Control valve design aspects for critical applications in petrochemical plants – part II

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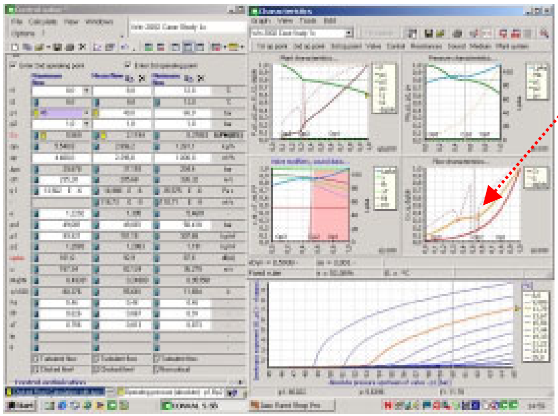
This second section of Mr Holger Siemers article on control valve design and sizing continues on from part I, which can be found in the June 2004 issue of Valve World. This section presents information on design, size and use of severe service control valves, the kind of troubles that can be predicted with control valve sizing as well as suggestions for troubleshooting control valve failures. The final section, part III, will be ready and waiting in the upcoming October issue.

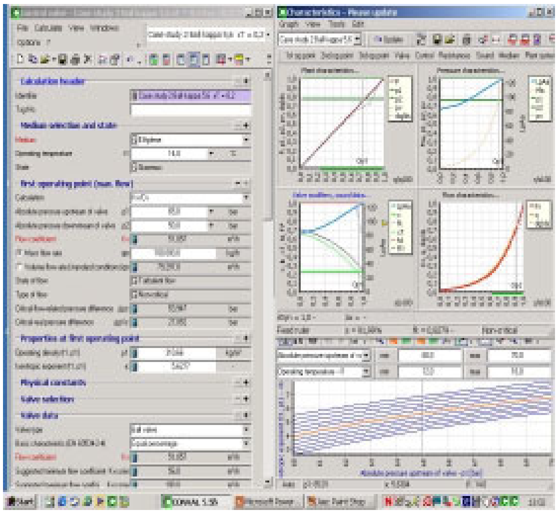
4) Predictable troubles with control valve sizing in case of sub-critical flow conditions

It is well-known that sensitive valve sizing areas exist with supercritical gases and slightly sub-cooled or non-sub-cooled liquids (flashing). Vapors and gases are calculated with the isentropic exponent k as one of the property values. Some hydrocarbons, e.g. ethylene, are near or above the "critical points t_ crit. and p_crit." during the process.



Critical flow

Predictable control instability, if application data are near the critical point because of sudden change of density and isentropic exponent.



Not critical flow

Incorrect result:
Cv calc = 81
xT = 0.2
at operating point
wrong κ=1.2
Correct result:
Cv calc= 59 with
κ = 5.6 !

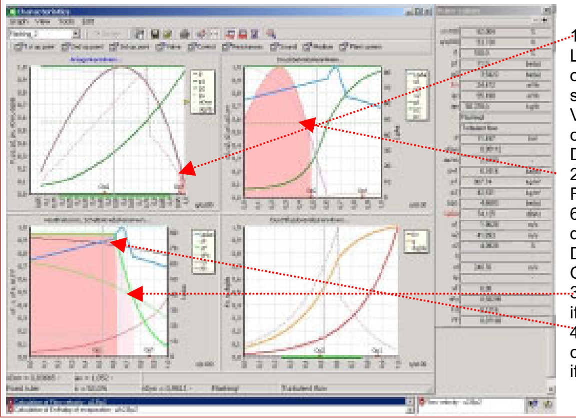
Range of κ from p1 = 60 to 70 bar and t1 from 12 to 16 °C

Fig. 16: Sensitive sizing areas in case of supercritical flow "isentropic exponent above the critical point" > 2

The sizing standard IEC 60534 2-1 includes an information table with typical isentropic exponents used for steam and gas sizing. The total range 1 < k < 2 is well-known for all compressible fluids. However, it is less-well-known that values 2 < k < 20 exist with supercritical fluids near and above the property critical point.

We would like to introduce this matter with the help of latest development in precise property calculation, published at the Ruhr University of Bochum for more than 60 industrial gases and integrated into the CONVAL“ software.

The third case study shows tremendous sizing differences in flow calculation for an ethylene application at the critical point of properties by using the real isentropic exponent >> 2. This can have a negative influence on plant safety valves and other devices. In the past, devices for supercritical flows were oversized because the wrong isentropic exponents and “choked flow limits” were used. We are interested to start an open discussion on how to define and handle this phenomenon and on how to validate it with measurements.



1)*Red area: Planning error: Loss of control quality at operating point qmax, see Fig. 18

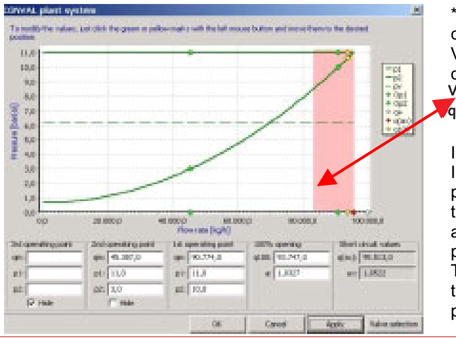
Valve authority too small to control qmax related to: SHELL DEP 32.36.01.17.-GEN

2)*Red area: Selection error Flashing with outlet velocities > 60 m/s, risk of mechanical damage, pipe vibration. Larger DN is recommended, if control < Op2

3)Light red area: cavitation start if $x_F > x_{Fz}$

4)Red area: choked flow, max. cavitation or flashing start, if $x_F > Fl^2$

Fig. 17: Example of warning indicators in a hot water application to indicate the onset of cavitation and flashing at smaller loads. If not controlled below Op2 no risk, if often control smaller loads < Op2, valve DN too small.



*Red area: Planning error leads to reduced control quality at operating point qmax Valve authority Vdyn too small to control qmax: CONVAL red area alarm if:

$V_{dyn} = \Delta p_{q90} / \Delta p_0 < 0{,}27$;

$q_{max} > 0{,}9q_{100}$

Input of one to three operating points. Illogical characteristics can be corrected by picking up an operating point and shifting the point to the logical place. This helps to avoid time-consuming plant system pressure loss calculations.

The red area shows here that Op. 1 is near the max. plant system flow –short circuit performance- and the valve pressure drop

Fig. 18: Dynamic plant system: – pressure versus flow-

*Red area: Planning error: Loss of control quality at operating point qmax. Valve authority too small to control qmax. Optimised, following: SHELL DEP 32.36.01.17.-GEN (Design and Engineering Practise)

1-Butene
Air
Ammonia
Argon
Benzene
Butane
Carbon monoxide
Carbon dioxide
Chlorine
Cyclohexane
Cyclopentan
Cyclopropan
Decane
Diethylether
Diisopropyl
Dipropylether
Ethane
Ethylbenzol
Ethylene
Fluorine
Helium
Heptane
Hexane
Hydrogen
Hydrogensulphide
Isobutane
Isohexan
Isopentan
Krypton
Methane
Methanol
Natural gas (AGA8)
Neon
Neopentan
Nitrogen
Nitrous oxide
Nonane
Octane
Oxygen
Pentane
Phenol
Propane
Propylbenzol
Propylene
SF6
Toluene
Water
Xenon
R11
R113
R12
R123
R124
R125
R134a
R141b
R142b
R143a
R152a
R218
R22
R23
R32
R41

Table 3: Available substances calculated with thermodynamic equations

Fig. 19: Typical damage due to cavitation if pressure differential > 20 bar. Feedwater control valve mismatched for start-up 70 to 1 bar.

Fig. 20: Damage due to flashing if p2 << pv and v2 >> 60 m/s.

Fig. 21: Damage due to a rotary plug body due to cavitation v2 >> 5 m/s.

Fig. 22: Damage due to steam pressure letdown Ma >> 1.

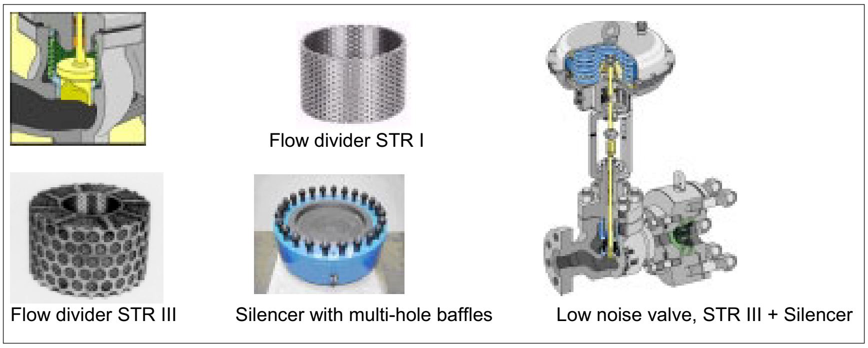


Fig. 23: The simplified noise abatement system used for compressible fluids.

Predictable troubles with control valve sizing in case of flashing as well as installation cost saving which results in poor planning parameters

Figure 17 shows an example of warning indicators in a hot water application to indicate the onset of cavitation and flashing at smaller loads. If not controlled below Op2 no risk, if often control smaller loads <Op2, valve DN too small.

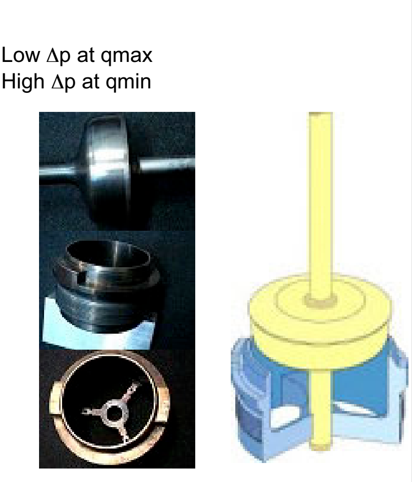


Fig. 24: AC Trim I System.

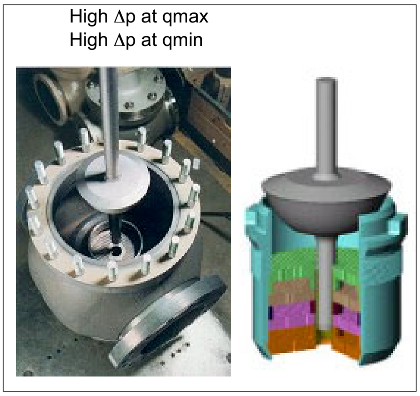


Fig. 25: AC Trim II System

CONVAL calculates real thermodynamic flashing conditions with about sixty hydrocarbons [see Table 3] and recommends the minimum valve DN to avoid critical outlet velocities. The calculations resemble steam table mathematics. This is based on a reliable source, the "Lehrstuhl für Thermodynamik Fakultät für Maschinenbau der Ruhr-Universität Bochum"

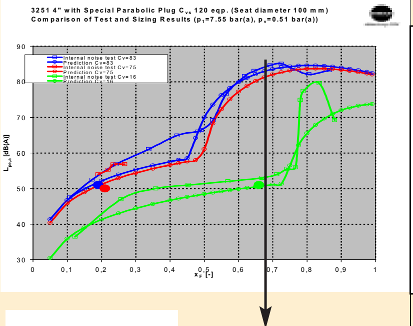
www.ruhr-uni-bochum.de/themo/index-eng.htm

Installation cost saving which results to poor planning parameters

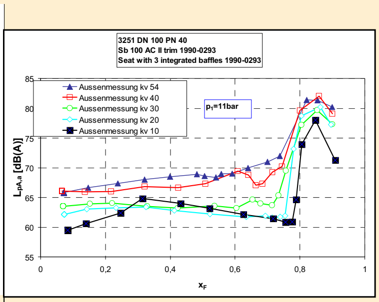
Detecting planning mistakes: qmax > 0.9 q100, Δp at qmax too small. See Figure 18.

5) Control valve failure and troubleshooting.

Ranging from seat guided V-port to CFD optimized trims and their applications. There are different solutions to avoid critical sound and mechanical valve failure (see Figures 19 through 22). This section introduces anti-cavitation valve trim designs [2] and noise attenua-



AC Trim I System
Application with:
Low Δp at qmax
High Δp at qmin



AC Trim II System
Application with:
Low Δp at qmax
High Δp at qmin

p1 [bar]	11	11	11
p2 [bar]	4	4	4
pv [bar]	0.01	0.01	0.01
Q [m^3/h]	30	108	144
rho [kg/m^3]	835	835	835
kv ges [m^3/h]	10.36	37.3	49.73
Lp [dB(A)]	< 70	< 70	< 70
xF	0.64	0.64	0.64

Fig. 26: Case history: application with low Δp at qmax and high Δp at qmin. Troubleshooting for an acetic acid plant, replaciong a noisy cage valve >> 85 dB(A) at a petrochemical plant in Hull (UK) with an AC Trim I System. The requirements were to avoid cavitation in the range of control in case of corrosive fluids. XFz > 0.75 at critical min. flow.

Fig 27: Case history: application with high Δp at qmax and high Δp at qmin. Troubleshooting for a gasoline loading station at a refinery in Hamburg (Germany) with AC Trim II System and the requirement to reduce SPL > 90 dB(A) to < 70 dB(A) in the entire range of control. XFz > 0.75 in the total range of control.

Globe valve type	X_{Fz} for valve 75% load	X_{Fz} for valve << 75% load	Resistance to contamination	Vibration behavior
Parabolic plug	0.25 to 0.35	clearly up to 0.8	high	poor for single-guided plugs
Piston-balanced plug with cage	0.25 to 0.35	up to 0.5	low	good
V-port plug	0.25 to 0.35	up to 0.5	high	excellent
Perforated plug	0.25 to 0.35	0.25 to 0.35	low	good
AC Trim System	0.35 to 0.5	clearly up to 0.85	high	good

Table 4: Different trim designs and their advantages and disadvantages in severe service applications.

tion devices and discuss their advantages and disadvantages as well as their application limits. Note that too high velocities at the valve moving parts and at valve outlet are mainly responsible for valve failure especially where corrosive fluids are handled.

SAMSON AG offers under strong limitations of valve outlet velocities and other parameters the high performance V-port trim for general service; flow dividers I and III and downstream low noise devices for gas and steam pressure letdown. See Figure 23.
If the V-port trim sound pressure level (SPL) is not acceptable for liquid applications or cavitation and corrosion must be avoided in general, the unique AC Trim System is recommended (see Figures 24 and 25) with top and seat guided plug; it is vibration-free and dirt-insensitive. The max. pressure differential 25 to 40 bar depends on the fluid properties. For case histories of troubleshooting with the AC Trim system , please see Figures 26 and 27. Further, Table 4 gives an overview of the advantages and disadvantages of different trim designs.


Fig. 28: AC Trim III System.

AC Trim III system multistage design

The AC Trim III System is ideal for liquid application to avoid cavitaion, wear and noise (see Figuire 28). Features include top and seat guided plug, vibration free and dirt-insensitive, with/without pressure balance, pressure dfferential 25 up to 120 bar; AC Trim V System-5 stages-120 bar < Δp <200 bar. Three and five stages in the cv range from Cv =1 (3 stages) to Cv=116 from DN 1 to DN 6 inch in globe and angle type valves are used in case of severe cavitation problems e.g. high Δp together with a larger control range qmin to qmax. Typical applications are feed-water start-up valves, refinery valves, snow gun valves, injection valves, boiler applications, high pressure letdown service, etc.

6) The hidden valve enemy: Critical outlet velocities need to take priority

Beating "quick and dirty" sizing philosophies, if selecting too small valve DN taking only the calculated Cv value into account. High flow capacity valves (Cv/DN^2) need to be selected with care when critical operation conditions are involved. Rule of thumb to avoid mix phase flow: in case of pv equal or near to p1 avoid 20xDN any pipe restriction at valve upstream, no elbows, no manual valves, no pipe reducers.
Sensitive sizing areas special valve DN selection by giving priority to the outlet velocity condition of cavitation and flashing in liquid application and gas and steam pressure letdown, taking important piping parameters into account.

Valve design	K_C	$\Delta p_{crit,cav}$ [bar]
Single-stage globe valves with stellited or hardened valve plug and seat	0.7	25
Single-stage globe valves with standard materials	0.7	15
Rotary plug valves (with eccentric spherical disk)	0.4	10
Butterfly and ball valves	0.2-0.3	5

Table 5: Recommendations to reduce cavitation erosion [2]. Using table 5 for non-corrosive liquids with cavitation: $X_F > X_{Fz}$

- **Outlet velocity should not exceed 2m/s to max 5m/s depends on valve design**
- **Low vibration valve plug design like seat, cage or top and bottom guided plugs.**
- **Low cavitation erosion: $\Delta p < K_C \bullet (p1-pv)$ or $\Delta p < \Delta pcrit,cav$, if $\Delta p > K_C \bullet (p1-pv)$!**
- **Cavitation erosion: $\Delta p > K_C \bullet (p1-pv)$ and $\Delta p > 25$ bar -> multistage globe valves (like AC Trim III System)**

In case of flashing conditions, the average outlet velocity has to be calculated for the mixture of liquid and wet steam or vapour. Severe pipe vibration and valve damage can be avoided if the valve outlet diameter restricts the outlet velocity to less than 60 m/s (average of 0.7 Ma of mixture sonic speed). SAMSON has developed equations of state for flashing outlet velocities used in CONVAL for all fluids in Table 3. ■

To be continued.

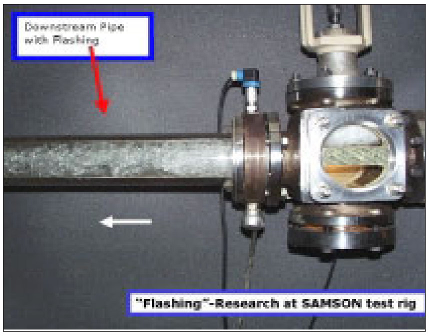


Fig. 29: Flashing Photo SAMSON AG test rig [2]

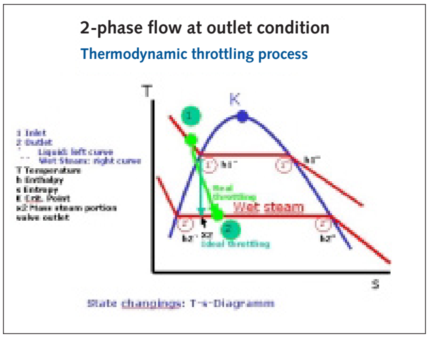


Fig. 30: The thermodynamic flashing process. T = temperature; s = entropy; K = critical point.


Fig. 31: Plant shutdown due to "quick and dirty" sizing with 8 inch rotary plug valve and too small DN.
Non-subcooled naphtha p1 = pv.
The application requires a 12 inch valve to avoid the risk of sonic speed "choked flow" at the valve outlet.