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TRANSLATION OF

APPARATUS FOR HIGH-PRESSURE RESEARCH

(Issledovatel'skie apparaty vysokogo davleniia)

by

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APPARATUS FOR HIGH PRESSURE RESEARCH

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V. A. Galaktionov

Pressure is one of the most effective means of altering the properties of a substance. With it one can act not only on the atoms comprising the substance but on the distance between the atoms. While great, but attainable, pressures are required to alter the electron shell of the atoms, the distance between the atoms can always be changed by varying the pressure. From the kinetic point of view, a combination of pressure and temperature is the most effective means of attaining structural changes.

Recently, pressures up to 100, 000 atm (100, 000 kg/cm^2) have been employed not only in science laboratories, but in some advanced branches of industry. However, even in laboratory practice pressure is not drawn on as willingly as is temperature, because of the complexity of the compression apparatus required and because of the lack of industrial models. The purpose of the present article is to acquaint the reader with the methods of developing high-pressure apparatus.

Hydrostatic pressure is employed in investigations of compressed substances to exclude unequal pressure effects. Up to pressures of 15, 000 to 20, 000 atm, hydraulic or gas pressure generators and reactors, in which a substance is to be studied or transformed, are used. Appropriate generators, electric leads, seals, and power lines already exist for this pressure range.

Hydraulic pressures up to 1000 atm can be obtained with the NZhR pump, developed and produced by the Special Designs Office of the Institute of Petrochemical Synthesis of the Soviet Academy of Sciences. Standard equipment is not available for pressures greater than 1000 atm. Manual piston pumps may be employed to create hydraulic pressures up to 2000 atm in small chambers. Hydrostatic pressures greater than 2000 atm in large chambers can be produced only with machines having a special system of seals. Hydraulic compressors, continuous piston-type devices with the piston rod sealed with a flexible metal sleeve, are used to create pressures up to 12,000 to 15,000 atm in liquid and 5000 atm in gas. A great variety of such compressors is available, and they all work steadily and reliably. L. F. Vereshchagin, Corresponding Member of the Soviet Academy of Sciences, was awarded the State Prize of the USSR for developing the theory and design of hydraulic compressors, original Soviet pressure generators.

Hydrostatic pressures above 15,000 atm cannot be produced with pressure generators in chambers of arbitrary size; single-pass boosters are used for this purpose.

The famous American scientist, P. W. Bridgman, who developed the so-called incompressible seal, has experimented with hydrostatic pressures up to 50,000 to 70,000 atm. Attempts to increase the pressure above that point with simple boosters were unsuccessful, because the piston broke. This raised a fundamental problem: can the pressure be raised numerically higher than the strength of the container material? In the case of the booster, the problem amounted to the following: to create a pressure of 80,000 atm under the piston of the booster (fig. 1a), the piston would have to withstand a compressive force of the same magnitude, which cannot be accomplished with present materials. The best steels have a compressive strength of only 25,000 atm, the strongest hard alloys (e. g., tungsten carbide with 6% cobalt) have compressive strengths of 50,000 to 70,000 atm.

This difficulty, which arose in developing high-pressure apparatus, was overcome because the strength of the material increases with increasing pressure. Employing this principle, Bridgman attained a pressure of 100,000 atm using a device comprised of a booster within a booster, i.e., a booster with a hydrostatic support.

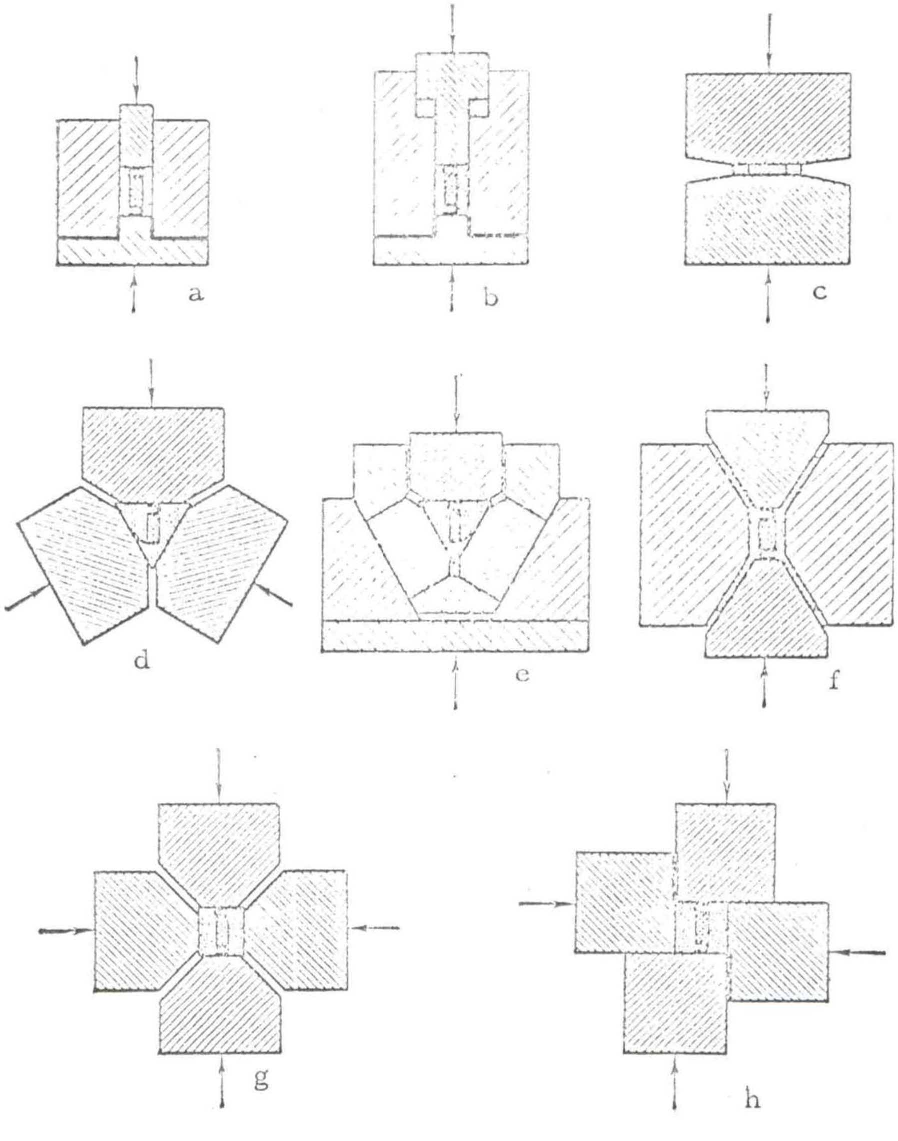

Fig. 1. Various types of high-pressure chambers

The principle of supporting the most highly stressed parts of the apparatus, given a record pressure of 100, 000 atm, was also employed by the Soviet physicists Iu. N. Riabinin, L. F. Vereshchagin, and L. D. Livshits. However, their investigations with such apparatus showed that it was very difficult to realize this principle in practice. The main difficulties arose in developing liquid seals, in transmitting information about the investigated phenomena from the double vessel, and in creating thermal insulation when the sample was heated. New means had to be sought.

Fig. 2. Press with six hydraulic cylinders

Substantial progress was attained by converting from hydrostatic pressure in gaseous or liquid media to quasi-hydrostatic pressure in a plastic solid. Plastic solids were used as the pressure-transmitting medium, for sealing, and for thermal insulation of the working area in all the methods described below.

Following Bridgman, one may attain very high pressures by compressing a substance between two hard pistons with flat ends (fig. 1c). In this and the other systems shown in fig. 1, the pistons are indicated by the close-hatched lines; as they approach each other, the space containing the medium (indicated by the dots) that transmits pressure to the investigated substance (indicated by the cross-hatching) decreases. The stationary parts are indicated by the wide hatching. The solid line indicates electric insulation and the arrows indicate the direction of force.

The main disadvantage of this type of device is that only a very small volume of test material can be employed. T. Hall obviated this by using four pistons (instead of two) at tetrahedral angles. With this arrangement, he was able to increase the amount of test substance considerably. Figure ld shows a three-piston system that elucidates the volumetric four-piston design.

The operation of Hall's four-cylinder press was tested by L. F. Vereshchagin and his associates. They established that the chamber design of this type of high-pressure apparatus was unsatisfactory and that it was very difficult to move the four pistons independently toward the center of the tetrahedron. A slight departure from the given geometry lead to destruction of one of the pistons, and thus, to the appearance of unbalanced moments of force and malfunction of the whole apparatus.

The pistons in the tetrahedral variant of the high-pressure chamber can be synchronized by guiding three of them with a rigid frame (fig. le) that moves along a corresponding runner (E. Lloyd et al., and, independently, V. P. Butuzov and colleagues).

The cube and the cylinder are more suitable forms of working space. Figures lf and lg show planar systems of compressing a plastic substance with a sample placed inside it, in a cubic chamber. A press with six hydraulic cylinders arranged in opposing pairs along three perpendicular axes (fig. 2) are used to compress the substance.

In view of the structural complexity of this type of press, attempts were made to develop simpler high-pressure chambers with one-cylinder presses.

F. R. Boyd and I. L. England, and independent of them Iu. N. Riabinin and L. D. Livshits, improved the boosters with a cylindrical piston, supporting the stressed end of the piston quasi-hydrostatically by means of a plastic gasket (fig. 1b).

In turn, L. F. Vereshchagin and colleagues strengthened the booster piston by using a tapered instead of a cyclindrical piston (fig. 1f). The piston moves into the working space of the chamber as the plastic conical gasket leaks out. T. Hall used a piston of complex shape with a multilayered gasket for this purpose. In these variants, a filler of supporting rings keeps the cyclindrical chamber from breaking.

Returning to the possibilities of the high-pressure method, let us note that Vereshchagin was able to obtain a pressure of 170,000 atm at a temperature of 1500°C using the apparatus design principles examined above. A new, denser modification of SiO_2, stipoverite (stishovite), was obtained using this apparatus. Stipoverite (stishovite) was named after the scientists who discovered and studied it, viz., S. M. Stishov, S. V. Popova, and L. F. Vereshchagin.

New structural forms of substances may be obtained at lower pressures as well. Recently V. V. Evdokimova discovered a new variant of NaCl at 18,000 atm, which, at atmospheric pressure, is either metastable or transforms very slowly into normal structure.

Rearrangement of the structure of substances under pressure is also very important for fields other than investigation of the properties of substances in a condensed state. Geophysical, geochemical, and metallurgical investigations at high pressures and high temperatures are of both scientific and technological interest.