


ESTIMATING THE CARRYING CAPACITY OF SPHERICAL VESSELS
FROM DYNAMIC LOADING DATA

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Methods and results are presented of experimental investigations on explosive loading of four-layer metallic spherical vessels. Tested showed the operational reliability of pressure vessels of this type under dynamic loads in a range of pressures up to 200 MPa.

Experience with low-cycle hydraulic testing of monolithic steel spheres with an internal diameter of 270 mm and a wall thickness up to 16 mm, which were cooled to 210 K showed that they broke up explosively into 8–12 fragments [1]. At a test temperature of 293 K, analogous spherical high-pressure vessels broke up into three fragments. Replacing the monolithic (single-layer) high-pressure vessel design by a multilayer design (in particular with four layers) made it possible to avoid fragment formation during uncooled high-pressure vessel tests, but the problem of reducing the number of fragments remained for reduced-temperature tests at 210 K, even for a multilayer vessel [2].

The whole system of hydraulic tests of monolayer high-pressure vessels [1, 2] of a given design in the range of failure pressure from 70 to 190 MPa has remained a problem in using this type of high-pressure vessel in the case of internal dynamic loads where the working fluid is a gas (air). With this in mind, we used the detonation of an explosive charge inside the vessel, in analogy to [3–5], in dynamic tests of four-layer spherical high-pressure vessels.

Previous hydraulic tests to failure of spherical high-pressure vessels [1, 2], which were made of various brands of steel (12Kh2N4A, 10KhSND, 12KhGNMF, 09G2S, 09G2SF, and 09G2)* re-
Fig. 1. Overall view of the reservoir test model: 1) charging device; 2) drain opening; 3) reinforcing ring; 4) hemispherical multilayer element; 5) neck.

Fig. 2. The pressure (open points) and the impulse (filled points) of the first wave reflected from the inner surface of the high-pressure vessel as a function of the mass of the hexogen charge. The curves are data from [3].

revealed a preference for 12KhGNMF and 09G2 for this purpose. In subsequent dynamic tests, four-layer spherical high-pressure vessels were used, whose design is shown in Fig. 1.

Two vessels (#1 and #2) were made from 09G2 steel and two (#3 and #4) from 12KhGNMF steel. In all cases the hemispheres were hot milled a four-layer stack. Then they were welded along the equator of the high-pressure vessel. The quality of the weld joint was monitored by x-rays. After they were manufactured, vessels #1 and #3 were quenched (1130 K), tempered (740 K) and cooled in water; #2 and #4 were hot-tempered (970 K) and cooled in air.

The four-layered spherical high-pressure vessels were dynamically loaded by detonating explosive charges of various masses of PETN and hexogen [trimethylene trinitramine], which were suspended in the center of the vessel along with an electric detonator. A metallic plug with a 4 mm diameter axial hole for the contact conductors was screwed into the neck of the vessel. The pressure on the inner surface of the vessel after the explosive was detonated was measured by piezoelectric pressure transducers. After the explosion, the visual information from the recording magnetometer was fed through digital oscillographs or directly from them. The dependence of the pressure on time and applied distance was determined by sequentially increasing the mass of the charge. As the mass of the explosive charge was increased, so did the amplitude and the impulse [momentum per unit area] of the first phase of the shock wave reflected from the inner surface, as shown in Fig. 2.

Failure criteria were taken to be loss of integrity of the parts, the appearance of cracks in the wall, or disintegration of the vessel into parts. The critical failure pressure was determined from the average value of the two nearest charge masses for which the high-pressure vessel did and did not fail. After the detonation of explosive charges which corresponded to maximum pressures with no visual cracks on the outer surface, the vessel leakage was monitored by submersing it in a tank and pumping air into it.

One of the important parameters which give information on the irreversible plastic deformation of the vessel during the explosion is the residual change in the vessel dimensions after the explosion. Table 1 shows data of the growth in the vessel diameters, which were measured in four diametrical directions after each explosion. The points 1-1' and 2-2' correspond to measurements in the equatorial section of the vessel (here the angle between them is 90°), and 3-3' and 4-4' are in the meridional section.
TABLE 1. Character of the Diameter Increase for Internal Impulse Loading of Spherical Vessels

<table>
<thead>
<tr>
<th>Vessel #1</th>
<th>Vessel #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w$, kg</td>
<td>$P_{dyn}$, MPa</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td>0.015</td>
<td>34</td>
</tr>
<tr>
<td>0.040</td>
<td>64</td>
</tr>
<tr>
<td>0.040</td>
<td>64</td>
</tr>
<tr>
<td>0.06</td>
<td>80</td>
</tr>
<tr>
<td>0.08</td>
<td>95</td>
</tr>
<tr>
<td>0.10</td>
<td>106</td>
</tr>
<tr>
<td>0.400</td>
<td>225</td>
</tr>
<tr>
<td>0.000</td>
<td>250</td>
</tr>
</tbody>
</table>

With dynamic loading of the vessel to a pressure $P_{dyn}$ on the inner surface equal to the calculated hydraulic failure pressure $P_f$, only a change in the vessel dimensions was noted, with no change of shape. As the mass of the explosive charge was increased, it was noted that vessel #4 failed and formed fragments when loaded by an explosion with $P_{dyn} = 259$ MPa (the calculated failure pressure is $P_f = 212$ MPa). When vessel #3 was loaded to $P_{dyn} = 228$ MPa, there were failures in the inner layer (average crack length 18 mm) and in the threaded connection of the plug to the neck ($P_f = 175$ MPa). When vessel #1 was loaded to $P_{dyn} = 235$ MPa, the inner layer failed, a crack 40 mm long was formed, and threaded connection of the plug to the neck failed ($P_f = 100$ MPa). When vessel #2 was loaded to $P_{dyn} = 176$ MPa ($P_f = 110$ MPa), a visual microscopic investigation of the vessel surfaces and a leak test showed no signs of failure.

From an analysis of this effort, including the choice of the high-pressure vessel design and construction and the testing to internal explosive failure at a positive temperature [$>0^\circ$C], it follows that:

1. The proposed design and the manufacturing techniques provide a high structural integrity under conditions of dynamic testing. Based on one of the basic standard requirements on a vessel of this type (for use in the push-pull mechanism in the T-800 tractor [2], where the maximum operational working pressure does not exceed 30 MPa), it can be concluded that the proposed high-pressure vessel design has a sixfold margin of safety.

2. The four-layered spherical vessel made from 09G2 and 12KhGNNMF steels has a high resistance to brittle failure under dynamic loading conditions.

LITERATURE CITED


