

HIGH SPEED, HIGH TEMPERATURE THREE-WAY VALVE FOR
SWITCHING HIGH PRESSURE FLUIDS UNDER LOW PRESSURE CONTROL

This invention relates to a three way sliding poppet valve for
 5 switching high pressure, high temperature fluids under low pressure
 control and, in particular, this invention relates to a low internal
 volume three way valve for high speed switching of high pressure, high
 temperature fluids without volume change for precision laboratory
 measurements such as is encountered in permeameter tests with corrosive
 10 fluids involving core samples.

In permeameter tests, high temperature (such as 280°F (121°C)) and
 high pressure (such as 10,000 psi (68.9MPa)) corrosive fluids (such as
 brine, oil, and gas) are injected into core samples to measure relative
 or specific permeability of the core sample. A computer operated
 15 permeameter requires a multi-port, three way valve capable of zero
 volume change and having low internal volume as well as a rapid
 response time. One prior art approach used "Valco" (Registered Trade
 Mark) rotary valves such as those manufactured by Valco Instruments
 Inc. PO Box 55602, Houston, Texas 77255. These rotary valves, however,
 20 have small flow paths and a slow response time such as 0.5 - 2.0
 seconds.

Prior to the filing of the present invention, a patentability
 search was conducted resulting in the following US patents:

	<u>Inventor</u>	<u>US Patent No</u>
25	C.M. Carlson	3, 002, 532
	N.C. Hunt	3, 016, 917
	Maurice F Franz	3, 570, 541
	Gerald Sorenson	3, 587, 156
	Gerald Sorenson	3, 762, 443
30	Stoll et al.	3, 794, 075
	Brake et al.	3, 902, 526
	Charles Perkins	4, 027, 700
	Erich Ruchser	4, 067, 357
	Paul Arvin	4, 103, 711
35	Clifford Peters	4, 209, 040
	Clifford Peters	4, 217, 934
	Coppola et al.	4, 567, 914

The two patents to Sorenson pertain to the method of manufacturing a pressurised fluid control valve utilizing a valve spool centrally located in a valve body. The embodiment shown in Figure 17 of Sorenson shows a multi-passage valve utilizing a symmetrically shaped spool wherein the spool has an incline surface that seats against a sharp circular edge formed in the body. The Sorenson spool or valve body is constructed of deformable resilient materials such as polyurethane, neoprene, polyethylene or rubber. Deformability of the valve spool or body of Sorenson is critical since in the manufacturing of the valve, the spool or body must deform in order to be inserted into the body. After the insertion, the deformed part recovers to its original condition. In such an embodiment, the forces of deformation are much greater than the forces experienced by the valve in operation. As such, it is believed that the valve of Sorenson would not be suitable to the high temperature, high pressure environments for which the valve of the present invention is ideally suited. Furthermore, Sorenson requires fluid exhaust ports. The present invention has no exhaust ports since it is applied to the flow of high pressure, high temperature fluids which must be completely contained within the valve. Sorenson relies on multiple annular rings providing simultaneous multiple seals caused by moving the spool. The current invention requires only one sealing surface to contact the spool at a time. Sorenson valves are commonly known as 4-way valves, whereas the present valve is specifically a 3-way valve. Finally, the present valve provides means of applying very large forces to a sealing line formed by the poppet (or spool) contacting the sealing surface in the body, namely the large diameter pistons.

US patent 3, 794, 075 to Stoll sets forth a multi-way valve having a switching time of six milliseconds and exhibiting short physical valve travel. The stoll invention makes use of disc plane seals located on a symmetrical centre spool. The spool is driven by the snap action of opposing diaphragms which are hydraulically activated. The rubber diaphragms comprising the spool end seals and snap action diaphragms make this valve unsuitable for high pressure applications. High internal pressures would collapse these parts causing the valve to fail. The central O-ring seal of the spool is not constrained so that back pressure on the seal would unseat the O-ring

causing leakage. This is not the case in the present invention. Because of flexure of the rubber parts some internal volume change must occur in the Stoll valve after the seals make initial contact. This volume change will compress the fluid in one part of the valve causing a pressure change. This problem does not exist in the present invention. Under high differential pressure the unsupported elastomeric seals used by Stoll may experience extrusion. The problem is accentuated at high temperature. The present valve uses metallic sealing surfaces to eliminate the problem.

US Patent 3, 016, 917 issued to Hunt sets forth a valve for controlling high pressure fluid. The valve plunger of Hunt has an enlarged central body portion terminating in an angled seating surface on an enlargement of the valve which selectively abuts against a corresponding angled seat in the cavity. Hunt utilizes a metal to metal engagement between the valve enlargement and the seat to provide a seal against leakage of fluid pressure. The valve is held in the closed position by means of a solenoid and is returned to the opened condition by means of a spring. In this embodiment the central valve spool is not hydrostatically balanced.

The US Patent 3, 570, 541 to Franz sets forth a three way directional control valve having a formed poppet member located internally to a body wherein the body has internally disposed conically shaped seats for selective engagement with the poppet member to open and close the three way valve. The poppet member and seat incorporate an elastomeric material. The Franz valve is designed to operate at 100 psi (689.5kPa) with an activating piston driven valve control operating at 70 psi (483kPa).

US Patent 4, 567, 914 to Coppola relates to a two-stage hydraulic solenoid valve having a centrally disposed poppet member having incline surfaces that selectively seat with conical seats. The Coppola invention is designed for steam turbine control systems.

The US Patent 4, 067, 357 to Ruchser relates to a sliding/spool direction control valve wherein the spool is of symmetrical construction and is driven by two opposing control pistons. The Ruchser embodiment provides a novel seating arrangement that selectively seals despite loss of tolerances due to wear, manufacturing, or use.

The remaining patents uncovered in the search are not pertinent to the present invention as those discussed above.

In the course of making relative permeability measurements on core samples, high temperature and high pressure corrosive fluids must
5 be quickly switched by means of a fast acting valve that does not change in volume during switching to preserve the accuracy of the permeability measurements. Similar high pressure and high temperature environments exist in other types of measurements and the valve of the present invention finds particular application in use with positive
10 displacement pumps for precision laboratory measurements.

In accordance with the present invention, a fast acting three way valve is provided which is capable of switching in less than fifteen milliseconds, exhibits no change in volume during switching, and which can be operated by an extremely small actuation distance, eg of less
15 than 0.03 inches (0.76mm) and which can be controlled by a low pressure system having a magnitude two orders less than that of high pressure of the fluid.

In more detail the three way valve of the present invention comprises:

20 a valve body constructed of a material capable of withstanding the temperature and pressure of the high temperature, high pressure fluid, and having an inlet port formed therein for the admission of the high pressure fluid and two outlet ports positioned symmetrically on either side of the inlet port for the discharge of the high pressure
25 fluid;

a high pressure fluid flow path in the valve body connecting the inlet port symmetrically to each of the outlet ports and comprising a central cavity formed in the valve body and in fluid communication with the inlet port and with each of the outlet ports said cavity having an
30 elongated symmetrical shape with a central cylindrical section and two opposed cylindrical end sections of lesser radius than the larger central section, the inlet port communicating directly with the centre of the enlarged central section, and the two outlet ports each communicating directly with a different one of the two end sections at
35 points equispaced from the enlarged central section, the transition between the central section and each of the two end sections forming two opposed valve seats;

an elongated symmetrical valve spool likewise constructed of a material resistant to the temperature and pressure of the high temperature, high pressure fluid reciprocally mounted in said cavity and comprising an enlarged central section situated in the enlarged central section of the cavity and two opposed shaft sections extending therefrom, the two shaft sections being situated in, and having an external radius less than the radius of the end sections of the cavity, thereby providing an annular passageway between those shafts and the valve body for the flow of high pressure fluid from the central cavity to the outlet ports, the said enlarged central section of the valve spool having two symmetrical, opposed frusto-conical spool valve surfaces sealingly engageable each with a different one of the two valve seats formed in the central cavity between the enlarged central section and the two end sections as the valve spool is reciprocated within the valve cavity, thereby to switch the high pressure fluid flow from the inlet to each of outlets in turn whilst sealing off the other;

and means for reciprocating the valve spool relative to the valve body to effect the closing of the two valve seats alternately and the consequent switching of the high pressure fluid between the two outlets, said spool reciprocating means comprising:

a pair of opposed pistons mounted on the valve body and operatively connected to the opposite ends of the elongated valve spool, the shaft sections of which project from the valve body to engage said pistons, with gas tight seals being positioned around said shaft sections, between each shaft section and the valve body to prevent leakage of the high pressure fluid around the shaft;

and means for feeding a low pressure control fluid from the low pressure control system to each of the pistons in turn whilst venting the other.

Preferably the operating pistons have a diameter at least ten times greater than the diameter of the sealing surfaces on the enlarged portion of the valve spool.

Preferably the operative travel distance of the spool is less than 0.76 mm (0.03 inches).

Reference will now be made, by way of example, to the accompanying drawings, in which:

Figure 1 is a cross sectional view of the high pressure, high

temperature three way valve of the present invention,

Figures 2 and 3 show the operation of the three way valve of the Figure 1,

Figure 4 shows the details of the central enlarged portion of the
5 spool engaging the valve seats of the valve of Figures 1, 2 and 3,

Figure 5 shows the details of the actual engagement between the spool seat and the valve seat,

Figure 6 shows an alternative embodiment of the valve of the present invention,

10 Figure 7 is an exploded perspective view showing the components of the three way valve,

Figure 8 is a side planar view of the piston end caps of the valve of the present invention,

Figure 9 is a side planar view of the piston,

15 Figure 10 is a side planar view of the packing ring,

Figure 11 is a side planar view of the spool,

Figure 12 is a side planar view of the first half of the valve body,

20 Figure 13 is a side planar view of the other half of the valve body,

Figure 14 is a block diagram showing the valves of the present invention interconnected in a relative permeameter.

Referring to Figure 1, the three way valve comprises a main body 10 and a second body 20 both machined from a nickel alloy ("Hastelloy"
25 - C276 Registered Trade Mark) with a yield strength of approximately 70,000 psi (482 MPa). The primary advantage of this alloy is its extreme corrosion resistance to brines, hydrogen sulfides, and other chemicals found in petroleum reservoirs at temperatures up to 400°F (204°C), although the alloy will operate even at much higher
30 temperatures. The two bodies 10 and 20 are machined to fit together to form combined structure having three formed ports 40, 50 and 60 contained therein. Formed port 40 is a fluid inlet, whereas formed ports 50 and 60 are fluid outlets. As mentioned for permeability tests, the fluids may comprise gas or liquid corrosives at high
35 pressures over 8,000 psig (55MPa) and up to 10,000 psig (68.9 MPa). In addition, the valve functions at temperatures from ambient 70°F (21°C) up to 250-350°F (121-177°C). The only temperature limitation is the

"Viton" (Registered Trade Mark) elastomer material on the piston and shaft seals. Using "Teflon" (Registered Trade Mark) material temperatures of up to 500°F (260°C) could be attained. Pressures may range from less than 1.00 psi (68.9kPa) to 10,000 psi (68.9 MPa).

5 On opposing ends of bodies 10 and 20 are located threaded rings 70 and 70a. Engaging threaded rings 70 and 70a are opposing end caps 80 and 80a. Disposed centrally through combined body 30 (ie. first body 10 and second body 20 and rings 70 and 70a) is a valve spool 90 (See Figure 11) having an enlarged middle portion 140 with first 90a and second 90b opposing longitudinal shafts. Resting against opposing ends 92 and 92a of spool 90 are the piston heads 100 and 100a. The formed ports 110 and 110a are centrally located in opposing end caps 80 and 80a. A fluid, for example, low air pressure of 80 psig (550kPa) is selectively delivered into the formed ports 110. The formed port 110
10 provides fluid communication through the end cap 80 and into a formed cavity 120 located between the inner wall 82 of the end cap 80 and the outer surface 102 of the piston head 100.
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O-rings 104 fit around the piston 100 to provide a fluid seal between chamber 120 and the rest of the apparatus. Likewise, an O-ring
20 seal 22 is provided in body 20 and around shaft 90 between body 20 and threaded ring 70. Likewise, an O-ring seal 12 is provided between body 10 and threaded ring 70a along the shaft 90. The O-rings 12 and 22 form pressure seals and are pre-loaded using an external packing assembly and spacer ring 29. The external packing assembly is
25 comprised of the threaded rings 70 and 70a. These rings are drawn together, as shown in Figure 7, by four "Allen" (Registered Trade Mark) head cap screws 700 and 710 which serve to hold the rings 70 and 70a and body parts 10 and 20 together. When tightened the bolts 700 and 710 also cause the O-rings 12 and 22 to be compressed causing a static
30 seal around shaft 90. The spacer rings 29 and 29a placed inside O-rings 12 and 22 insure a pressurised fluid path across the front face of the O-rings 12 and 22. This provides a dynamically actuated seal with the sealing force being proportional to the applied pressure. In addition, an O-ring seal 14 is provided between bodies 10 and 20.

35 A chamber 130 is provided between the inlet fluid port 40 and the two outlet fluid ports 50 and 60. The fluid O-ring seals 12, 14 and 22 selectively seal chamber 130 from the rest of the apparatus. The end

cap 80 releasably engages the threaded ring 70 and when threaded over ring 70 provides a firm engagement to the end cap 80 to fully define the chamber 120.

In Figures 2 and 3, the operation of the present invention is set forth in illustrated form. The apparatus 200 of the present invention is interconnected with a fluid input source 210, to fluid output receivers 220 and 230, and to air input and vent sources 240 and 250. The fluid input source 210 is conventionally interconnected with port 40, the two fluid receivers 220 and 230 are conventionally interconnected with ports 50 and 60 respectively. The two air input/vents 240 and 250 are interconnected with ports 110 and 110a, respectively. Hence, in operation, when a low pressure gas such as air, at 80 psig (552kPa) is delivered into cavity 120, piston 100 drives in direction of arrow 260 to firmly seat the central section of the spool 90 against the edge 150. Port 84 vents the rear side of piston 100 to atmosphere and permits the piston to travel. This enables the fluid 270 delivered from the fluid input source 210 to be delivered in the direction of arrows 272 downwardly through port 260 and into the second fluid output or receiver 230. Hence, the flow of the high pressure, high temperature fluid is through a formed passageway from the input port 40 to the second output port 60. Likewise, in Figure 3, the spool 90 is delivered in the direction of arrow 300 so that enlarge section 140 firmly seats against edges 160. In this manner, fluid 270 is delivered in the direction of arrows 310 into the fluid output 220. Hence, the flow of the high pressure, high temperature fluid is through a formed passageway from the input port 40 to the second output port 50.

In Figure 4, the enlarged portion 140 of the spool 90 is shown selectively seating against circular edge 150 which comprises the valve seat. In the embodiment shown in Figure 4, the valve seat 150 is a right angle edge engaging the spool seat which is an inclined angle 142 of approximately 30° from axial. When the spool seat 140 engages the valve seat 150, the total resultant force 400 as shown in Figure 4 is principally equal to the force 410 corresponding to the low gas pressure such as 80 psig (550kPa) being delivered in from source 240 and impacting upon the piston 100.

The force 410 is transmitted from the piston 100 as π times the radius (r) squared times the pressure (p). In the preferred embodiment where the radius of the piston is 0.81 inches (2.05cm) and the pressure

is 80psi (550kPa), the force 410 is 165 flb (734N). There are other forces present. Forces 420 act on both sides of port 140 and counteract each other to provide no net effect on combined force 400. Force 430 consists of the fluid pressure (up to 10,000 psi (68.9 MPa)), acting on the annular space 450 between shaft 90 and body 20 with diameters, in the preferred embodiment of 0.125 and 0.150 inches (3.17mm and 3.8mm) respectively. At 10,000 psi (68.9MPa), this contributes a force of 54 flb (240N). At the same time, force 440 opposes closing of the valve by applying the outlet fluid pressure to the same annular area 450. Hence, before closing of the valve forces 430 and 440 balance exactly so the only net force is 410.

An alternate embodiment for the valve 140 is shown by valve 140a in Figure 6 engaging a circular edge 150a wherein the angled side 142a of valve 140a selectively abuts against the inclined edge 150a. In this embodiment, the angle of inclinations of circular edge 150a and surface 142a differ slightly. The angled surface 150a must have an included angle slightly larger than the angle included by surface 142a. A difference of angles of 2° - 5° is sufficient. This arrangement allows a line seal to be maintained at low stresses. As the applied load forcing the surfaces 150a and 142a together increases the material at the sealing line deforms elastically to increase the area of contact thus reducing the stress and decreasing the possibility of permanently deforming the parts.

Figure 7 sets forth, in perspective view, the assembly of the present invention. In Figure 7, the shaft 90 is inserted through formed passageway 24 of body 20 and then through formed passageway 74 of threaded ring 70. Likewise, end 92a of shaft 90 is placed through formed passageway 14 of body 10 and through formed passageway 74a of threaded ring 70a. Once bodies 10 and 20 are placed over the shaft 90 and the threaded rings 70 and 70a are placed over ends 90 and 92a, two bolts 700 are inserted through passageways 702 of threaded ring 70 and 704 of body 20, 706 of body 10 to engage threaded region 708 of threaded ring 70a. Likewise two opposing bolts 710 are inserted through passageways 712 of ring 70a, 713 of body 10 and 716 of body 12 to engage threaded region 718 of ring 70. The opposing bolts 700 and 710 are tightened firmly to hold threaded rings 70 and 70a to the combined body 30. After tightening of the bolts 700, the pistons 100

and 100a are placed over ends 92 and 92a respectively of shaft 90 and the end caps 80 and 80a are screwed onto the threaded rings 70 and 70a, respectively. In this fashion, the three way valve 12 of the present invention is totally assembled.

5 The details of the end caps 80 and 80a are shown in Figure 8. In Figure 8, the end cap 80 is preferably machined from material such as aluminum and after machining is hard-anodised to one mil (0.0254mm) thickness. The vent 84 is drilled through the side 86 of the end cap 80. In the preferred embodiment, the end cap 80 has an outside
10 diameter of 2.00 inches (5cm) as shown by arrow 800. Cavity 120 has an inside diameter of 1.625 inches (4.13 cm) as shown by arrow 810. The port 110 typically has an inside diameter of 5/16ths of an inch (7.93mm). Internal threads 820 are provided as shown.

 In Figure 9, the details of the piston 100 are shown. In the
15 preferred embodiment, the outside diameter of the piston 100 is 1.620 inches (4.11cm) as shown by arrow 900 and the inner diameter of the formed slot 106 is 0.127 inches (3.22mm). The formed opening 106, as shown in Figure 1, extends substantially into the piston 100 and, in the preferred embodiment, the piston is 0.32 inches (8.13 mm) in
20 thickness and formed opening 106 extends inwardly 0.262 inches (6.65mm). A formed slot 104a extends around the outer surface of the piston head to receive the O-ring 104. The piston head 100 in the preferred embodiment is machined from aluminum material.

 The ring 70 is shown in Figure 10 and in the preferred
25 embodiment, has an outer diameter of 1.75 inches (4.45cm) as shown by arrow 1000. The formed passageway 74 has an inner diameter of 0.125 inches (3.17mm). The threaded ring 70 has a boss 76 which engages a corresponding circular cavity 26 in body 20. The diameter of boss 76 is 0.25 inches (6.35mm). The holes 702 and 718 for receiving the bolts
30 700 and 710 are shown in Figure 10.

 In Figure 11, the details of the spool 90 are shown. The spool
90 is preferably made from a corrosion resistant material such as Hastelloy C-276. In another embodiment a much harder material such as Satellite (Registered Trade Mark) 6B can be used. This material
35 possesses slightly less corrosion resistance but is more resistant to wear and deformation after repeated use. The spool in the preferred embodiment is 2.610 inches (6.63cm) long and surface 142 is oriented

from the axial at 30 degrees as shown by arrow 1100.

In Figure 12, details of the body 20 are shown. The body 20 has an outer diameter of 2 inches (5.08cm) as shown by arrow 1200. The body 20 is preferably made from Hastelloy-C-276 material. Holes 704 and 716 are drilled through body 20 to receive bolts 700 and 710. Cavity 26 has an inner diameter of 0.25 inches (6.35mm) and receives the boss 76 from the threaded ring 70 to form a region for the O-ring as shown in Figure 1. Reduced diameter region 28 receives the spool 90 and is integral with the enlarged diameter region 24 which is part of the formed passageway 130 as shown in Figure 1. Region 24 terminates in edge 160 as shown in Figure 1. Two raised cylindrical bosses 21 and 26 are formed on the opposite surface 23 of body 20. As shown in Figure 1, these bosses 21 and 26 co-operate with body 10 to form a cavity for O-ring 14. In the preferred embodiment, annular region 21 has an outer diameter of 0.400 inches (10.16mm) and annular region 22 has an outer diameter of 0.500 inches (1.27cm). Also shown in Figure 12, is the placement of the fluid outlet port 60 which is machined into body 20 in a conventional fashion. Fluid output port 60 has a threaded region 62 integral with a region of taper 63 which is in fluid communication with a passageway 64 to cavity 130 as shown in Figure 1.

In Figure 13 the details of the body 10 of the valve of the present invention are shown. Body 10 also has an outer diameter as shown by arrow 1300 of 2.00 inches (5.08cm) in the preferred embodiment. Holes 706 and 714 are machined through the body for the bolts 700 and 710. The left body 10 is also machined from Hastelloy-C-276 material. The formed fluid inlet port 40 with its threaded region 42, its taper region 43, and its passageway provides fluid communication with cavity 130 as shown in Figure 1. Likewise, the fluid outlet port 50 is machined into body 10 and has a threaded region 52, a region of taper 53 and a fluid passageway 54 for putting it in fluid communication with cavity 130. As shown in Figure 13, the circular cavity 11 in the preferred embodiment has an inner diameter of 0.500 inches (1.27cm). A second and inwardly disposed cavity 13 has, in the preferred embodiment, an inner diameter of 0.219 inches (5.56 mm). Area 15 is of reduced diameter which in the preferred embodiment is 0.150 inches (3.81mm) and forms the remaining part of cavity 130. This region 15 is in fluid communication with passageway 54 and port

50. Finally, on the opposing surface 25 is an annular cavity receptive of O-ring seal 12 and spacer ring 29.

When fully assembled, the piston 100 travels, in the preferred embodiment, only 15 to 20 thousands of an inch (0.381mm - 0.508mm) in order to transfer fluid flow from port 40 to either port 50 or 60. With the pressures involved, the time for switching the high pressure fluid from the inlet port 40 to either one of the outlet ports 50 or 60 is on the order of 15 milliseconds. The present invention, therefore, provides a hydrostatically balanced three way valve which is symmetrically constructed. The air pressure of 80 psig (550kPa) for sources 240 and 250, in the preferred embodiment, provides sufficient pressure to overcome the differential pressure between the fluid inlet port 40 and either one of the outlet ports 50 or 60. Because of the symmetrical arrangement of the valves, upon switching there is no change in the internal volume of the valve and, therefore, the present invention finds significant application in areas such as permeability tests. In prior valves with some volume change during switching, a slight but significant "pumping action" occurs during each valve switch. This causes upsets in the recorded pressure trace and displaces fluid in the valve body. The fluid displacement is cumulative and causes errors in material balance calculations during the displacement. These errors in accounting for the displaced fluid volumes generate significant errors in the final results of the experiment. This does not occur in the valve of the present invention. The valve finds application, in the preferred embodiment, for use in high pressure - high temperature (single phase flow, two phase and three phase) relative permeameter tests. In such cases, the three way valve of the present invention operates at up to 280°F (138°C) and 10,000 psig (68.9MPa) in the presence of corrosive fluids such as brine, oil, gas. Clearly the valve of the present invention finds application in other high temperature and high pressure environments including other precision laboratory measurements.

In Figure 14, a fluid saturated core sample, not shown, is contained in the core holder of standard Hassler type design 1400. Fluid, such as brine, is injected into the core through a pump 1410 in this case consisting of two positive displacement cylinders 1412 and 1414. Flow into and out of the pump cylinders is directed by 3-way

valves 1420, 1422 and 1424 by the present invention which are operated by electric solenoid valves 1430, 1432 and 1450 under computer control. In this way either cylinder 1412 or 1444 may be selected as the inlet or outlet for the pump.

5 Likewise a second fluid, such as oil, can be delivered into the core sample from a second pump 1460 having cylinders 1462 and 1464. Flow from these cylinders are directed by valves 1470 and 1470 under control of solenoids 1480 and 1482.

10 Valve 1450 is used to select between pumps 1410 and 1460 so that the injected fluid may be chosen. This arrangement can be expanded or contracted to allow flow of one, two, three or more fluids in a similar fashion.

15 Flow from the core sample enters a separation vessel 149 where the multiple fluids segregate. Each fluid is then returned to its respective pump through the series of valves 1420, 1422, 1470 and 1472. In this arrangement the fluid can be continuously recirculated through the sample. Flow rate measurements from the pumps and differential pressure 1492 measured across the core provide the data necessary for permeability measurements.

20 While there has been shown and described what is considered two preferred embodiments of the invention, it is understood that various other modifications may be made therein without departing from the scope of the invention herein described.



CLAIMS:

1. A three-way valve for switching a high pressure, high temperature fluid from a source to either of two outlets under the control of a low pressure fluid from a low pressure control system, said valve
5 comprising:

a valve body constructed of a material capable of withstanding the temperature and pressure of the high temperature, high pressure fluid, and having an inlet port formed therein for the admission of the high pressure fluid and two outlet ports positioned symmetrically on
10 either side of the inlet port for the discharge of the high pressure fluid;

a high pressure fluid flow path in the valve body connecting the inlet port symmetrically to each of the outlet ports and comprising a central cavity formed in the valve body and in fluid communication with
15 the inlet port and with each of the outlet ports said cavity having an elongated symmetrical shape with a central cylindrical section and two opposed cylindrical end sections of lesser radius than the larger central section, the inlet port communicating directly with the centre of the enlarged central section, and the two outlet ports each
20 communicating directly with a different one of the two end sections at points equispaced from the enlarged central section, the transition between the central section and each of the two end sections forming two opposed valve seats;

an elongated symmetrical valve spool likewise constructed of a
25 material resistant to the temperature and pressure of the high temperature, high pressure fluid reciprocally mounted in said cavity and comprising an enlarged central section situated in the enlarged central section of the cavity and two opposed shaft sections extending therefrom, the two shaft sections being situated in, and having an
30 external radius less than the radius of the end sections of the cavity, thereby providing an annular passageway between those shafts and the valve body for the flow of high pressure fluid from the central cavity to the outlet ports, the said enlarged central section of the valve spool having two symmetrical, opposed frusto-conical spool valve
35 surfaces sealingly engageable each with a different one of the two valve seats formed in the central cavity between the enlarged central section and the two end sections as the valve spool is reciprocated



within the valve cavity, thereby to switch the high pressure fluid flow from the inlet to each of outlets in turn whilst sealing off the other;

and means for reciprocating the valve spool relative to the valve body to effect the closing of the two valve seats alternately and the consequent switching of the high pressure fluid between the two outlets, said spool reciprocating means comprising:

a pair of opposed pistons mounted on the valve body and operatively connected to the opposite ends of the elongated valve spool, the shaft sections of which project from the valve body to engage said pistons, with gas tight seals being positioned around said shaft sections, between each shaft section and the valve body to prevent leakage of the high pressure fluid around the shaft;

and means for feeding a low pressure control fluid from the low pressure control system to each of the pistons in turn whilst venting the other.

2. A three-way valve according to Claim 1, wherein the diameter of the two opposed pistons is at least ten times greater than the diameter of the sealing surfaces of the enlarged central section of the valve spool.

3. A three-way valve according to Claim 1 or 2, wherein the dimensions of the central enlarged section of the valve cavity and of the enlarged central section of the valve spool are such that the switching of the high pressure fluid from one outlet port to the other requires the valve spool to travel a distance of less than 0.03 inches (0.762mm).

4. A three-way valve according to any one of Claims 1-3, wherein each of the valve seats in said cavity is provided by a 90° transition between the enlarged central section of the cavity and each of the two end sections, thereby to provide line contact with the respective one of the frusto-conical valve surfaces on the enlarged central section of the spool valve.

5. A three-way valve according to any one of Claims 1-3, wherein each of the valve seats in said cavity is provided by a frusto-conical



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transition surface between the enlarged central section of the cavity and each of the two end sections, the angle of that frusto-conical surface relative to the axis of the valve opening being greater than the corresponding angle of the respective one of the frusto-conical valve surfaces on the enlarged central section of the spool valve.

6. A three-way valve according to Claim 1, substantially as hereinbefore described with reference to the accompanying drawings.
