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OIL AND GAS EQUIPMENT

FIRE-RESISTANCE TESTS OF FITTINGS AND EQUIPMENT FOR OIL AND GAS AND TRANSPORT SYSTEMS

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Beginning in the mid-1990s, and running concurrently with work on the basic subject, testing of oil and gas fittings and gas-cylinder equipment for vehicular transport facilities has been conducted at the test center for rocket and space equipment administered by the NIIKhIMMASh. Various type sizes of cocks and valves, including fittings with a nominal-bore diameter D_n = 700 mm have been tested, and climatic tests on fittings have been performed in the temperature range from –60 to +50°C. Certification tests of vehicular liquefied-propane cylinders manufactured by different, including foreign plants, have also been conducted.

Demand for more complex tests, associated with determination of the fire resistance of fittings with a large flow-through section and equipment for oil-and-gas and transport systems, has arisen at the present time.

Modern world practice involving the production and operation of stop valves in oil and gas lines requires their mandatory testing for fire resistance under a flame temperature of the order of 800–1000°C. These requirements are set forth in API standard 6 FA.

Similar domestic regulatory documents are currently being developed and made effective, for example, OST 001-2003, “Pipeline fittings. General requirements for fire-resistance tests*,” developed by the company NPF TsKBA and the NPAA.

Fire-resistance tests of fittings are conducted to obtain data on their serviceability and characteristics when fires ignite in oil and gas lines, since reliable operation of fittings under these conditions will depend heavily on their fire and ecological safety.

In 2002, NIIKhIMMASh introduced a test-bed assembly for fire-resistance testing of gas and oil fittings with a large flow section.

Basic characteristics of the assembly are as follows: fuel – liquefied propane; oxidizer – compressed atmospheric air; temperature of 600–1200°C in the effective zone; and a maximum nominal-bore diameter of up to 700 mm for the fitting.

The selection of liquefied propane as a fuel is dictated by the high pressure of its saturated vapors (by its high vaporability), and the feasibility of effective combustion when the gaseous phase of the propane burns in air at low temperatures. Organization of the working process calls for heating of the propane to 50–80°C in a special high-strength vessel ($V \approx 150$ liters, p_des = 25–30 MPa) to increase the output of its gaseous phase per unit time, and improve conditions for ignition and combustion at negative temperatures (in testing during the winter), a high delivery pressure for the gaseous phase of the propane and air (0.2–0.3 MPa and higher) in the gas-burning device (GBD), and regulation of the propane and air flows and their preliminary mixing at the inlet to the GBD.

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* The standard is expanded to include manually driven fittings intended for operation in systems at nuclear power plants and in nuclear reactors, and in high fire-risk plants employed in the chemical and petrochemical industries.

NIIKhIMMASh FGUP. Translated from Khimicheskoe i Neftegazovoe Mashinostroenie, No. 8, pp. 12–15, August, 2004.

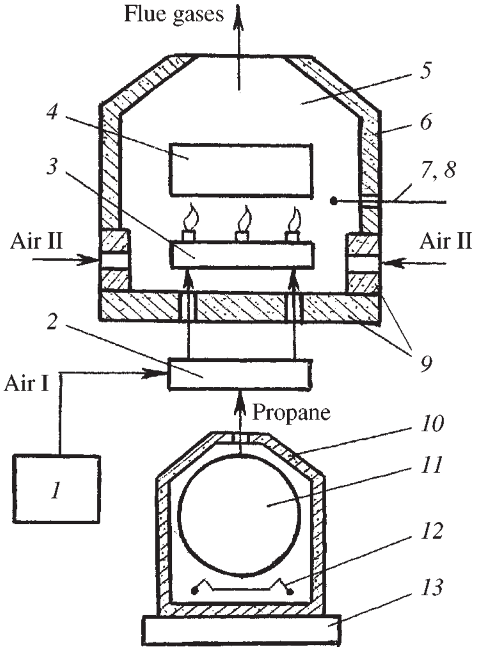

Fig. 1. Schematic diagram of low-heat-value assembly for testing fire resistance of fittings.

Several alternate schemes for the propane feed have been developed and implemented. In assemblies with a low heat value ($\leq 2 \cdot 10^6$ kJ/h) and an evaporative feed system, the gaseous phase of propane is tapped from a service tank, and the flow rates of the gaseous propane and primary air are controlled by pressure regulators.

In assemblies having a high heat value and a displacement feed system, heated liquid propane is forced from a service tank by its own vapors (self-displacement system), or by an inert gas. Subsequent gasification of the propane prior to its delivery to the GBD is conducted in a receiver-evaporator, and the flow rate is regulated by a liquid throttling valve.

Figure 1 shows a schematic of a low-heat-value fire assembly. A propane-feed system, air-feed system *1*, control unit *2*, gas-burning device *3*, measurement system, and fire chamber (combustion chamber) *5* are component parts of the assembly.

The *propane-feed system* consists of high-strength portable cylinder *11*, mounted on balances *13* and equipped with electric-heating system *12* and thermal-insulating housing *10*, pipelines for the delivery of the gaseous phase of propane from the cylinder to the GBD via the control unit, and elements for the control, regulation, and monitoring of propane parameters.

The *system for the compressed-(primary) air feed* includes a battery of high-pressure cylinders, a pneumatic shield, pipelines for the delivery of air to the GBD via the control unit, and elements for the control, regulation, and monitoring of parameters of the primary air.

The *control unit* consists of basic elements for the control (fans, electric valves), monitoring (manometers), and regulation of the delivery pressure (pressure regulators) for the propane and air. The unit is fitted with a desk and instrumentation for visual monitoring of the test time and flame temperature. The required duration of the fire-resistance tests (the time during which the flame acts on the object being tested) is ensured by a timing diagram of the operation (opening-closing) of the electric valve controlling the propane feed to the GBD of the assembly.

The *gas-burning device* is a modular construction, and has a mixer for the gaseous phase of the propane and compressed air, which is connected to a collector that delivers the propane-air mixture to fire nozzles with a large number of openings for discharge of the mixture. The flame nozzles are interchangeable; this makes it possible to alter the format of the GBD, depending on the dimensions of object *4* being tested (see Fig. 1).

Fig. 2. Fire-resistance testing of ball cock (D_n = 400 mm, and p_{eff} = 8 MPa) produced by Tyazhpromarmatura (heat-insulating housing is removed).

The multiple-torch design of the GBD and the preliminary mixing of the gasified fuel with compressed air ensures effective combustion and high uniformity of the temperature field; this is of particular importance for the testing of fittings with large nominal-bore diameters. Structural components are introduced to the GBD to improve mixing of the gasified propane and air and eliminate suppression of combustion and overshooting of flames into the mixer. The required flame temperature is provided by appropriate flow rates (delivery pressure) of the propane and air, and by the distance from the GBD to the object being tested.

The *system for flame-temperature measurement* consists of open-type thermocouples *7* (see Fig. 1), which are established at a distance of approximately 20 mm from the surface of the object under test. Calorimeters *8* – cubes with a side of 40 mm, which are fitted out with a rubber socket for attachment of a thermocouple and provide for reliable contact of its junction with the metal at the center of the cube – are located at these same points. The thermocouples are fabricated from KTMS-KhA thermocouple cable 4 mm in diameter, which is embedded in a protective steel 12Kh18N10T tube with an inside diameter of 6 mm (the thermocouple junction protrudes 20–25 mm from the protective tube). Thermocouple readings are recorded in real time. Express data are output to a monitor.

The *combustion chamber* (fire chamber) has a rectangular section. Its lower part *9* is built of several tiers of monolithic reinforced-concrete blocks, while its upper part (reheat chamber) *6* is a heat-insulating housing for the object being tested, and is fabricated from panels of a fire-resistant insulation – basaltine. A window for delivery of air from the atmosphere to the reheat zone is called for in the combustion chamber. Two modifications of the combustion chamber are fabricated: stationary and portable versions mounted on a rail platform, which is moved onto the test-bed fire platform prior to testing.

The modular design of the assembly enhances mobility, and makes it possible to easily alter its “architecture,” depending on the dimensions and form of the object being tested.

The following oil and gas fittings manufactured by the company Tyazhpromarmatura (Aleksin) were tested for fire resistance on the test-bed assembly in accordance with API standard 6 FA: a ball cock with D_n = 400 mm, and p_{eff} = 8 MPa (Fig. 2); a double-disk gate valve with D_n = 350 mm, and p_{eff} = 8 MPa; and a ball cock with, D_n = 100 mm and p_{eff} = 16 MPa.

The testing formula was as follows: (800–1000°C) × 30 min.

Tests of the first two articles were conducted without incident; after the tests, the fittings functioned normally and provided for effective *open-close* displacements, while airtightness corresponded to norms established by API standard 6 FA; no burn-throughs, cracks, or mechanical failures of the fittings were revealed.

Testing of the ball cock with D_n = 100 mm was curtailed after 10 min due to failure of a sealing element in a stuffing-box subassembly and loss of the cock’s airtightness.

Fig. 3. Fire-resistance test of vehicular cylinder produced by the KMZ (ambient temperature of –15°C).

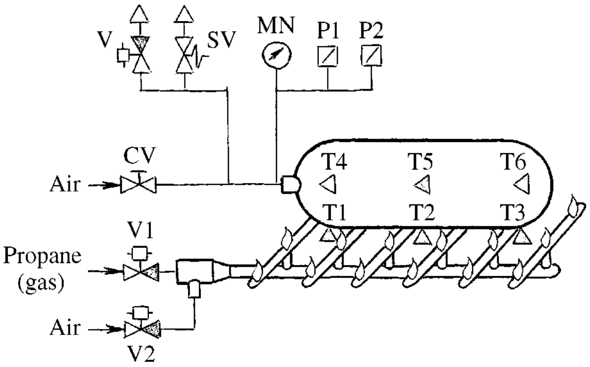

Fig. 4. Schematic diagram of fire-resistance tests for vehicular cylinder.

Different test results for fittings with appreciably different (by more than an order) weights and internal-cavity volumes, which were filled with water during the tests, are explained by the different thermal states and operating conditions that this dictates for the sealing materials during testing. The test procedure for the fittings and regulatory documents (especially the duration of the fire-resistance tests) should therefore take into account the scale factor of the fitting. Let us also point out that the problem of the feasibility of fire-resistance tests for electrically driven fittings has yet to be resolved.

In contrast to oil and gas fittings, fire-resistance tests of high-pressure vehicular cylinders for compressed natural gas (hereafter cylinders) are mandatory. These tests are performed in conformity with GOST R 51753-2001 (effective since January 1, 2002) in formulating a new design for the production of cylinders. This standard became effective on January 1, 2004 for cylinders produced prior to January 1, 2002.

Metal-plastic cylinders (p_{eff} = 20 MPa) manufactured by the Kotlasskii Élektromekhanicheskii Zavod (KMZ) were tested for fire resistance in conformity with GOST R 51753-2001 on the test-bed assembly developed by the NIIKhIMMASh. We tested a cylinder with a volume of 60 liters (Fig. 3) filled with air to a pressure of $0.25p_{\text{eff}}$ = 5 MPa in an assemblage with a safeguard device (SGD) constructed in conformity with PB 03-576-03 at an operating pressure $p_{\text{op}} = 1.1p_{\text{eff}}$ = 22 MPa.

Figure 4 shows a schematic diagram of the system employed to test cylinders for fire resistance. The pneumatic fastening system for the cylinder being tested consists of control valve CV, safety valve SV, and manometer MN for measure-

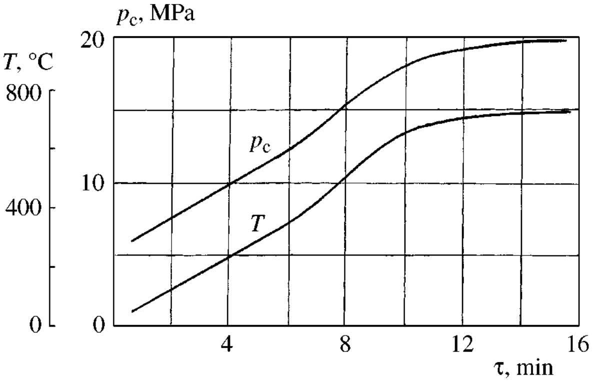

Fig. 5. Dependence of pressure p_c and gas temperature T in cylinder on flame-exposure time.

ment and control of the pressure in the cylinder when preparing for testing. Two MD-250 pressure transducers P1 and P2 were installed to measure and regulate the pressure in the cylinder, and valve V for release of pressure to the atmosphere.

The flame temperature was measured by open-type Kh–A thermocouples deployed in the immediate vicinity (at a distance of approximately 10 mm) from the surface of the cylinder and at a distance of about 400 mm from one another in two tiers: three thermocouples T1, T2, and T3 in a vertical diametric plane beneath the cylinder, and three thermocouples T4, T5, and T6 in a horizontal diametric plane. The gas temperature in the cylinder – an integral parameter of the thermal effect of the flames – was determined simultaneously from readings of the pressure transducers.

The flame temperature averaged from readings of the six thermocouples exceeded 600°C 30 sec after the start of fire-resistance testing of the cylinder. The flame temperature was maintained within the range from 600 to 1000°C during the entire test.

After 5 min (300 sec), the gas temperature in the cylinder, which was calculated from readings of pressure transducers P1 and P2, was approximately 300°C, and the pressure in the cylinder was about 11.5 MPa (Fig. 5). After 10 min (600 sec), the gas temperature in the cylinder reached 600–650°C, and the pressure in the cylinder 18 MPa. In the 16th minute (954 sec) of the test, the cylinder exploded, fracturing into four large fragments. The safety valve had failed to function at the moment of the explosion, since the pressure in the tank was lower than p_{op} = 22 MPa. The cause of the cylinder's explosion was failure of the lining, which was fashioned from the composition material, in connection with flame-induced loss of strength in the metallic liner.

Results of the fire-resistance testing of the cylinders, which was conducted by the NIIKhIMMASh, exposed the need for correction of certain positions taken in Section 7.15 of GOST R 51753-2001:

- the two basic parameters of the tests – the temperature of the flame and the duration of its effect on the object being tested – should be clearly defined, since formulation of the "required test temperature" does not carry specific information on test conditions;
- formulation of the "test duration prior to SGD operation" is not well defined, and requires more precise definition, since the time "to SGD operation," i.e., the actual time of the flame effect, for these cylinders will differ for different initial pressures in the cylinders (p_{eff} and $0.25p_{eff}$); the condition of the cylinders will differ, therefore, from the standpoint of loading, temperature, and strength;
- the position concerning the fact that "the cylinder should release gas through the SGD" is incorrect; firstly, the cylinder cannot "release gas" through the SGD; it may "release" it up to the operating pressure, and not below; and, secondly, the duration of the gas "release" (at the operating pressure of the SGD) is lengthened indefinitely;
- measurement of the cylinder's surface temperature is associated with significant procedural and technical difficulties and errors: to provide a reliable contact between the thermocouples and the surface of the cylinder, it is required to caulk the thermocouple junctions into the wall of the cylinder, i.e., break the integrity of the lining, or create significant mechani-

cal deformations in the metal; this is unacceptable. During fire-resistance tests, monitoring of the thermal state of the object under test and the temperature of the source of the fire is usually accomplished by measuring the flame temperature near the surface of the article (from API standard 6 FA). This requirement should therefore be incorporated – the temperature must be measured at a distance of 10–20 mm from the surface of the cylinder; and

- an element – valve for releasing pressure to the atmosphere – is mandatory in conducting fire-resistance tests in the cylinder's pneumatic fastening system, and pressure transducers are also required as a means of measuring the pressure, and as a means of determining the gas temperature in the cylinder.