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by Alexander Vorozhtsov, V. Arkhipov, and I. Plekhanov

Abstract

The new design AZK-T of the automatic independent device for emergency shut-down of gas pipelines is considered. By results of numerical modeling the basic geometrical and regime parameters of AZK-T have been chosen. The pre-production models of the automatic device have been investigated on compressed air and actual tests for GP were conducted.

Keywords: *Gas pipeline, emergency shut-down valve, one-dimensional non-stationary gas flow, numerical solution, experimental study.*

A very effective way of assaulting the society is by demolishing the energy distribution networks. Gas pipelines (GP) are example of such networks and it is critical infrastructures. It is necessary to have the emergency preparedness to ensure adequate response to accidents caused by terrorist attack or by malicious actions.

The paper is aiming to present special device using at protecting the infrastructure related to power supply. Pipelines can loss of integrity at explosive processes caused by widening of fracturing, or entire pipeline damage. Outflow of great gas volume can be a danger of large-scale accidents owing to explosion of flammable air-gas mixture. This problem for a main GP is especially pressing question. The natural gas extracted on deposits, is transported on GP in diameter about 1.4 m at pressure up to 7.5 *MPa*. If pipeline is not equipped by reliable automatic devices and telemechanics that rupture of main GP results to outflow on a distance between compressor stations ≈ 130 km about 0.006 km^3 of gas.

In the present report the new design AZK-T of the automatic independent device for emergency shut-down of GP is considered. For designing the automatic valve AZK-T it is necessary to know character of pressure change in GP at occurrence of an emergency situation. We consider a model of one-dimensional non-stationary flow of ideal gas in a horizontal pipe with the account of friction and heat exchange with an environment. The initial system of the differential equations is given in form:

$$\frac{\partial}{\partial t}+\frac{\partial(\rho u)}{\partial x}=0,$$
$$\frac{\partial(\rho u)}{\partial t}+\frac{\partial}{\partial x}\left(p+\rho u^2\right)=-\frac{\psi}{2D}\rho u^2,$$
$$\frac{\partial}{\partial t}\left[\rho\left(e+\frac{u^2}{2}\right)\right]+\frac{\partial}{\partial x}\left[\rho u\left(e+\frac{p}{\rho}+\frac{u^2}{2}\right)\right]=\frac{4\alpha}{D}(T_0-T),$$
$$p=\rho RT,$$

where *p, T, u* are density, temperature and velocity of gas; *y* is coefficient of resistance; *D* is a pipeline diameter; *e* is specific internal energy; *a* is heat-transfer coefficient; T_0 is the initial gas temperature (equal to an ambient temperature). *R* is a gas constant.

For the solution of the equations system the following boundary conditions were used. At *x=0* the boundary condition of a solid wall were put; At *x=L* (the place of break) the pressure equal atmospheric. Values of temperature and velocity communicate under characteristics. For the numerical solution of the equations Godunov's method was used. Calculations of gas flow at sudden destruction of GP were carried out at the following values of initial parameters.

Length of GP is 20 *km, D*=1.02 *m, ψ* = 0.01, *α* = 1.72 *W/(m*^{2} *× K), T*= 298 *K, R* =520 *J/(kg × K),* c_p= 2303 *J/(kg × K).*

In Figure 1 dependences of pressure of gas on the ends of the pipeline from time are resulted at initial pressure p_0= 3,5 *MPa.* As is obvious from figure while the rarefaction wave arising in the initial moment of time in a zone of destruction *(x = L)* and extending with a sound speed, fall short the closed end of a pipe, pressure of gas at *x* = 0 remains constant and equal to initial value.

The numerical calculation and experimental data testify that pressure change in GP at its break has exponential dependence

$$p(t)=p_0\cdot exp(-bt) \quad (*)$$

where *b* is coefficient, which depends on rate pressure release (dp/dt).

AZK-T consists (Figure 2) of the cylindrical case in which the piston with calibrated nozzles is placed. With the piston the rod is rigidly connected with a sharp head. Before a head the membrane from annealed copper is tightly established. In case of the AZK-T four chambers are formed.

- Chamber I (ballast capacity) is connected with receiver *A* containing gas under pressure $p_I \approx p_0$;
- Chamber II is connected directly with a gas pipeline;
- Chamber III is connected with a receiver *B* – an emergency gas stock (EGS);
- Chamber IV connected with hydraulic stop valve.

AZK-T operation in a regular mode . In a regular mode pressure in a gas pipeline $p_0 \approx const$ or slowly varies $\left({dp}/{dt} << 0.1\, {MPa}/{min}\right)$. Pressure in receiver *A* gets out equal to average pressure in a gas pipeline $p_A \approx p_0$. At slow pressure change in a gas pipeline p_0 the flow rate of gas through calibrated nozzles in the piston equalizes pressure p_0 and p_A. The piston thus is motionless, as gas has time to flow through nozzles.

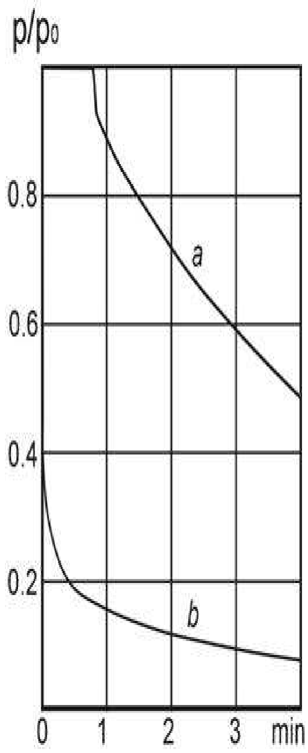

Figure 1: Dependence *p(t)* on closed (a) and open (b) the ends of a gas pipeline at emergency break

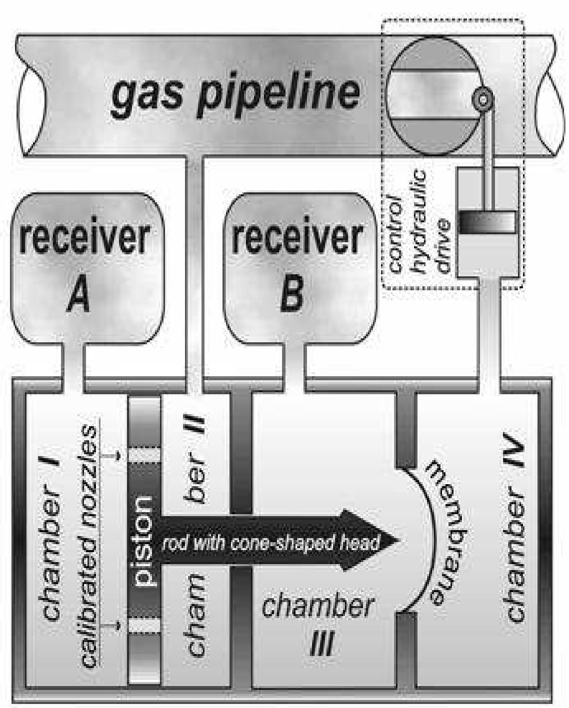

Figure 2: Scheme of AZK-T

AZK-T operation in emergency operation . Let during some moment of time pressure in a gas pipeline sharply falls during failure with a gradient $dp_0/dt > \left(dp_0/dt\right)_{krit} \cong 0.1\,MPa/min$ —the given level is specified from calculations. Thus in the chamber II connected to a gas pipeline, pressure also falls and becomes less $p_{II} < p_0$. In chamber I pressure remains practically constant (nozzles have not time to pass gas from volume I in II). There is a pressure difference $\Delta p = p_I - p_{II}$ due to which the piston moves to the right together with the rod fixed on it and a sharp tip pierces a membrane. After that chambers III and IV are connected through the destroyed membrane. Gas from receiver *B* – (an emergency gas stock) flows from the chamber III to the chamber IV and moves on a drive hydraulic stop valve which, in turn, blocks a gas pipeline turn of a sphere with a through aperture.

The equivalent scheme of AZK-T includes three elements: ballast capacity with the free volume *V*, nozzle with the area of cross-section *F*, and GP, pressure in which *p(t)* at emergency changes under the known law (*).

Let's find change of pressure in ballast capacity $p_k(t)$ which will correspond to change of pressure in the first controlling chamber I.

The mass conservation equation in ballast capacity is $dM(t) = -G(t)dt$, where *M(t)* is mass of gas in ballast capacity, *G(t)* is the mass flow rate.

In the assumption of adiabatic process the equations system for calculation $p_k(t)$, $T_k(t)$ looks like

$$\frac{dp_k}{dt} + \frac{1}{V} \varphi F k \sqrt{\frac{2kRT_0}{k-1}} p_0^{(1-k)/2k} p(t)_k^{(3k-1)/2k} \sqrt{\left(\frac{p(t)}{p_k(t)}\right)^{2/k} - \left(\frac{p(t)}{p_k(t)}\right)^{(k+1)/k}} = 0,$$

$$T_k = T_0 \left(\frac{p_k}{p_0}\right)^{(k-1)/k}, \qquad (**)$$

where k is specific heat ratio, j is discharge coefficient.

This system (**) was solved numerically at initial conditions: $t=0$: $p=p_k=p_0$, $T_k=T_0$.

Results of numerical modeling were used for the basic geometrical and regime parameters of AZK-T choosing. The pre-production model of the automatic device has been investigated on compressed air and actual tests for GP were conducted. Taking into account simplicity in operation, absence of adjustable elements and performance reliability the given design AZK-T can be recommended for the gas pipeline of different types.

About the Author

Alexander Vorozhtsov is Professor and Head of Laboratory at Tomsk State University, and Deputy Director of the Institute of Problems of Chemical and Energetic Technologies.