.

Impulse temperature change of a pipe wall causes synchronous change of adjoining ground temperature and humidity. That is why it may be regarded as the impellent that activates electrochemical corrosion and bio-corrosion. This phenomena reveals itself in discrete stress-cracking of metal and in pipeline outer surface failure in the direction of maximum development of stress.

Such an explanation doesn't contradict the bio-corrosion model but is more like in conformity with it [6]. A corrosion fracture is a wide-open conical cavity which very often has some branch fractures and is filled with products of corrosion including organogen carbonate deposits. As a result of influence of pipe wall temperature differences, inner stresses, ground humidity and discrete fracture growth an access of nutrient medium and of new microorganisms to the fracture cavity periodically opens there.

It also explains the fact that at linear sections there's usually no SCC. At jammed linear sections a fracture plugs itself and doesn't grow any more (bacteria immure themselves). At pipe branches a fracture opens again and again under the influence of high stresses and shifts and new contacting surfaces are exposed on a microlevel.

CONCLUSION

On the basis of the researches made it is possible to conclude that impulse change of a pipe wall temperature by 1…3 degrees or more induces almost synchronous change of the humidity of the ground contacting with the gas pipeline and activates corrosion processes.

The analysis shows that heat exchange parameters are not stable at the initial part of the gas pipeline even if the temperature of injected gas is stable $t_g=30^oC=const$. According to Table 1 temperature differences at the measuring point N2 reached 6…7^{o}C for the mentioned period.

That is why the authors propose to stabilize heat exchange parameters not at the beginning of a pipeline but at critical segments. According to regulations [7] summer and winter temperatures at the beginning of a gas pipeline should differ by 1…2^{o}C.

Stabilization of ground hydraulic conditions in the active zone of gas main heat influence decreases the risk of SCC development and increases ecological safety of a gas pipeline as an industrial object.

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