API RECOMMENDED PRACTICES USED FOR TESTING OF FLOAT EQUIPMENT

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ABSTRACT

American Petroleum Institute (API) proposed Recommended Practices (RP)[1] present standards of performance to be used in testing of floating equipment that is used in oil and gas well completions. Extensive laboratory testing has been done following API proposed procedures. Testing at levels beyond API standards have also been accomplished.

A paper has been prepared to present data resulting from API tests conducted. Procedures used and test results gained from testing at more stringent standards are also presented. Data reported include (1) impact and pressure force tests exerted through the cementing plugs to floating equipment, and (2) flow tests in which a large volume of lost circulation material was passed through floating equipment.

Subject paper also presents statistical data from an extensive body of cementing work performed in domestic operations in the United States. Many pipe sizes are represented in this information. Data include pipe size, flow rates, circulation times, and cementing times. Results presented justify the need for and the severity of the standards in the API proposed RP.

INTRODUCTION

API has prepared for release in 1989 a proposed RP[1] on the testing of floating equipment. The proposed RP defines "cementing floating equipment" as one or more check valve(s) incorporated into a well casing string to prevent fluid flow up the casing, while allowing fluid flow down the casing. Floating equipment also serves other purposes:

1. Allows cement to set up in the annular area between the casing and the hole while having lower pressure inside the casing than the hydrostatic head of the cement on the outside of the casing. This reduces the chance of forming a micro-annulus.

2. The buoyant force acting on the casing will lessen the hook load on the rig if the fluid inside the casing has less density than the fluid in the hole.

3. The capability of floating equipment to prevent flow up the casing can help in well control situations where fluid density on the inside of the casing is less than that needed to control flow from a formation. In this case the float equipment becomes a primary well control device.

4. When one or more cementing plugs that stop flow down the casing are landed on the floating equipment, the lower portion of the casing can be sealed (1) to allow pressure testing of the pipe or (2) to apply a higher pressure on the inside the casing than is exerted by the hydrostatic head of the cement (to reduce the chance of buckling the pipe).

5. Floating equipment is also used by some operators to control the free fall of cement inside the casing by constricting the inside diameter (ID) the cement must pass through at the bottom of the casing.

Another feature available on some styles of floating equipment is casing fill-up. This type of floating equipment allows the casing to fill from the bottom as the casing is being run. The advantages of this type equipment are:

1. It helps reduce pressure surges as the casing is being lowered.
2. Fill-up type float equipment helps ensure that the collapse pressure of the casing is not exceeded.
3. Reduces the amount of rig time by eliminating or reducing the time required to fill the casing.

Once casing is run, the check valve is normally activated by pumping a ball down the casing or by circulating above a certain rate.

The objective of the RP is to set up testing procedures and standards to measure the performance of floating equipment. The performance criteria selected by API as the most important and on which they have set up testing procedure and performance standards are:

1. Durability under down hole conditions: As normally used, cementing floating equipment must function after a fluid, usually containing abrasive solids, has been circulated through the equipment for a period of time. The equipment must function in various orientations and while exposed to elevated temperatures and pressures.
2. Differential Pressure Capability from Below: Because the hydrostatic pressure of the fluid occupying the annulus immediately after the cement has been placed is usually greater than the hydrostatic pressure of the corresponding column of fluid inside the casing, float equipment must be capable of withstanding a differential pressure with the higher pressure being exerted from below the check valve mechanism.

Other areas API considers important, but on which no testing procedures or performance criteria have been established are:

1. Ability to withstand force exerted through cementing plugs from above: When floating equipment is used to land cementing plugs, and pressure is applied from above to test the casing and/or to prevent buckling, the ability of the floating equipment to withstand the pressure load is another measure of performance.
2. Drillability of the equipment: In many cases floating equipment must be drilled out after cementing, therefore drillability of the equipment is another measure of performance criteria.
3. Ability to pass lost circulation materials: Material designed to bridge off highly permeable formations to lessen the loss of fluids is sometimes pumped through the floating equipment. Since floating equipment generally provides a constricted flow area for fluid passage there is a chance the lost circulation material may partially or totally block fluid circulation through the floating

equipment valve. Therefore the ease with which pass through the floating equipment may be a performance criterion for some wells.

4. Flow coefficient of the valve. Since the floating equipment provides an ID restriction in the flow path of the cement there will be a pressure loss associated with circulating fluid through the equipment. If the pressure loss is too high, circulation rates may be limited. On the other hand the flow restriction may be used by some operators to reduce the free fall rate of the cement. Therefore the flow coefficient of the valve provides a means of estimating the pressure flow for a given fluid density at a given rate.
5. Reverse flow resistance of casing fill-up valves. One of the functions of casing fill-up floating equipment is to reduce pressure surges as the casing is run, by allowing flow into the casing from the bottom. Therefore, resistance of the valve to reverse flow is indicative of the relative capability of the valve to reduce surge pressure.

API has proposed the following test procedure and performance criteria to measure the performance of the floating equipment for flow durability.

A. Flow Loop (See Figure 1 for a schematic of one possible configuration). The flow loop is a piping network that allows continuous flow through the floating equipment for a long period of time by circulating a finite amount of fluid. The flow loop also allows periodic back-pressuring of floating equipment to determine whether the valve is holding back pressure. This schematic shows the floating equipment in the horizontal position; other configurations with the equipment in the vertical position are also permissible. (API recommends that the equipment be tested in the horizontal position if the inclination of the well will exceed 45 degrees.) Also, if necessary, floating equipment can be back-pressured by breaking the equipment out of the flow stream and back-pressuring the valve on a separate test fixture. (See Figure 2 for a schematic of another possible configuration with the equipment run in the vertical position.)

B. Circulating test fluid. The circulating test fluid should consist of a water base drilling fluid that has the following properties at 120° F.

Density	12 - 12.5 lb/gal
Plastic Viscosity	10 - 22 cp
Yield Point	5 - 20 lb/100 sq. ft.
10 - S Gel Strength	¶ 4 lb/100 sq. ft.
Sand Content	2 - 4% by volume

Weighting material used in the test fluid should be barite that meets the specifications in API Specification 13A. Fluid properties should be measured in accordance with API RP 13B. The sand used in the test fluid should be 80/200 mesh silica sand.

C. Performance categories API has set up three performance categories for flow testing of float equipment. They are shown in Table 1. If the floating equipment has the automatic fill up feature additional flow tests should be run from the bottom prior to doing the performance flow testing from the top side. These are listed in Table 2.

API has proposed the following procedure to measure the static high temperature/high pressure holding capability of the floating equipment from the bottom.

A. High pressure/high temperature test chamber (See Figure 3 for a schematic of one possible apparatus). The test chamber for applying high temperature/high pressure to a piece of floating equipment should be large enough to allow the entire piece of floating equipment to be submerged in the test fluid so that pressure is applied to the outside diameter (OD) of the floating equipment as well as to the bottom of the equipment (API does allow the application of pressure directly to the bottom of the floating equipment with a swage, if desired). Temperature of the test chamber must be maintained within +/- 10° F of the specified temperature.

B. API requires flow testing of floating equipment prior to its submission to a high temperature/high pressure test.

C. Shown in Table 3 are the performance categories API has established for high temperature/high pressure applications.

Equipment tested to these specifications can be rated in the following manner: "Meets or exceeds the proposed API RP on floating equipment for categories I-A, I-B, I-C, II-A, II-B, II-C, III-A, III-B, or III-C." Another method of designating equipment performance is to designate all the categories the equipment has passed, e.g., "Meets or exceeds Categories I, II, and III; and A, B, and C."

TESTING TO API STANDARDS AND BEYOND

In general there are three styles of check valves used in floating equipment. They are the ball check (Figure 4), the flapper valve (Figure 5), and the poppet valve (Figure 6). Testing described in this paper will be limited to the ball check and the poppet valve.

A. Flow testing arrangement. Flow testing was done with tested devices held in the vertical position (Figure 2) with a variation. Most of the testing was done with multiple valve in the string. A minimum pup joint length of 10 casing diameters of pipe was run between each float collar and the float collar positions were changed after each pressure test with the bottom float collar being moved to the top and all the float collars below being moved down one position. Another variation made after testing started was the addition of a screen below each valve then the 10 diameter lengths to the next valve (Figure 7).

B. Flow test procedure. All testing was done with the API flow test fluid described earlier in the paper. Rates were varied on different tests and are designated on each summary. Low temperature, back-pressure testing was done with the equipment in the horizontal position (Figure 8). Equipment failure was designated when the equipment could no longer hold back pressure.

C. High temperature/high pressure test. After the flow test, surviving equipment was installed, for high temperature/high pressure testing, in a test chamber like that shown in Figure 3. Temperatures varied on the tests and will be noted on the individual results. Test pressure was increased to the point of destruction.

D. Results.

Test Number 1
Flow Rate: 10 BPM
Total flow time: 36 hours
Mud Properties: Matched API Mud Requirements
Equipment:
  Equipment: (See Figure 9 for flow test schematic)
  Casing size and threads: 7 in. 8Rd
  Case Material: K-55 coupling stock
  Manufacturer's Specification: Suitable for use with casing grades through N-80
Maximum test pressure for categories III and C.
  7 in. 38 lb/ft N-80 Casing - 5,000 psi
Equipment Description:
  A. Poppet valve - float collar
     Entrance ID 2.62 in.
     Entrance float valve - plastic
  B. Poppet valve - float shoe
     Entrance ID 2.62 in.
     Entrance into float valve - plastic

Flow testing procedure. Both the float collar (A) and the float shoe (B) were pressure tested to 50 psi, which was held for 15 minutes and then the pressure was increased to 500 psi and held for 15 minutes in the pressure chamber shown in Figure 3 (with no temperature on the system). There were no leaks. Every two hours during the flow test the float collar was pressure tested with water on the surface in the test fixture shown in Figure 8 to 500 psi and the pressure was held for 5 minutes. At the end of 36 hours, the float collar was pressure tested to 5,000 psi, and the pressure was held for 30 minutes. No leaks. The float shoe was not pressure tested.

High Temperature/High pressure test. Both the float collar and the float shoe were tested individually to destruction (See Figure 3 for testing setup).
Test fluid: Water based systetic oil with a flash point of 525° F.
Test temperature: 350° F.
Test procedure: The equipment was soaked at temperature for 16 hours (overnight) prior to the application of any pressure. Initial pressure was 50 psi, which was held for 15 minutes. The pressure was then increased to 500 psi and held 15 minutes. Thereafter, the pressure was increased 500 psi every 15 minutes until destruction pressure was reached. Temperature was maintained on the equipment during the full pressure test cycle.

Destruction Pressure:
  A. Float collar - 10,000 psi (7 minutes at final pressure)
     Total time at temperature - 21 hours 7 minutes
  B. Float shoe - 8,000 psi (5 minutes at final pressure)

Total time at temperature - 20 hours 20 minutes

Test Number 2

Flow rate: 20 BPM

Total flow time: 24 hours (scheduled)

Mud properties: matched API mud requirements

Equipment: Two float collars (Same properties as described in test number 1:A). Initial pressure test: 50 psi to check for leaks increased to 500 psi - room temperature - no leaks. (See Figure 3 for pressure test setup)

Pressure testing during flow: (See Figure 8 for pressure test setup)

After 1 hour of flow*	Top float collar	Held 500 psi
	Bottom float collar	Held 500 psi
After 2 hours of flow	Top float collar	Held 500 psi
	Bottom float collar	Held 500 psi
After 4 hours of flow	Top float collar	Held 500 psi
	Bottom float collar	No test**
After 6 hours of flow	Top float collar	No test**

* Total hours of flow

** Valve washed out; would not hold pressure.

Test Number 3

Flow rate: 15 BPM

Flow time: 24 hrs (scheduled)

Mud properties: Matched API Mud Requirements

Equipment (See Figure 10 for location and spacing of equipment)

Casing size and threads: 9-5/8 in. 8 Rd

Case material: K-55 coupling stock

Purchase specification: Standard equipment suitable for use with N-80 grade casing.

Maximum test pressure required for Categories III and C:
9-5/8 in. N-80 53.5 lb/ft - 5,000 psi

Equipment Description:

A. Ball check valve - float collar
Entrance ID 2.62 in.
Entrance into float valve - concrete

B. Ball check valve - float collar
Entrance ID 2.50 in.
Entrance into float valve - concrete

C. Poppet valve - float collar
Entrance ID 3.20 in.
Entrance into float valve - concrete

D. Ball check valve - float collar
Entrance ID 2.25 in.
Entrance into float valve - concrete

E. Poppet valve - float collar
Entrance ID 2.62 in.
Entrance into float valve - plastic.

F. (Same as E)

G. Poppet valve - float collar
   Entrance ID 3.35 in.
   Entrance into float valve - plastic and concrete
H. (Same as G)
I. Poppet valve - float shoe
   Entrance ID 2.62 in.
   Entrance into float valve - plastic

Initial Pressure Tests: All equipment was pressure tested in the horizontal position (See Figure 10 for pressure test diaphragm). All equipment held 50 psi and 500 psi on the initial pressure test. Water was used for pressure testing. Results of the 500 psi pressure testing done in the horizontal position with water during the flow test. See Table 4 for pressure test results conducted during flow testing.

High pressure/high temperature testing After the flow test, surviving equipment was pressure tested to destruction. Equipment was tested individually (See Figure 3 for test set up).

Test Fluid: Water Based Synthetic Oil with a 525° F flash point.
Test Temperature: 400° F
Test Procedure: Soaked equipment at temperature for 16 hours (overnight). Applied 50 psi and held for 15 minutes. Increased pressure to 500 psi and held 15 minutes. Thereafter increased pressure 500 psi every 15 minutes until destruction.
Test Results: See Table 5.

Test Number 4
Flow rate: 20 BPM
Mud Properties: Matched API mud requirements
Equipment:
(See Figure 11 for location and spacing of equipment)
Casing size and threads: 9-5/8 in. 8 Rd.
Case material: K-55 coupling stock
Manufacturers specification: Standard equipment suitable for use with API casing
grades up to N-80.
Maximum Test Pressure Required for Categories III and C:
9-5/8 in. 53.5 lb/ft N-80 - 5,000 psi
Equipment Description:
A. Poppet valve - float collar
   Entrance ID 2.62 in.
   Entrance into float valve - plastic
B. Poppet valve - float collar
   Entrance ID 4.11 in.
   Entrance into float valve - plastic
C. Poppet Valve - Float Collar
   Entrance ID 3.35 in.
   Entrance into float valve - plastic followed by concrete

D. (Same as A)
E. (Same as B)
F. Poppet valve - float shoe
Entrance ID 4.11 in.
Entrance in float valve - plastic

Initial Test Pressure: All equipment was pressure tested to 50 psi and 500 psi (See Figure 8 for pressure test setup).

Results of the 500 psi pressure tests (performed in the horizontal position) with water at various points during the flow. (See Table 6).

High Pressure/High Temperature Testing. After the flow test float collar B was pressured tested to destruction. The other surviving equipment was cut in half to examine them for wear.

Test fluid: Water based systhetic oil with 525° F flash point.
Test temperature: 400° F Test procedure: After soaking at Temperature for 16 hours (overnight) an initial pressure of 50 psi was applied and held for 15 minutes. Pressure was then increased to 500 psi and held for 15 minutes. Thereafter pressure was increased in 500 psi increments until destruction pressure was reached.
Test Results: Float Collar B destructed at 6,300 psi after being at temperature for a total of 19 hours and 15 minutes.

IMPACT AND PRESSURE TESTING WITH CEMENTING PLUGS ON FLOATING EQUIPMENT

The objective of this testing was to determine whether impact load and pressure testing casing after landing the cementing plugs would have an adverse effect on the floating equipment, testing was conducted in two phases. One was the impact of cementing plugs on the floating equipment in the dry condition to determine whether the impact would cause the equipment to fail. Second, equipment was placed in a test chamber and cementing plug(s) were installed on top of the floating equipment and pressure applied until failure, or until 80% of the burst of the test fixture was reached, whichever was less.

1. Impact Testing Procedure: Testing was done with 4-1/2 in. and 5-1/2 in. 8Rd float collars. The floating equipment was run 1,500 ft deep (Figure 12) in the test well, after being back-pressure tested for 5 minutes at the surface (in the horizontal position) with water. The casing was filled with water. A bottom plug was then launched and pumped down at a rate of 20 BPM. Once the bottom plug was landed a top plug was then launched and pumped down at 20 BPM. Relief valves set for 1,000 psi were installed in the line to prevent excessive pressure buildup. Pumping was never slowed down, the plugs were released on the fly. Later tests used top plug only. Water was used to pump the plug(s) down. The float collar was back pressure tested for 5 minutes at the surface in the horizontal position with water after the test.

Equipment: A. 5-1/2 in. 8 Rd. float collar
Entrance ID 2.62 in.
Entrance into float valve - plastic
B. 5-1/2 in. 8 Rd. float collar

Entrance ID 2.06 in.
Entrance into float valve - plastic

C. 4-1/2" 8 Rd. float collar
Entrance ID 2.06 in.
Entrance into float valve - plastic

Test Results: See Table 7

2. Pressure Testing with Cementing Plug: This testing consisted on placing a new cementing plug on top of a float collar and pressuring up to failure of the plug, collar, or the limit of the test fixture - whichever was less (See Figure 13 for test setup).

Equipment:

A. 4-1/2 in. float collar
Entrance ID 2.06 in.
Entrance into float valve - plastic

B. 5-1/2 in. Float Collar
Entrance ID 2.62 in.
Entrance into float valve - plastic

C. 5-1/2 in. float Collar
Entrance ID 2.06 in.
Entrance into float valve - plastic

Test Results: See Table 8

FLOW TESTING FLOATING EQUIPMENT WITH LOST CIRCULATION MATERIAL IN MUD

The objective of this testing was to determine whether mud containing large amounts of lost circulation material would bridge off in selected floating equipment.

Equipment:

A. 9-5/8 in. Float Collar
Entrance ID 2.62 in.
Entrance into float valve - plastic

B. 9-5/8 in. Float Collar
Entrance ID 4.11 in.
Entrance into float valve - plastic

Procedure: While pumping an 11.7 lb/gal mud system at 5 BPM through floating equipment A and B, cottonseed hulls were added to the mud system. No more was added after 27 lb/bbl had been added for fear the centrifugal pump would lose prime. Pumping was stopped for 30 minutes after one hour. Because the centrifugal pump would not prime to resume pumping, water was added to the mud. The centrifugal pump started pumping when the concentration of cottonseed hulls was reduced to 22 lb/bbl. This mud system was used for the remainder of the test, which consisted of pumping for 1 hour and sitting idle for 30 minutes. This was repeated until a total of 8 hours of pumping had been accomplished. At no time did the floating equipment plug off.

CONCLUSIONS ABOUT TESTING FLOATING EQUIPMENT TO API STANDARDS AND BEYOND

1. There is floating equipment available that will meet the categories III and C testing requirements in standard grade equipment.
2. If floating equipment is to be used at a higher flow rate than

specified by API category III, the equipment should be tested at that higher flow rate.

3. Equipment that can pass the category III flow testing may not necessarily pass category C pressure/temperature requirements.
4. Impacting plugs at 20 BPM (approximately 21 ft/second velocity in 4-1/2 in. 10.5 lb/ft casing) does not appear to have adverse effects on the floating equipment tested.
5. Large volumes of cottonseed hulls (a common lost circulation material additive in certain areas) do not appear to plug off the floating equipment tested.

ADDENDUM

During the formulation of the API RP recommendations, a discussion occurred as to whether or not the 10 BPM flow rate was too severe for the smaller sizes of casing. Because of this question an extensive survey was run on all domestic cementing jobs for a three month period in the casing sizes in question. More than 25,000 jobs were involved in the survey. The results of the survey are summarized in Tables 9 and 10.

Based on the above data the API flow rate of 10 BPM will cover in excess of 90% of the cementing jobs being done in 2-7/8 in. thru 8-5/8 in. in domestic cementing operations. Data for the larger casing sizes has not been compiled.

BIBLIOGRAPHY

1. "API Recommended Practice For Performance Testing Of Cementing Float Equipment" (Proposed), American Petroleum Institute, 1987.

ACKNOWLEDGMENTS

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Table 1
Flow Durability Tests

Category	Duration (hr)	Maximum Pressure (psi)
I	8	1,500
II	12	3,000
III	24	5,000

Notes: a. Circulation rate for all categories is 10 BPM.
b. The maximum test pressure, or 80% of collapse pressure of the best grade and heaviest weight of casing the floating equipment is rated for - whichever is less - is to be applied to the bottom of the floating equipment at the conclusion of the flow test at room-temperature and held for 30 minutes.

Table 2
Flow Durability Tests for Casing Fill-up Equipment

Category	Duration (hr)
I	2
II	4
III	6

Notes: a. Flow is from the bottom at 3 BPM for all categories.
b. The same mud system is used on the reverse flow as that used in the forward flow test.
c. The check valve is activated after the reverse flow test, and then the forward flow test must be performed as described in Table 1.

Table 3
Static High Temperature/High Pressure Tests

Category	Temperature (F)	Maximum Pressure (psi)
A	200	1,500
B	300	3,000
C	400	5,000

Notes:
a. Equipment is to be maintain at temperature 8 hours for all categories prior to applying any pressure.
b. Initial pressure is to be 50 psi to check for low pressure sealing ability of the floating equipment. Increase pressure to 500 psi and hold for 15 minutes. Every 15 minutes thereafter increase pressure 500 psi until maximum pressure is reached or the floating equipment fails. If the maximum pressure exceeds 80% of the burst or collapse pressure of the highest grade and heaviest weight of casing the floating equipment is rated for then the 80% figure shall be used as the test pressure.

Table 4
Pressure Test Results of Floating Equipment in 15 BPM Flow Test

Floating Equipment	Total Flow Time at 15 BPM						
Letter	2 hrs	4 hrs	6 hrs	8 hrs	12 hrs	18 hrs	24 hrs*
A	OK	OK	OK	OK	OK	**	--
B	***	--	--	--	--	--	--
C	OK	OK	OK	OK	OK	OK	OK
D	OK	OK	OK	OK	OK	OK	OK
E	OK	OK	OK	OK	OK	OK	OK
F	OK	OK	OK	OK	OK	OK	OK
G	OK	OK	OK	OK	OK	OK	OK
H	OK	OK	OK	OK	OK	OK	OK
I	****	****	****	****	--	--	--

* Final test was still 500 psi
** Valve washed out somewhere between 12 and 18 hours of flow
*** Valve washed out somewhere between 0 and 2 hours of flow
**** No back pressure test on the float shoe - valve washed out between 6 and 8 hours of flow

Table 5
Destruction Pressure of Equipment Flowed at 15 BPM, Then Subjected to 400° F High Temperature/High Pressure Testing

Floating Equipment Letter	Destruction Pressure psi	Time at Temperature hr:min
A	*	*
B	*	*
C	1,200	16:45
D	**	**
E	6,500	19:45
F	6,000	19:30
G	8,500	20:30
H	***	***
I	*	*

Notes: * No pressure/temperature test - failed in flow
** Equipment fell apart at 400 F - No pressure test
*** Threads damaged could not make up test fixture - No Test

Table 6
Pressure Test Results of Floating Equipment in 20 BPM Flow

(Floating Equipment)	Total Flow Time at 20 BPM						
Letter	2 hr	4 hr	6 hr	8 hr	12 hr	18 hr	24 hr*
A	OK	OK	OK	**	--	--	--
B	OK	OK	OK	OK	OK	OK	OK
C	OK	OK	OK	OK	OK	OK	OK
D	OK	OK	OK	**	--	--	--
E	OK	OK	OK	OK	OK	OK	OK
F	***	--	--	--	--	--	--

Notes: * Final pressure test still 500 psi
** Valve washed out no pressure test
*** No back-pressure test on float shoe because of lack of fixture. No visible damage to shoe during entire test.

Table 7
Impact Pressure Test Results

Test Number	Float Collar	Pressure Test (psi)*		Plug Insert Mat'l	
		Before	After	Top	Bottom
1**	A	1,000	1,500	aluminum	aluminum
2**	A	1,000	1,500	plastic	plastic
3**	A	1,000	1,500	aluminum	--
4	B	1,500	1,500	aluminum	--
5	B	1,500	1,500	aluminum	--
6	C	1,500	1,500	aluminum	--
7	C	1,500	1,500	aluminum	--
8	C	1,500	1,500	aluminum	--

Notes: * Pressure applied at the surface with water while the float collars were in the horizontal position and held for 5 minutes.
** The same float collar was used in all three tests.

Table 8
Maximum Pressure Reached When Testing Cementing Plugs on Float Collars

Test Number	Float Collar	Destruction Pressure (psi)	Description of Failure
1	A	10,000	a
2	B	3,840	a
3	A	7,920	b
4	B	1,920	b
5	C	12,000	c
6	A	9,840	a
7	C	9,360	b
8	B	5,000	a

a Aluminum insert plugs started extruding into I.D. of float collar.
b Plastic insert plugs started extruding into I.D. of float collar.
c Aluminum insert plugs - no failure, reached limits of test fixture.

Table 9
Percent of Cementing Jobs with Mud Circulation Rates

Pipe Size OD (inches)	Less than 6 BPM	6 to 8 BPM	8 to 10 BPM	Greater than 10 BPM	Total Hours
2-7/8	88.5	1.8	0.8	0.2	0.90
3-1/2	89.4	2.7	---	---	1.21
4-1/2	42.7	33.5	6.2	0.6	1.07
5	58.7	22.9	13.5	4.2	1.52
5-1/2	33.4	43.2	21.0	4.1	1.49
7	19.8	30.7	19.1	6.4	1.38
8-5/8	22.6	34.7	19.7	9.3	1.09

Table 10
Percent of Cementing Jobs with Cementing and Displacement Rates

Pipe Size OD (inches)	less than 6 BPM	6 to 8 BPM	8 to 10 BPM	greater than 10 BPM	Total Hours
2-7/8	94.7	4.5	0.6	0.2	0.79
3-1/2	93.9	5.4	0.7	---	0.83
4-1/2	24.4	50.3	21.0	4.4	1.68
5	56.7	31.0	11.1	1.2	1.49
5-1/2	24.3	47.7	22.1	5.9	1.28
7	20.3	38.9	36.0	4.8	1.56
8-5/8	17.5	54.5	23.0	5.1	1.76

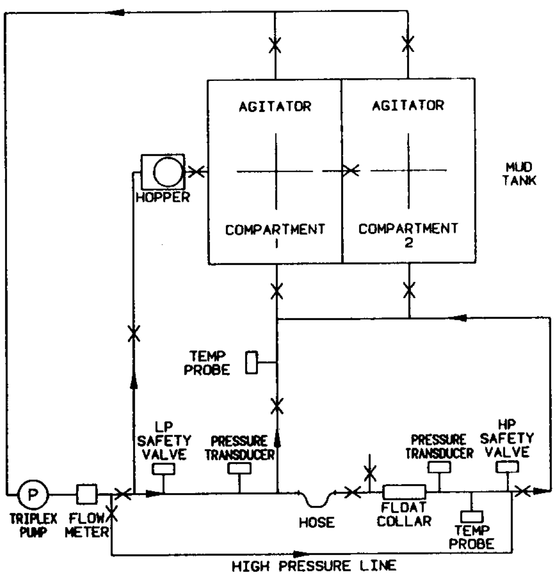

Figure 1 — Suggested layout for cementing float equipment testing flow loop

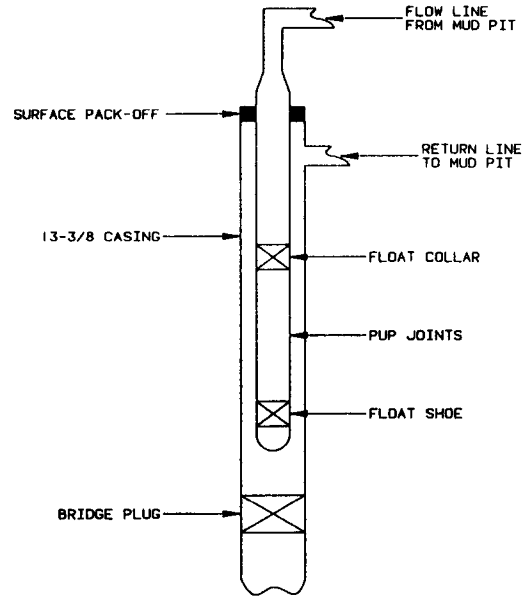

Figure 2 — Schematic of floating equipment for vertical flow test

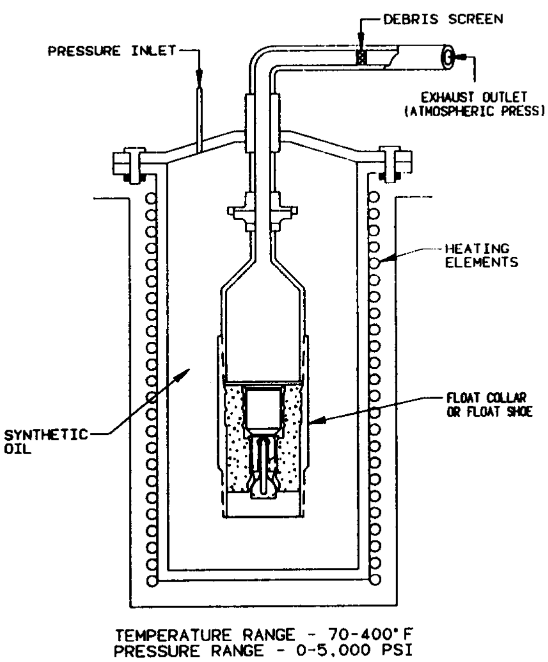

Figure 3 — Controlled pressure - temperature test cell

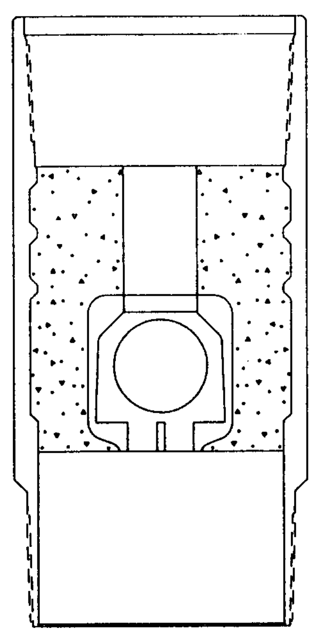

Figure 4 — Ball check valve float collar

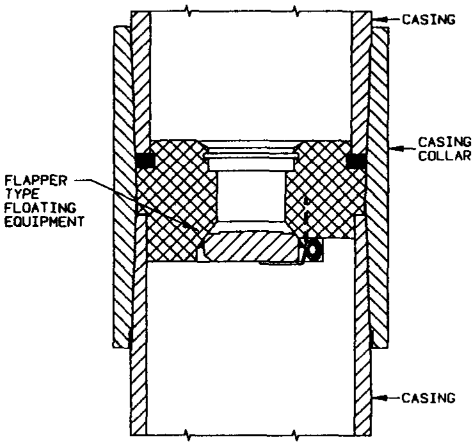

Figure 5 — Flapper-type floating equipment installed between pin threads in a casing collar

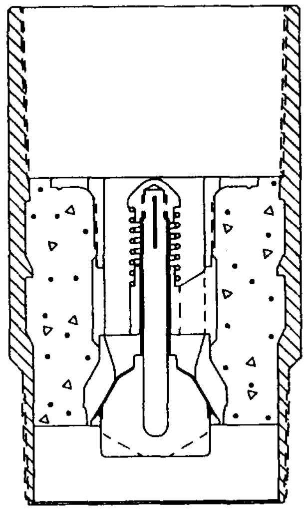

Figure 6 — Poppet valve float collar

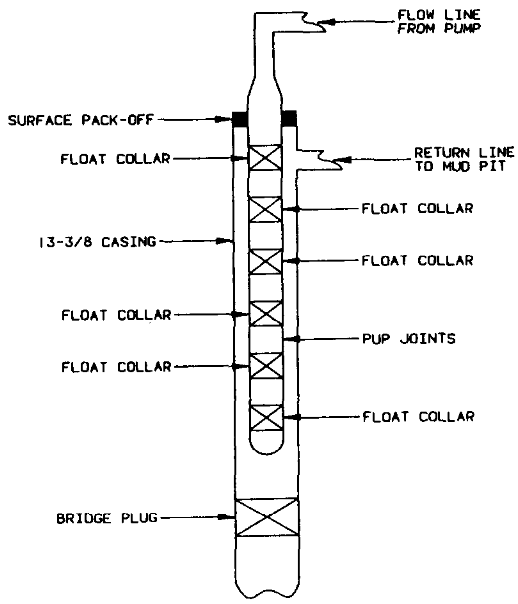

Figure 7 — Schematic of flow testing multiple float collars and a float shoe

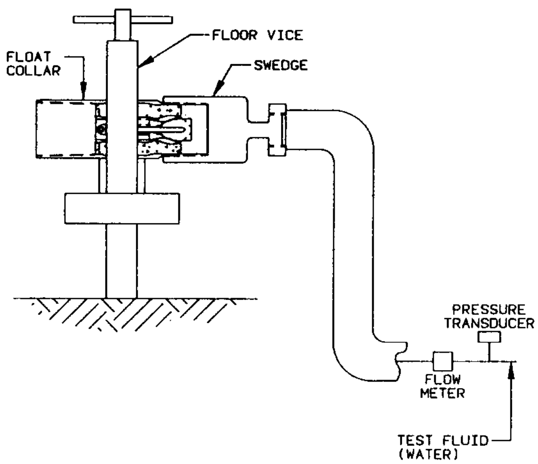

Figure 8 — Schematic of horizontal surface pressure test set-up

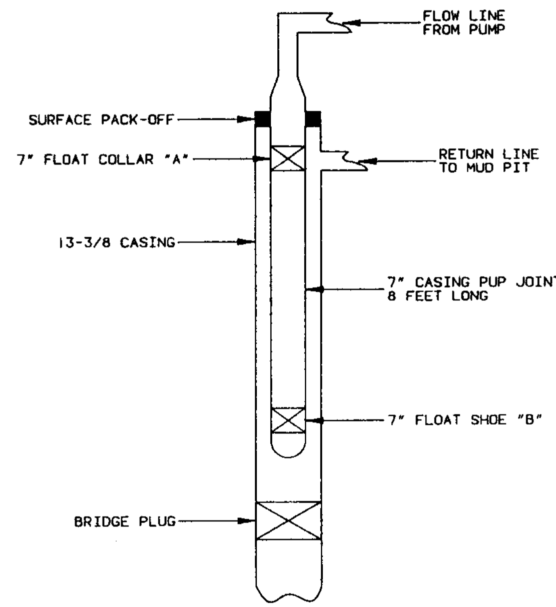

Figure 9 — Schematic of floating equipment for 10 BPM test

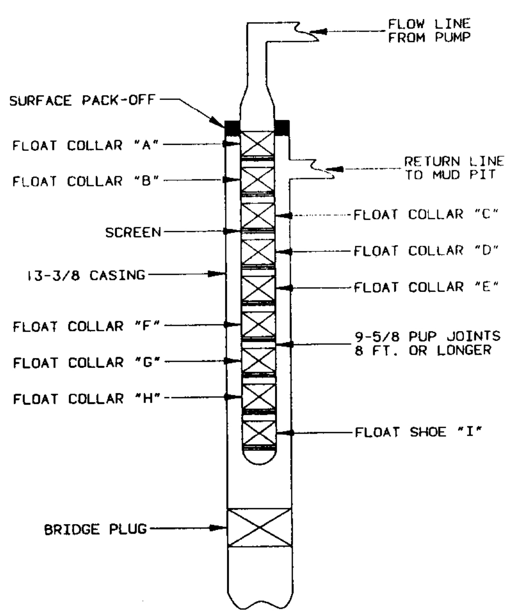

Figure 10 — Schematic of floating equipment during 15 BPM flow test

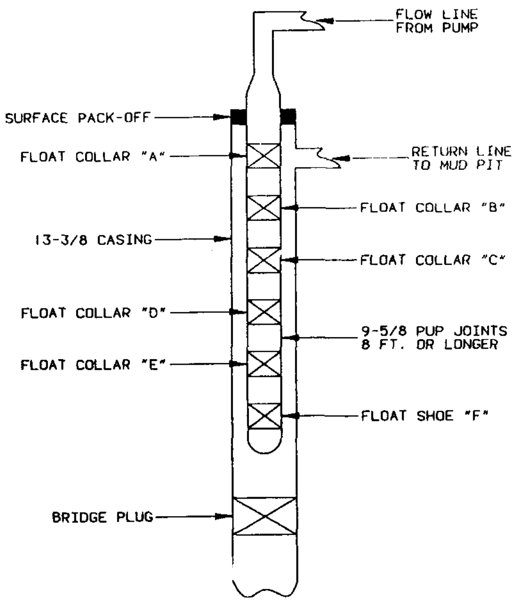

Figure 11 — Schematic of floating equipment during 20 BPM flow test

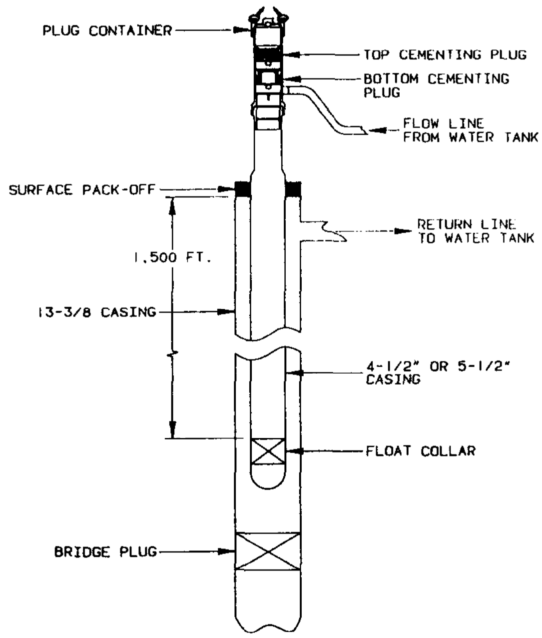

Figure 12 — Schematic of plug impact testing set-up

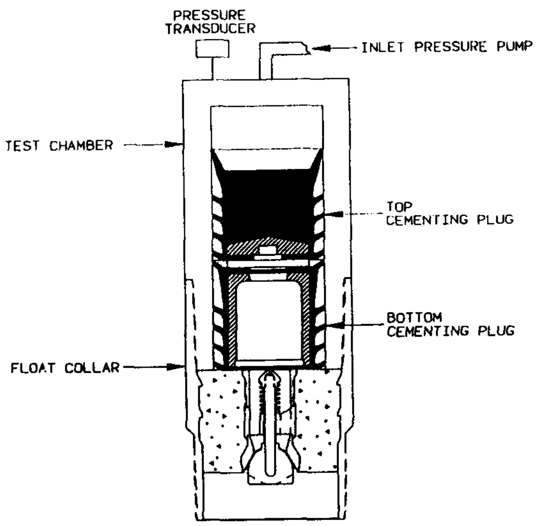

Figure 13 — Schematic of pressure test fixture with cementing plugs