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ON THE PERFORMANCE OF BALL CHECK VALVES

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ABSTRACT

Ball check valves are used to stop water from entering the steam pipeworks system of geothermal installations. However, from the very beginning of their use, it has been frequently found that they do not consistently operate as it was expected.

This paper describes the tests performed by the Instituto de Investigaciones Electricas (IIE) for Comisión Federal de Electricidad (CFE) on transparent models using air-water mixtures to simulate steam-water flows and the conclusions reached from them, namely, that ball check valves cannot work as intended at the conditions found in all practical instances, so that money can be saved and operational problems avoided by taking them off the well-pad layout.

DESCRIPTION OF BALL CHECK VALVES

Ball check valve or spherical valve is the name given in geothermal installations to a safety device, similar to the one shown in Fig. 1, used to avoid the entrance of water gulps into steam lines. It is formed by an spherical float (1) usually made out of stainless steel, which blocks the steam outlet (11) when lifted by the water collected in its body. It has a drain connection so that the float operates in the rare occasions in which its discharge capacity is not enough to manage the accumulated liquid. The valve may be fitted with other elements, like guides (8), shields (2), seats, etc. which supposedly improve its operation.

BACKGROUND

The great damage that a water gulp could cause if it entered into a turbine was something the designers of Wairakei, the first geothermal plant to generate electric power from a liquid-dominated reservoir, tried to avoid by the insertion of ball check valves in the steam take-off pipe of each separator. (Armstead, 1961). All the power plants installed in liquid-dominated fields thereafter: Cerro Prieto, Matsukawa, Hatchobaru, Ahuachapan, Latera, etc., were also supplied with this type of valves. However, from the very beginning of their operation, it was clear that spherical valves could pass substancial amounts of water without actuating (Armstead and Shaw, 1970), which was attributed to defects in their parts, drain orifices too small or stuck floats (Armstead, 1978). In other instances, ball check valves closed without any apparent reason, causing rupture-disks blowouts.

CFE has been experiencing these same problems, so it engaged IIE to study spherical valves performance and improve their design as well.

BALL CHECK VALVE OPERATION ANALYSIS

The rationale of ball check valve operation is that, as long as reasonably dry steam enters it, the float will rest on its lower part and any normal amount of condensate or water carried over will fall to the bottom and be discharged from there. If the quantity of liquid is larger than what can be drained, it will gather in the valve, putting the sphere afloat until a level is reached that makes it to obstruct the oulet pipe.

In Fig. 2, h is the height of the submerged portion of the sphere, which shall supply enough buoyancy to counteract its weight and also to leave above the water surface an spherical segment whose chord is no less than the outlet pipe inside diameter. If we define

$$\alpha = \frac{h}{d}$$

and

$$\beta = \frac{D}{d}$$

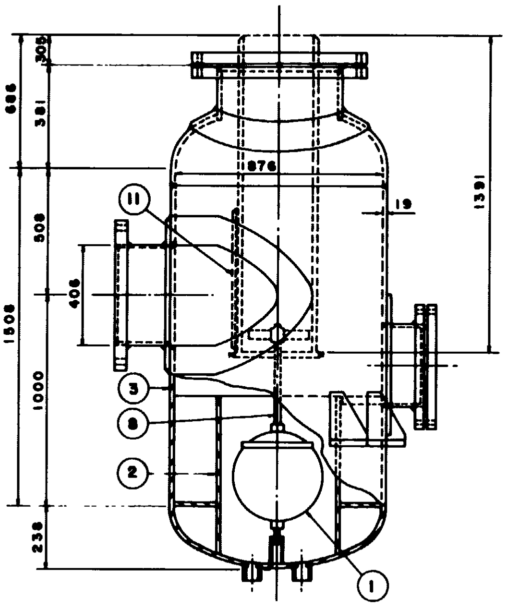

FIG. 1

it can be seen from fig 2 that

$$\alpha = \frac{1+\sqrt{1-\beta}}{2}$$

If

γ_a Specific weight of water at operating conditions

γ_s Specific weight of the sphere material

equating the buoyancy force acting on the sphere and its weight, we arrive to

$$\alpha^3 - \frac{3}{2}\alpha^2 + \frac{3t}{d}\frac{\gamma_s}{\gamma_a} = 0$$

being the ranges of practical interest

$$0 < \frac{t}{d}\frac{\gamma_s}{\gamma_a} < \frac{1}{6}$$

and

$$0 < \beta < 1$$

If, as it is usual, the float is made out of stainless steel, which means that (γ_s / γ_a) is approximately equal to 9, and it is designed for external pressure according to Section VIII of ASME Code, the maximum pressure for which a buoyant spherical valve can be manufactured is 3 MPa (445 psi). Besides, at that or a lower pressure, its design shall satisfy the relationships expressed in the graph of Fig. 3.

It could be thought that the valve closes, not because a rise in the water level, but because of the momentum imparted by a mass of water irrupting into its body. Calculating with the dimensions shown in Fig. 1, the inlet velocity v_i (Fig. 4) found necessary to lift the sphere is 61.5 m/s (200 fps), or greater which is quite higher than the current values used in practice. However, if the draft force (See Fig 4)

$$D = C_D \frac{\pi \gamma_a}{2g} d^2 \left(\frac{D_i}{D_c}\right)^4 v_i^2$$

is figured out using the drag factors given in Fig. 10.10 of Daugherty and Franzini (1977), with fluid entering the valve at 40 m/s' (130 fps), the upward force it exerts on the sphere is 3500 N (787 lbf) for water, ten times greater than its weight, while for steam it is just 30 N (6.7 lbf), not enough to lift the float. So it seems that the ball check valve could work on this principle with an adequate design.

EXPERIMENTAL INSTALLATION

In order to ascertain the operation of ball check valves, a transparent model of Fig. 1 valve was made out of acrylic plastic, to a scale 1:5, with the guiding rod (8) and the fasteners being the only metallic parts, while the float was a hollow polyethylene sphere with weight added up to the one it would have if made out of steel. The outlet pipe could be moved in and out of the valve's body and also the float shield could be raised or

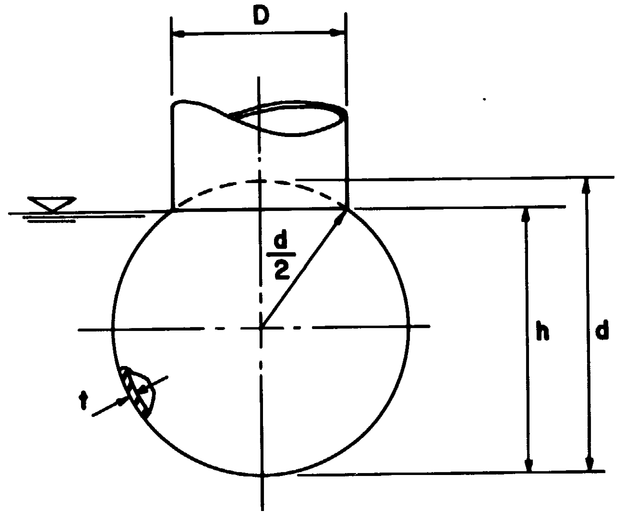

FIG. 2

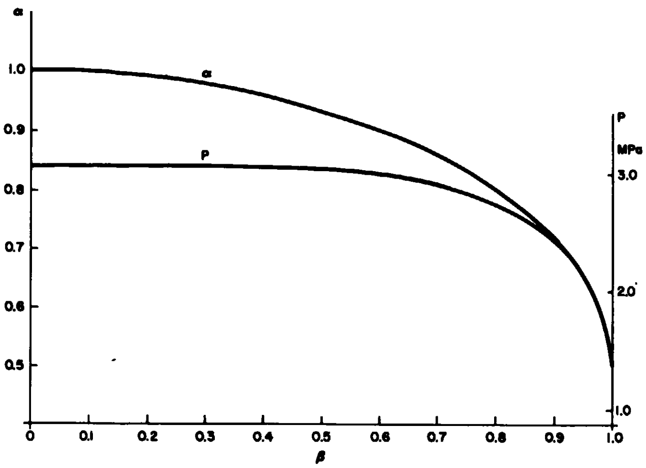

FIG. 3

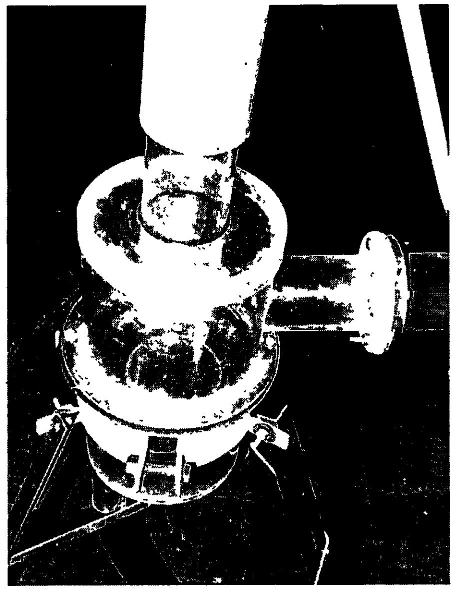

FIG. 5

lowered. Two different positions of the inlet tube were tested: radial (Fig. 5) and tangential (Fig. 6). The general arrangement of the experimental facilities is schematically shown in Fig. 7.

The working fluid used was a mixture of air and dyed water. Tests were conducted at the (homogeneous) velocities and qualities shown in the Kosterin type flow pattern chart of Fig. 8.

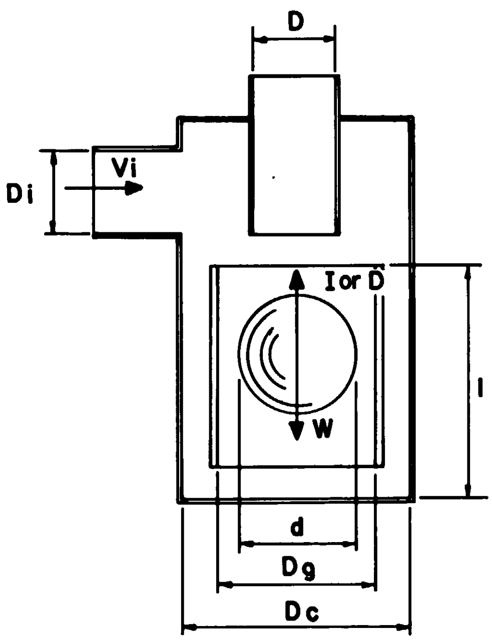

FIG. 4

TEST DESCRIPTION AND RESULTS

The outlet pipe edge was located from an upper position slightly above the inlet pipe axis plane (0.07 D_i) to well below the entrance circunference (1.1 D_i from the axis) without detecting any difference in the valve performance. The same could be said about the float shield height. Its lower edge went from 70 mm (2 3/4") or 80% of the sphere diameter over the botton plate to close contact with it, and it did not show any influence on the valve performance except that, when located at its lowest position, water could not enter into the shield's interior, so the float rested on the bottom irrespectively of the water level outside the shield.

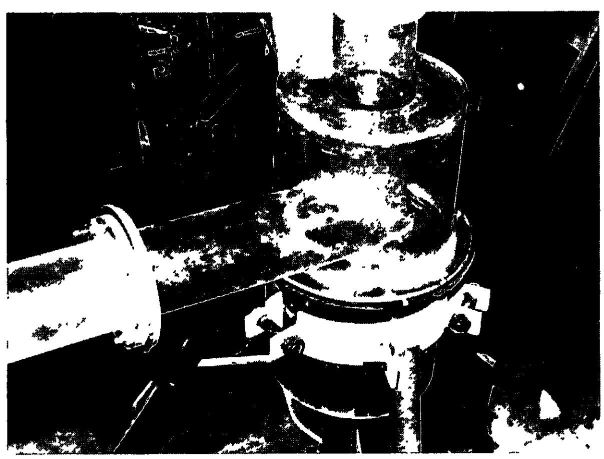

FIG. 6

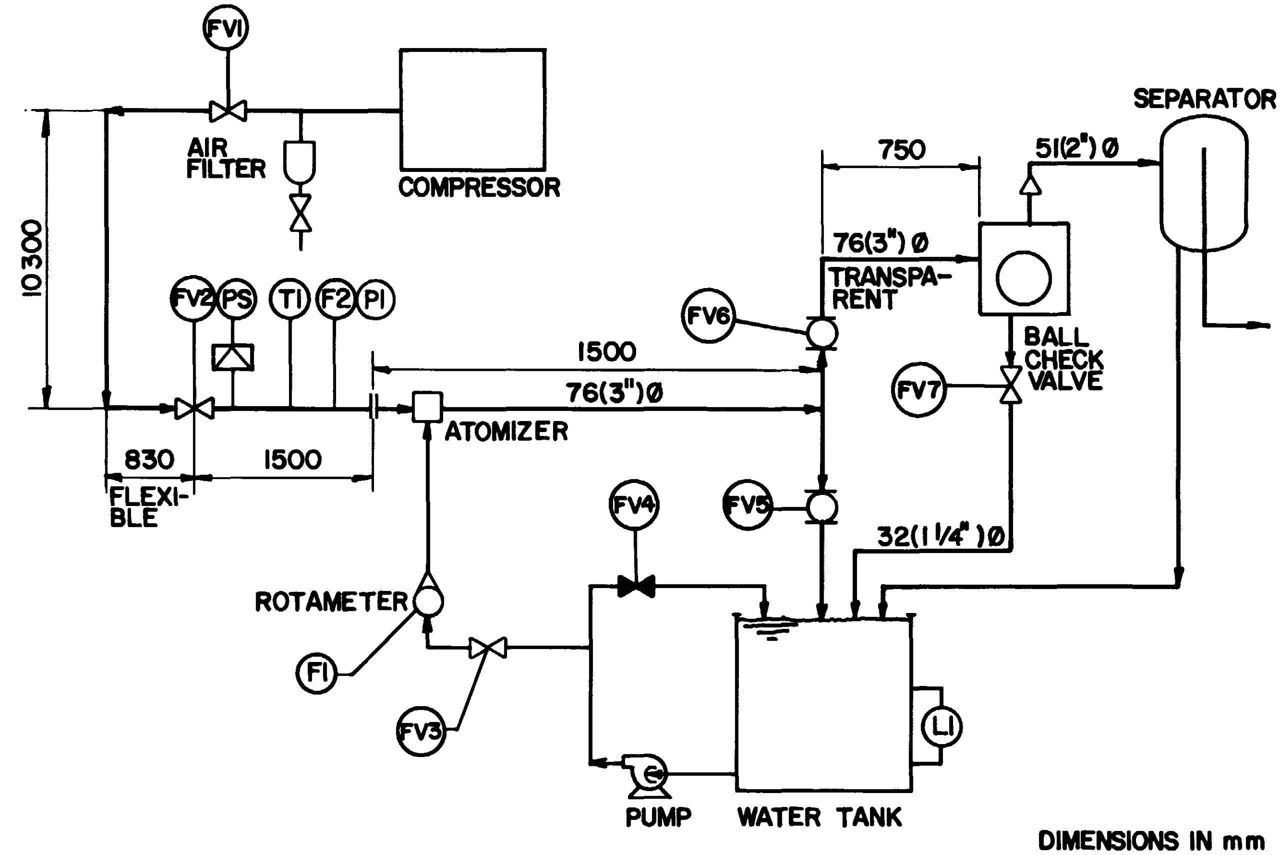

FIG.7 EXPERIMENTAL INSTALLATION

More than 160 runs were made at various conditions with very consistent results:

1. With very low velocities and water contents, so that the inlet flow pattern is stratified or slow wave, the liquid segregates on entering the valve and the gas leaves dry from it.

2. With all the other flow patterns at the inlet pipe, only an small fraction of the water falls to the valve's bottom and the rest of it is carried over by the air to the outlet pipe, where a two-phase, annular usually, flow is established. Carry over increases with velocity. See Fig 9.

3. With a tangential inlet, carry over is less, because the valve acts as an small (but inefficient) centrifugal separator. See Fig 10.

4. The valve closes when the level rises enough to bring the float close to the outlet pipe, be it because the drain valve is choked or because a plug flow is introduced with water gulps larger than its discharge capacity, filling the valve body then. See Fig 11. Before the sphere plugs the outlet, part of the water is carried over.

5. With a tangential inlet, the sphere starts spinning at a fluid homogeneuos velocity of 40.8 m/s (134 fps) notwithstanding whether the guiding rod (8) is in its place or removed. When the fluid velocity reaches 44.7 m/s (146 fps), the sphere rises to close the valve even when no water is admited.

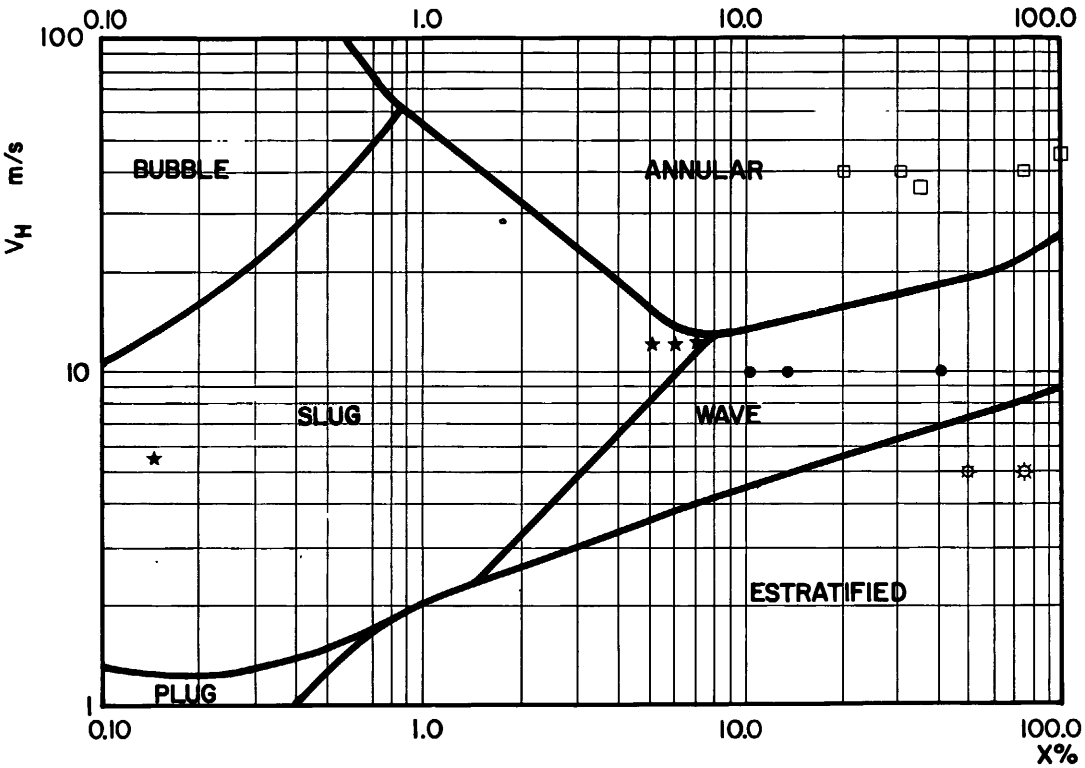

FIG.8 HORIZONTAL FLOW PATTERNS FOR p= 1 bar
HOMOGENEOUS VELOCITY (m/s) Vs QUALITY (%)

CONCLUSIONS

The performance shown by the valve model in the tests is what could be expected when the principles of two-phase flow dynamics are taken into account. The original design of ball check valves is based in an oversimplified conception of the way gas-liquid mixtures behave and the various elements added to improve its operation cannot make the equipment function any better. Ball check valves of the type currently used cannot impede water entrance to steam mains.

As ball check valves do not work and the cost of one of them goes around $15 000 dollars, plus transportation, installation and maintenance expenses, it is more convenient not to use them. Instead, an alarm system, with the possible addition of automatic interception valves installed in the steam mains, actuated by water detectors (Armstead and Shaw, 1970), by conductivity cells mounted in the pipes' drains, or by accelerometers detecting the vibrations induced by two-phase flows when a certain separators passes water, might protect geothermoelectric installations much better.

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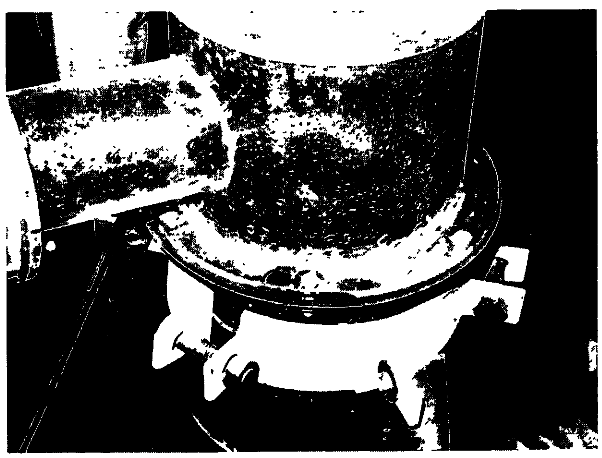

FIG. 9

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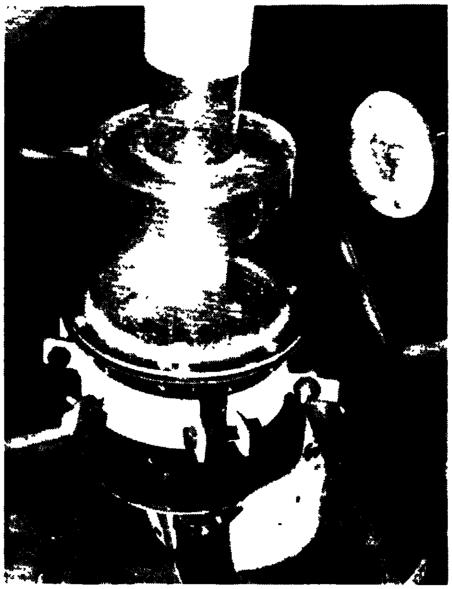

FIG. 10

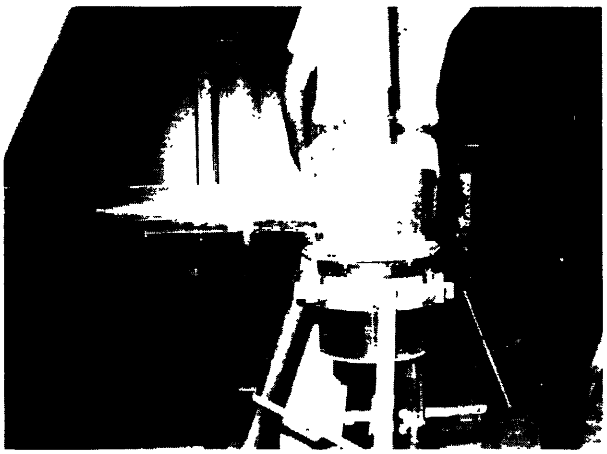

FIG. 11