LOW SHEAR VALVE PRINCIPLES

Fluid flow through valves

The majority of process valves can be divided into two types of applications: Isolation valves and control valves. Isolation valves have two positions of operation: Open and closed. They cause minimal or no disturbance to the flow passing through.

Control valves are designed to regulate the process specific parameters, such as flow rate, pressure drop, temperature and liquid level. Control valves resemble an orifice of some sort, which can change the opening depending on a signal from a controller. Fluid flow, passing through the restriction, experience intense turbulence and variations in pressure drop and flow velocities.

In the case when two or more immiscible liquids are present in the multiphase flow, the turbulence will stimulate the mixing. High intensity turbulence will lead to shearing of the liquid phases and the creation of an emulsion. An important characteristic of an emulsion is the droplet size distribution of the dispersed phase. The dispersed droplets vary in size and are usually spread in the range from 1 to 1000 µm. A common correlation is that the higher the mixing intensity, the greater the shearing, and the smaller the average droplet size of the dispersed phase. Emulsions can be classified as tight, medium or loose emulsions, following the increased average droplet size from smallest to largest.

Emulsions are undesired, but a commonly unavoidable phenomena during multiphase flow in a process plant. Large gravity-based separators are commonly used to separate mixed fluids into clean phases. Separation occurs by droplets from the dispersed phase travelling through the continuous phase to the phase interphase. The efficiency of gravity separators strongly depends on the droplet sizes of the dispersed phase as can be seen from Stokes' law, describing the droplet maximum vertical (settling) velocity.

$$v_t = \frac{g \cdot d^2 \cdot (\rho_c - \rho_d)}{18\mu_c} \qquad (1)$$

Where:

v_t = velocity of the droplet or particle rising or settling in a continuous phase, m/s

ρ_c = density of continuous phase, kg/m^3

ρ_d = density of dispersed phase, kg/m^3

g = gravitational constant, m/s^2

d = dispersed droplet diameter, m

μ_c = dynamic viscosity of continuous phase, kg/m·s

Hinze (1955) has described the shearing effect in the turbulent flow by formulating the maximum sustainable droplet size as a function of flow and fluid conditions:

$$d_{max} = We_{crit}^{3/5} \cdot \left(\frac{\sigma}{\rho_c}\right)^{3/5} \cdot \varepsilon^{-2/5} \quad (2)$$

Where:

d_{max} = maximum droplet diameter, m

We_{crit} = Critical Weber number

σ = interfacial tension between the oil and water phases, N/m

ρ_c = density of continuous phase, kg/m^3

ε = energy dissipation rate per unit mass, m^2/s^3 or W/kg

We_{crit} determines the state at which external deforming forces acting on the droplet exceed the counter-acting interfacial tension force, which lead to droplet break-up.

The mean energy dissipation rate per unit mass, ε, is the parameter that describes the intensity of the turbulence. As the kinetic energy in the turbulent flow cascades from large scale eddies down to smaller ones, energy dissipates into heat due to viscous forces. The energy dissipation rate is the parameter used to determine the amount of energy lost by the viscous forces in the turbulent flow. In order to reduce shear forces and increase maximum droplet size of the dispersed phase, the mean energy dissipation rate must be reduced.

For the flow through a control valve ε defines as:

$$\varepsilon = \frac{\Delta P_{perm} \cdot Q}{\rho_c \cdot V_{dis}} \quad (3)$$

Where:

ΔP_{perm} = permanent pressure drop, Pa

Q = volumetric flow rate, m3/s

ρ_c = density of continuous phase, kg/m3

V_{dis} = volume used for energy dissipation, m3

In a given system, the process determines flow rate, pressure and the fluid density. Therefore, the only parameter that can be used to decrease the energy dissipation rate is the volume involved in dissipating the required energy.

Low shear valve design principles

The definition and the purpose of the low shear valve is to reduce the shear forces acting on the fluids, while maintaining control properties. One effective way to reduce the shear forces in a control valve is to increase the volume involved in the energy dissipation.

Utilization of the hydrocyclone principle in a control valve increases the volume at which pressure drop occur. A swirl motion, similar to one that is established in the hydrocyclone, is induced in the fluid flow downstream the pressure-reducing element (globe or cage). In conventional control valves most of the pressure reduction occurs within the restriction itself. This is due to high velocity acceleration of the fluid during the flow through the restriction and following strong deceleration right after. The swirl motion in the cyclonic valve leads to maintaining the higher fluid velocities created by the flow through the restrictions. In addition, conical shape of valve's downstream volume accelerates the fluids further in a spiral direction, thereby contributing to the pressure decrease. The cyclonic valve's geometry utilizes the conical volume downstream the restriction in addition to the volume of restriction itself used for pressure reduction.

To enable the low shear operation, the following changes are implemented to the conventional valve (**Fig. 1.**):

- Tangentially oriented cage holes to regulate and transform an axial inlet flow into a vortex flow.
- A venturi-shaped cyclonic body installed downstream the cage to induce a suitable vortex pressure drop.
- A vortex breaker installed downstream the conical body to straighten the flow after the pressure reduction zone.

According to **Eq. 2** and **Eq. 3** this would lead to lower energy dissipation rate, and bigger maximum droplet diameter respectively.

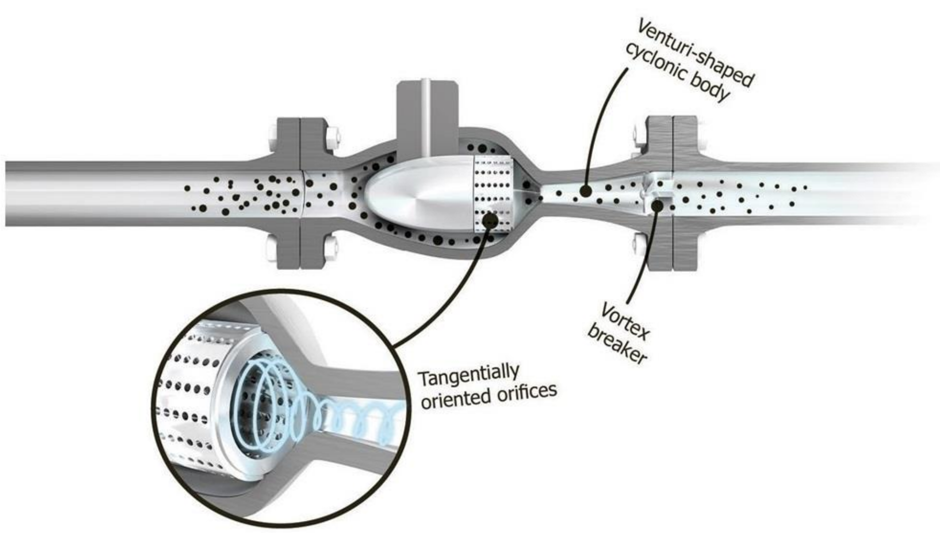

Figure 1. – Cyclonic valve design principles (courtesy to Typhonix.com)

It should be noted that a low shear valve is not a valve without shear forces but a valve with shear forces of less magnitude than conventional valves. Theoretically, the energy dissipation, which results in the pressure drop, is proportional to the shear forces. For a given energy dissipation, therefore, shear forces can only be reduced by involving a larger volume in the energy dissipation.

Advantages

Gravity based separation efficiency depends on average droplet size of the dispersed phase, retention time of the fluid in the separator and the density difference of the dispersed and continuous phases. The degree of emulsification created by choke and control valves, affects the average droplet size. The tighter the emulsion, the longer it takes to separate fluid phases. The representative parameters for oil-water separator performance would be oil-in-water (OiW) and water-in-oil (WiO) concentrations for the respective outlet streams.

Fig. 2. shows the relevance of retention time on water quality in gravity separation for emulsions created by a standard control valve and by a low shear valve. The implementation of a low shear valve in the process system results in less emulsified flow. This would lead to higher separation rate according to **Eq. 1**.

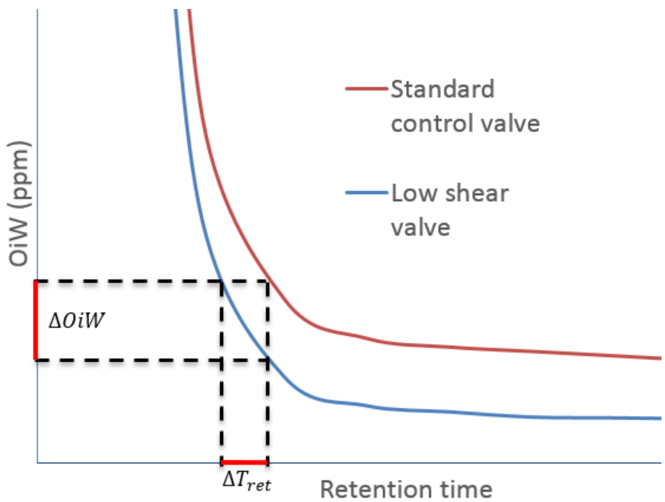

Figure 2. — Relation between water quality vs. retention time in gravity based separator for emulsions created by a standard control valve and by a low shear valve (representative estimate).

As can be seen from the graph, it is rather difficult to achieve complete separation. Certain amount of the dispersed phase is not possible to separate within the reasonable time frame due to presence of emulsified agents and other factors.

The replacement of a standard control valve with a low shear valve would allow following changes according to **Fig. 1**:

1) A reduction in the retention time necessary to achieve the desired quality of the water (OiW concentration) or
2) An improvement of the water quality while maintaining the original retention time.

In the first case, higher volume of process stream would be separated in the same time interval, thus increasing the separator capacity. In the second case, improved water quality may lead to reduction in the number of produced water treatment stages, or higher water treatment plant capacity due to less polluted water.

Additional reading:

Hinze, J.O. 1955. Fundamentals of the hydrodynamic mechanism of splitting in dispersion process. Vol. 1, No.3, 289-295, A.I.Ch.E. Journal. http://dx.doi.org/10.1002/aic.690010303.

Zande, M.J., van der, Muntinga J.H., Broek, W.M.G.T. van den. 1998. Emulsification of Production fluids in the Choke Valve. Presented at the SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, USA, 27-30 September. SPE-49173-MS. http://dx.doi.org/10.2118/49173-MS

Zande, M.J, van der. 2000. Droplet Break-up in Turbulent Oil-in-Water Flow Through a Restriction. PhD dissertation, Delft University of Technology, Delft, the Netherlands (June 2000)

Husveg, T., Bilstad, T., Guinee, P.G.A. et al. 2009 A Cyclone based Low Shear Valve for Enhanced Oil-Water Separation. Presented at the Offshore Technology Conference, Houston, Texas, USA, 4-7 May. OTC2029. http://dx.doi.org/10.4043/20029-MS See also: www.typhonix.com

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