Multi-stage valve

The multi-stage closure is designed to limit cavitation. If the pressure at a certain point during the flow through the valve or pipe falls below the value of the saturated vapor pressure of the liquid, corresponding to its temperature, cavitation occurs. The cavitation bubbles suddenly disappear when they reach a higher-pressure area with the liquid flow, and cavitation wear of the material is caused.
For the formation of cavitation, it is decisive whether the liquid pressure falls below the critical value of cavitation pressure, which favorably corresponds to the saturated vapor pressure P_T lies in the range of minimum pressure and pressure behind the valve, when cavitation occurs, and cavitation wear can be expected after a certain time. If the minimum pressure is greater than the saturated vapor pressure, steam cavitation will not occur.
The control valve, which must prevent cavitation, must be made for the given parameters and must be unique for the given situation (series-produced valves will not be functional for all situations). To prevent cavitation, it is necessary to use a multi-stage valve (there must be a gradual pressure drop in the valve by means of orifices), a single-stage valve is not suitable for larger pressure differences.

In the case of control valves, cavitation can develop if the condition is met:
$$(P_1 - P_2) \geq 0{,}6 * (P_1 - P_T)$$

P_1	inlet absolute static pressure	[Pa]
P_2	output absolute static pressure	[Pa]
P_T	saturated vapor pressure at a specific temperature	[Pa]

Pipeline speed:

$$v = \frac{Q}{\frac{\pi * D^2}{4}}$$

v	pipeline speed	[m/s]
Q	pipeline flow	[m^3/s]
D	internal pipe diameter	[m]

Pipeline flow:

$$Q = \mu * F * \sqrt{2\frac{P_1 - P_2}{\rho}}$$

$$\frac{F}{\frac{\pi * D^2}{4}} \leq 0{,}5$$

Q	pipeline flow	[m^3/s]
μ	output coefficient	[]
F	the flow area of the output hole	[m^2]
P_1	inlet absolute static pressure	[Pa]
P_2	output absolute static pressure	[Pa]
ρ	density	[Kg/m^3]

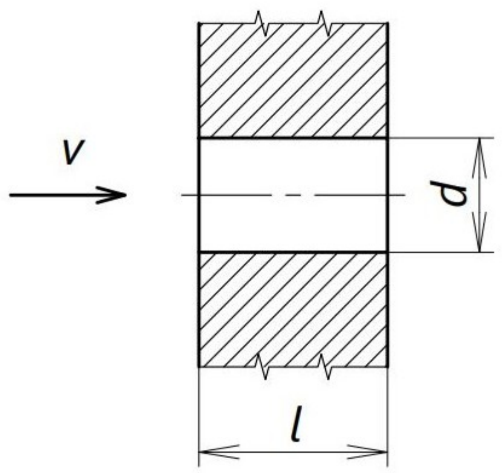
D	internal pipe diameter	[m]

Output coefficient:

- Sharp-edged hole

  $\mu = 0{,}65$

  $\frac{l}{d} = 1{,}65$

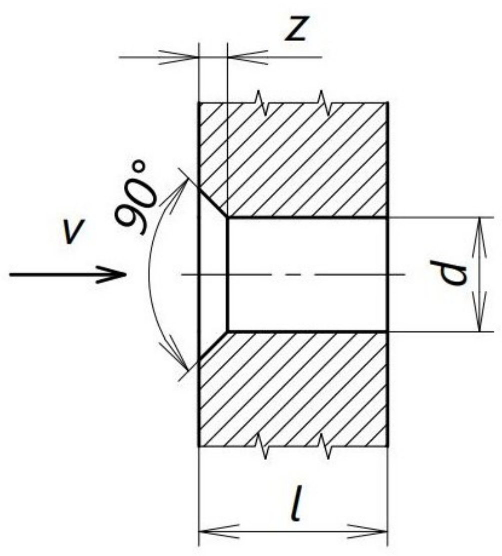


- Beveled hole

  $\mu = 0{,}78$

  $\frac{l}{d} = 1{,}65$

  $\frac{z}{d} = 0{,}25$

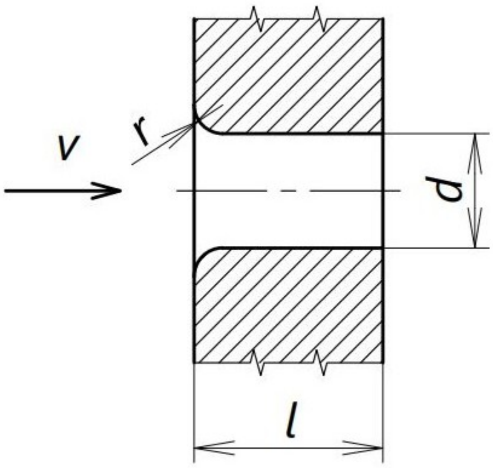


- Rounded hole

  $\mu = 0{,}84$

  $\frac{l}{d} = 1{,}65$

  $\frac{r}{d} = 0{,}25$



The flow area of the output hole:

$$F = i * \frac{\pi d^2}{4}$$

$$\frac{D}{50} \geq d$$

F	the flow area of the output hole	[m^2]
i	number of holes	[]
d	diameter of the output hole	[m]
D	internal pipe diameter	[m]

Density:

Density ρ [Kg/m^3] water depending on temperature and pressure

Temperature [°C]	Pressure [MPa]					
	0,1	0,25	0,5	1	1,5	2
0°	999,8	999,9	1000	1000,3	1000,6	1000,8
10°	999,7	999,8	999,9	1000,1	1000,4	1000,6
20°	998,2	998,3	998,4	998,6	998,8	999,1
30°	995,6	995,7	995,8	996	996,3	996,5
40°	992,2	992,3	992,4	992,7	992,9	993
50°	988,1	988,1	988,2	988,4	988,6	988,8
60°	983,2	983,3	983,4	983,6	983,9	984,1
70°	977,8	977,8	978	978,2	978,4	978,6

80°	971,8	971,9	972	972,2	972,4	972,7
90°	965,3	965,3	965,5	965,7	966	966,2
100°	-	958,4	958,5	958,8	959	959,2

Density ρ [Kg/m^3] water depending on temperature and pressure

Temperature [°C]	Pressure [MPa]					
	2,5	3	3,5	4	4,5	5
0°	1001,1	1001,3	1001,6	1001,8	1002,1	1002,3
10°	1000,8	1001	1001,3	1001,6	1001,8	1002
20°	999,3	999,5	999,8	1000	1000,2	1000,4
30°	996,7	996,9	997,2	997,4	997,6	997,8
40°	993,3	993,4	993,7	993,9	994,1	994,3
50°	989,1	989,2	989,5	989,7	989,9	990,2
60°	984,3	984,5	984,6	984,9	985,1	985,3
70°	978,9	979,1	979,2	979,5	979,7	979,9
80°	972,9	973,1	973,3	973,5	973,8	974
90°	966,4	966,6	966,8	967,1	967,3	967,6
100°	959,5	959,7	960	960,2	960,4	960,6

Density ρ [Kg/m^3] water depending on temperature and pressure

Temperature [°C]	Pressure [MPa]					
	6	7	8	9	10	12,5
0°	1002,8	1003,3	1003,8	1004,3	1004,8	1006
10°	1002,5	1003	1003,4	1003,9	1004,4	1005,5
20°	1000,9	1001,3	1001,8	1002,2	1002,7	1003,8
30°	998,3	998,7	999,1	999,6	1000	1001,1
40°	994,8	995,2	995,6	996,1	996,5	997,6
50°	990,6	991	991,5	991,9	992,3	993,3
60°	985,8	989,2	986,6	987,1	987,5	988,5
70°	980,4	980,8	981,3	981,6	982,1	983,2
80°	974,5	974,9	975,3	975,7	976,2	977,2
90°	968	968,4	968,9	969,4	969,7	970,9
100°	961,1	961,5	962	962,5	962,9	964

Density ρ [Kg/m^3] water depending on temperature and pressure

Temperature [°C]	Pressure [MPa]					
	15	17,5	20	25	30	35
0°	1007,3	1008,5	1009,7	1012,1	1014,5	1016,9
10°	1006,7	1007,9	1009	1011,3	1013,6	1015,7
20°	1004,9	1006	1007,2	1009,3	1011,4	1013,6
30°	1002,2	1003,2	1004,3	1006,5	1008,6	1010,6
40°	998,6	999,7	1000,8	1002,8	1004,9	1007
50°	994,4	995,5	996,5	998,6	1000,7	1002,7
60°	989,6	990,7	991,7	993,7	995,8	997,9
70°	984,3	985,3	986,4	988,4	990,5	992,6
80°	978,4	979,4	980,5	982,6	984,7	986,8
90°	972	973,1	974,2	976,4	978,5	980,6
100°	965,2	966,3	967,4	969,7	971,8	974

Density ρ [Kg/m^3] water depending on temperature and pressure

Temperature [°C]	Pressure [MPa]					
	40	45	50	60	70	80
0°	1019,3	1021,6	1023,9	1028,3	1032,7	1037
10°	1018	1020,2	1022,3	1026,6	1030,7	1034,9
20°	1015,7	1017,8	1019,9	1024,1	1028,1	1032
30°	1012,8	1014,7	1016,8	1020,8	1024,7	1028,5
40°	1009	1011	1013	1017	1020,8	1024,6
50°	1004,7	1006,8	1008,7	1012,6	1016,4	1020,2
60°	999,9	1001,9	1003,8	1007,8	1011,5	1015,3
70°	994,6	996,6	998,6	1002,5	1006,3	1010,1
80°	988,8	990,9	992,9	996,8	1000,7	1004,4
90°	982,7	984,7	986,8	990,8	994,6	998,5
100°	976,1	978,2	980,3	984,3	988,3	992,3

Saturated vapor pressure at a specific temperature:

Temperature [°C]	Saturated vapor pressure [Pa]
0°	611,3
10°	1228,1
20°	2338,8
30°	4245,5
40°	7381,4
50°	12344
60°	19932
70°	31176
80°	47373
90°	70117
100°	101320

Recommendation:

- The individual screens must be apart min. $5d$.
- The individual outlets located on one screen must be spaced apart min. $3d$.
- The individual outlet openings between the screens must not overlap.

d diameter of the output hole [m]

Example 1:
We have to determine the output absolute static pressure at which cavitation does not occur with the following parameters:
P_1 = 65000000Pa, P_T = 2338,8Pa.

$$P_2 = P_1 - 0{,}6(P_1 - P_T) = 65000000 - 0{,}6(65000000 - 2338{,}8) = 26001404{,}28Pa$$

Example 2:
We have to determine the input absolute static pressure at which cavitation does not occur with the following parameters:
P_2 = 101325Pa, P_T = 2338,8Pa.

$$P_1 = \frac{P_2 - 0{,}6P_T}{0{,}4} = \frac{101325 - 0{,}6 * 2338{,}8}{0{,}4} = 249804{,}3Pa$$

Literature:

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