FLOWNEX®
SIMULATION ENVIRONMENT

THE SIZING OF PRESSURE CONTROL AND PRESSURE SAFETY VALVES INCLUDING REACTION FORCE CALCULATION

This case study demonstrates the use of Flownex® to size properly performing pressure control valves for typical plant operation and to size and select a code compliant matching pressure safety valve, and calculate the associated relief flow reaction forces.

OIL AND GAS INDUSTRY

Challenge:

The main challenge is the application of Flownex® to:

1. Size pressure control valves (PCV) to perform properly over the entire flow duty envelope.
2. Size a matching pressure safety valve (PSV) capable of handling a pressure control valve failure case.
3. Check pipe sizes and upstream and downstream pressure drops and temperatures for code compliance.
4. Calculate the PSV relief flow reaction forces.

Benefits:

Pressure control and relief- or safety valve sizing is often done by the supplier, using their specialised and dedicated software. However, these do not take installation piping into account and often do not give reaction force values as the PSV supplier is normally not the plant designer. Flownex® is an excellent tool that enables the plant designer to quickly and simply size and select pressure control valves and determine the requirements for a matching PSV whilst accounting for the actual installation configuration. Furthermore, code compliance often dictates changes in the design or layout to satisfy pressure drop or other requirements. The advantage of a Flownex® model is that these compliance requirements can be tested during the preliminary design stage, well before significant design commitments have been made. This allows the plant designers to test layout concepts and prevent costly redesign work at a later stage.

Solution:

Flownex® can be used effectively to model pressure control and safety valves in a layout representative of the intended installation, even before significant CAD work is being undertaken.

"Flownex® has the ability out of the box to perform the complete sizing and code compliance checks for pressure control valves with their matching full-flow pressure safety valves. The further ability to model a dynamic relief situation in real time is almost unheard of in this industry."
Hannes van der Walt
Principal Thermal Engineer
Gasco (Pty) Ltd

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INTRODUCTION

Pressure control valves (PCVs), pressure regulating valves and pressure safety valves (PSVs) are an important part of any plant design in the oil and gas industry. Gas products are typically transported at very high pressures to reduce pumping costs and reduce line sizes. Pressure control valves (and the subset of pressure regulating valves) are then used to reduce the pressures to the required levels at the point of consumption. However, if a pressure control valve fails, the plant design must make provision for safety systems to prevent catastrophic events from taking place. The proper selection and installation of pressure safety valves is one option. Alternatively, two pressure control valves may be installed in series in a so called active-monitor arrangement. Furthermore, a slam-shut valve may be installed that is able to shut down the plant in a short period of time.

This paper discusses the combination of pressure control and pressure safety valves where the latter is used as the means of ensuring failure should the former fail. The usage of PSVs is commonplace in most oil and gas plants, in fact, all international design codes and standards in the oil and gas industry mandate their use at any position in the plant where pressures may exceed design parameters. Pressure increases beyond design values may occur mainly due to three causes:

5. Process failure – a situation where faulty equipment is no longer capable of controlling the pressure to acceptable limits. This may include a failed control valve, a blocked outlet, a tube rupture, a loss of utility such as cooling medium or power, gas blow-by etc.
6. Locked-in thermal expansion – a situation where a vessel or length of pressure piping may be locked in upstream and downstream and a resident heat source then causes the internal pressure to rise beyond design limits.
7. External fire relief – a situation where an external fire may add heat to a vessel or pressure piping, resulting in a similar scenario to the locked-in thermal expansion case.

A side-effect of the installation of a PSV is the resulting reaction force that may be created when the PSV opens. Since most PSVs "pop" open rather quickly, very high reaction forces may result and must be checked by the design engineer.

This case study demonstrates how Flownex® can be used to size a PCV as well as a matching full-flow PSV and easily calculate the resulting reaction forces. Checks for design code compliance are also performed.

PRESSURE CONTROL AND PRESSURE RELIEF VALVE SIZING AND SELECTION

In selecting a pressure control valve for a specific application, the maximum duty flow rate as well as the potential turn-down requirement must be considered. A well selected valve would be at approximately 70% to 80% opening at maximum duty flow rate and at approximately 20% to 30% opening at minimum flow (maximum turn-down). Checking these pressure control valve limits in a Flownex® model is as simple as it is in other software such as HYSYS or specialised valve manufacturer software such as Fisher's *Specification Manager*, Leser's *ValveStar*, Farris' *sizeMaster*, SAMSON's *Valve Sizing Program*, Flowserve's *ValQuo* etc. Similarly, once relief requirements are known, proprietary software is able to quickly and easily select a pressure safety valve.

However, in the case of a pressure control and a pressure safety valve operating in series in a real-world system, other software is often not able to determine the fail-open flow rate through the pressure control valve when installed with actual piping, reducers, filters or manual valves in a line. The sizing of an appropriate safety valve whilst simultaneously taking the actual installation into account, is similarly beyond the scope of most valve sizing software. The ability of Flownex® to perform all of this in a single and simple model sets it apart from other software.

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As explained, a common case of process failure is where an upstream pressure control valve fails open. The pressure control valves themselves are often assembled in a fail-to-close failure mode; however, a control system failure may still leave the valve open. It is also possible that the valve remains stuck in the open position due to a mechanical failure.

It is common practice to have a piping specification break immediately downstream of a pressure control valve as all downstream piping and equipment are subjected to a reduced pressure. For instance, high gas pressures at 10 000 kPa may require Class 900 piping and equipment, up to and including the pressure control valve which is set to reduce the pressure to 4 000 kPa. Piping and equipment downstream of the pressure control valve only require Class 300 equipment owing to the reduced pressure. However, if the pressure control valve fails open for any reason, the designer may incorporate an over-pressure sensor and switch with a slam shut valve arrangement, or alternatively if the flows are relatively moderate, a full flow pressure relief system may be more cost effective. If the flow rates are high, the required size of a full flow PSV may be prohibitive. The challenge then is to determine how much flow the failed pressure control valve will pass which will have to be relieved by the pressure safety valve. This flow rate may be evaluated in terms of the full installation of all components and their associated pressure losses in the system which may often serve to reduce the flow rate.

CASE STUDY

Sizing the Pressure Control Valve

As a typical example, a fuel gas pressure control valve is to be sized for a given duty flow and turn-down. In case of the control valve failing open, a full flow pressure safety valve must be selected. The example uses the following data specification:

Table 1: Input Data

Property	Unit	Value
Required maximum fuel gas flow rate	kg/hr	1200
Required minimum fuel gas flow rate	kg/hr	400
Maximum fuel gas inlet temperature	°C	35
Minimum fuel gas inlet temperature	°C	5
Maximum supply (design) pressure	kPa (g)	10200
Minimum supply pressure	kPa (g)	8000
Regulated pressure	kPa (g)	5000
Corrosion Allowance	mm	2
Piping Material	ASTM A106 Grade B	
Pressure Control Valve Opening Type	Equal Percentage	

When sizing a pressure control valve, the combinations of the above conditions resulting in the maximum and minimum valve openings have to be selected to ensure that the openings would be at acceptable settings. The maximum valve opening will occur at the maximum volume flow rate which will be at the maximum mass flow rate, minimum pressure and maximum temperature. The valve minimum opening will occur at the reverse conditions.

The pressure control valve's flow coefficient (Cv or Kv) have to be estimated and then tested against all conditions. This may require an iterative process to ensure that acceptable valve openings will result at the maximum and minimum valve positions.

For the example at hand, the required valve flow coefficient is calculated by selecting the conditions for maximum opening as discussed above and setting the valve opening to a typical value such as 70%. Then, by keeping the calculated valve flow coefficient constant, the minimum valve opening is checked at the conditions for minimum opening. The following results were obtained for the example:

Table 2: Initial Results

Property	Unit	Max. Opening	Min. Opening
Flow Rate	kg/hr	1200	200
Upstream Pressure	kPa (g)	8000	10200
Downstream Pressure	kPa (g)	5000	5000
Upstream Temperature	°C	35	5
Downstream Temperature	°C	21.5	-22.9
Opening	%	70	13.7
Flow Coefficient	Cv	3.896	3.896

It appears that the valve opening at minimum flow is a little too small and the valve's controllability at this opening may be compromised. The opening is too small because the calculated valve capacity is too large. A slightly smaller valve capacity will mean that the valve will have to open a little more at maximum flow, but at the low flow end the valve opening will be slightly larger. To calculate a slightly lower flow coefficient, select an 80% valve opening at maximum flow conditions and repeat the process:

Table 3: Final Results

Property	Unit	Max. Opening	Min. Opening
Flow Rate	kg/hr	1200	200
Upstream Pressure	kPa (g)	8000	10200
Downstream Pressure	kPa (g)	5000	5000
Upstream Temperature	°C	35	5
Downstream Temperature	°C	21.5	-22.9
Opening	%	80	23.7
Flow Coefficient	Cv	2.635	2.635

This is a much better selection, so a valve with a flow coefficient as indicated needs to be sourced. Once an actual valve is selected, the actual valve Cv or Kv value should be entered into the Flownex® model and the upper and lower flow limits verified. Note also the low gas temperatures expected in the minimum opening case. Of course, these low temperatures are not dependent on the flow rate, or valve opening per se, rather simply the upstream and downstream pressures and the upstream temperature. The property selection for the minimum opening case, however, conveniently selects the highest supply pressure and lowest supply temperature which will result in the lowest downstream temperature. It is important to take note of this temperature and ensure that this is comfortably above the minimum design metal temperature (MDMT). For the case at hand, the carbon steel piping selected has a MDMT of -29°C.

The Flownex® model and results for the final sizing is given in the following figures:

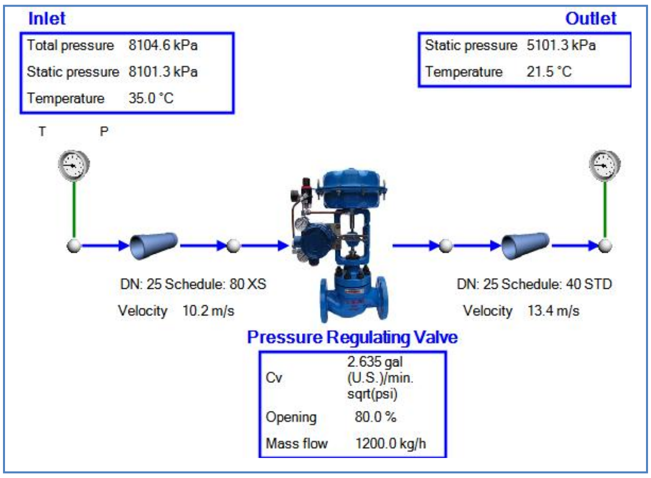

Figure 1: Maximum Valve Opening Case (Minimum Pressure, Maximum Temperature, Maximum Mass Flow Rate)

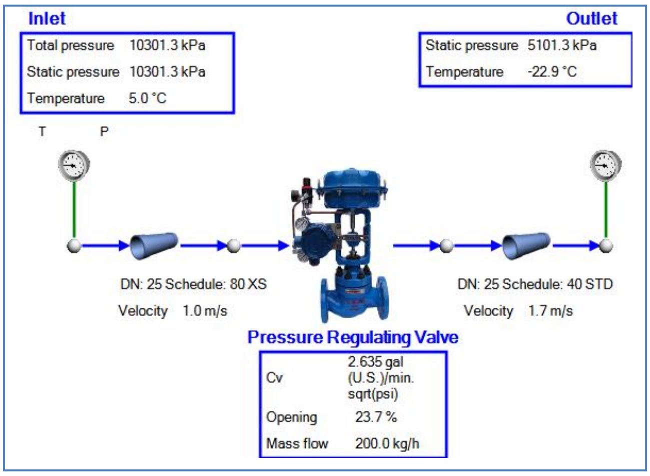

Figure 2: Minimum Valve Opening Case (Maximum Pressure, Minimum Temperature, Minimum Mass Flow Rate)

Note that Flownex conveniently allows the designer to check pipe velocities. According to ASME B31.3 a DN25 pipe with a design pressure of 10200 kPa (g) and a 2 mm corrosion allowance will require a Schedule 80 pipe. For the downstream DN25 piping, a design pressure of 5500 kPa (g) with a 2 mm corrosion allowance will require Schedule 40 piping. Note that all pressures shown on the Flownex® model are absolute.

The Flownex® valve component used in the above figures is the *ANSI Control Valve* which was assigned a more realistic picture.

The valve sizing is done using the Flownex® Designer, solving for three properties simultaneously as shown below. The Designer configurations provide for different pressure, temperature and flow rate combinations. The entries in the *Equality Constraints* (target values) are the upstream (supply) static pressure, the downstream (controlled) static pressure and the mass flow rate. Note that the target pressures are static pressures as pressure control valves normally sense only static pressure. The *Independent Variables* that the Flownex® solver will vary to obtain the target values are the supply total pressure, the downstream total pressure and the pressure control valve flow coefficient (Cv). Flownex® will find a solution for all three constraints within seconds.

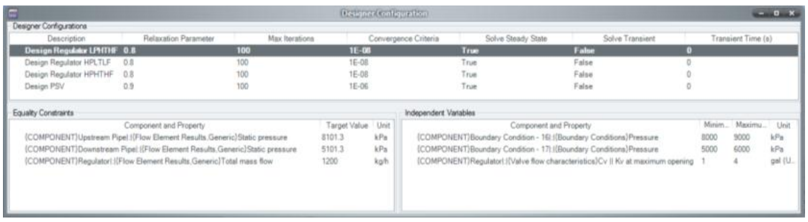

Figure 3: Flownex Designer Setup for Pressure Control Valve Sizing

Sizing the Pressure Safety Valve

As soon as the pressure control valve has been sized and selected, the pressure safety valve may be sized and selected. To ensure compliance to a design code such as API 520, the following needs to be checked:

1. The vessel or piping being protected must not be subjected to a pressure higher than 110% of design pressure.
2. The pressure drop in the PSV inlet piping must not exceed 3% of the set pressure (gauge). This is to ensure that there is only a small difference in the PSV relief pressure and the pressure the protected vessel or piping is subjected to.
3. Similarly, the pressure drop in the PSV discharge piping must not be larger than 10% of the set pressure (gauge) for conventional spring-loaded PSVs and 50% for pilot-operated PSVs.
4. Discharge temperatures must be within design limits.

The next figure shows the Flownex® model of the example PCV and PSV operating in a real-world installation.

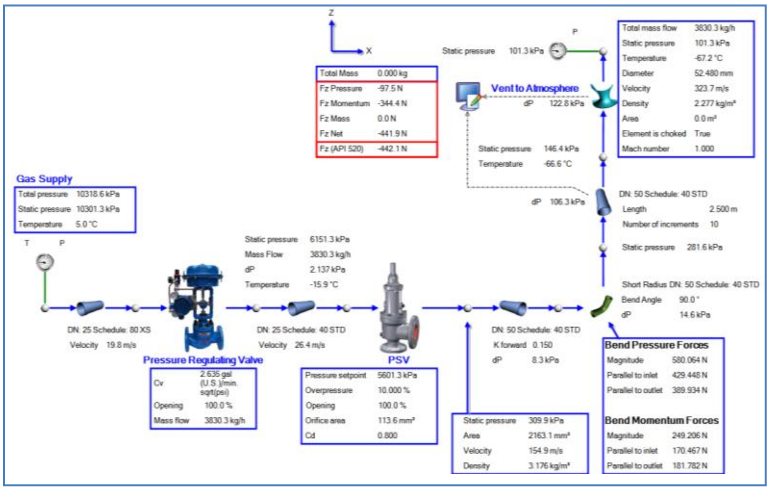

Figure 4: Flownex Model of Pressure Control Valve and Pressure Safety Valve Combination

The DN25 Schedule 40 piping directly downstream of the fail-to-open pressure control valve has a design pressure of 5500 kPa (g) as discussed above. It is the task of the PSV to prevent a pressure excursion in the piping downstream of the failed control valve. According to frequently used international standards such as API 520 and API 521, pressure piping and pressure vessels are allowed to reach pressures that are 10% higher than the design pressure in case of process failure. This means that the PSV may be set at the piping design pressure with full relief flow occurring at 110% of design pressure. For the case at hand, the PSV will be set at 5500 kPa (g) with 10% over-pressure as shown in Figure 4, thus the pressure is allowed to reach 6050 kPa (g). At this pressure, the PSV must be able to release all the flow that the failed pressure control valve is passing, otherwise the pressure will continue to increase beyond 110% of design pressure.

This flow situation is very easily modeled in Flownex® as shown in Figure 5, once again using the *Designer*. This time though, the pressure control valve and the pressure relief valve openings are both set to 100% to simulate the failed-open situation and full PSV relief flow.

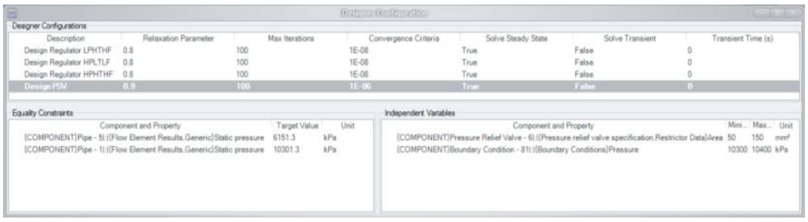

Figure 5: Flownex Designer Setup for Pressure Safety Valve Sizing

The *Equality Constraint* (target value) is the relief pressure:

110% x 5500 kPa (g) + 101.3 kPa = 6151.3 kPa (a)

The *Independent Variable* is the PSV orifice area. The second equality constraint and second independent variable are simply used to obtain the correct upstream static pressure by setting the upstream total pressure via the boundary condition.

As shown in the Flownex® model, the PSV needs to have an orifice area of at least 113.6 mm^2. This translates to an API (or ASME) "E" orifice size. PSV orifice discharge coefficients typically range from 0.8 to 0.95. The former, conservative value is a good start, but the value should be updated with manufacturer values as soon as these are known.

The pipe section between the pressure control and safety valves in Figure 4 is meant to represent the pipe run between the protected vessel or piping and the PSV. It is shown that this section of pipe has a pressure drop of 2.137 kPa which is 0.04% of the set pressure (gauge) and therefore is compliant. Of course, this section of piping may be more elaborate, including elbows and longer pipe runs, however, as a general rule, this pipe run should be kept as short and simple as possible. The pressure at the node immediately downstream of the PSV displays a pressure of 208.6 kPa (g) which is 3.8% of the set pressure (gauge) and therefore also is compliant.

Note that the discharge temperature is -67°C which is far below the MDMT of the piping material chosen. This means that the discharge piping may need to be from a different material such as ASTM A304 stainless steel. It may also be possible, using a Flownex® model with heat transfer, to show that the piping material temperature will not fall below the MDMT of -29°C if the PSV discharge can be shown to last only a few seconds before another safety shut-down system stops the flow. In such a case, ASTM A106 B may still be acceptable.

Although not shown in this case study, it is easy to extend this example to a transient analysis. Such an example is where the failed pressure control valve may discharge into a large vessel. The PSV connected to the vessel may then be smaller than a full-flow relief valve as the vessel pressure may be shown to increase slowly due to its volume. If the system is shut off after a reasonable time, the vessel pressure may not have exceeded the design pressure yet and the reduced size PSV then has enough time to relieve the built-up vessel content.

Much more elaborate installations may be modelled in Flownex®. One such example is shown in Figure 6. The PCV supplies a knock-out vessel. The normal outflow piping is not shown as only the PSV piping needs to be analysed.

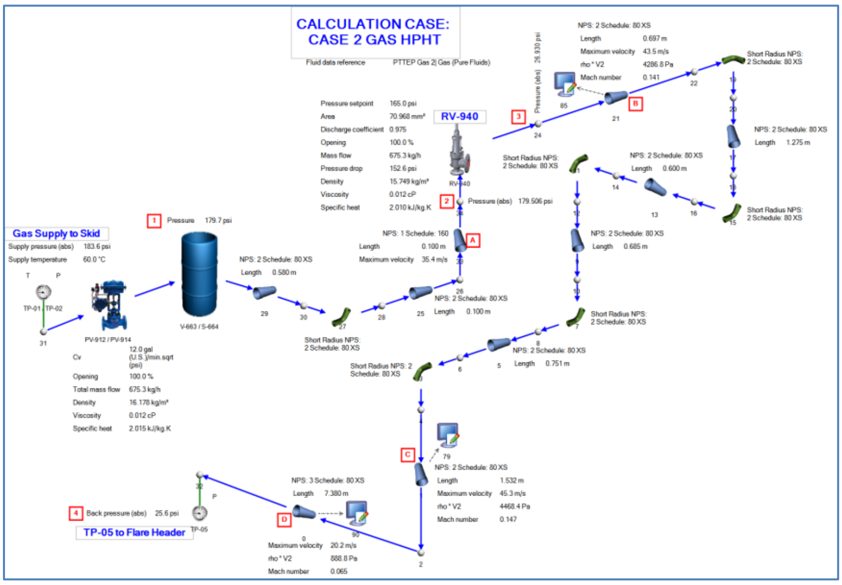

Figure 6: A More Comprehensive Flownex® PCV & PSV

Pressure Safety Valve Reaction Forces

As shown in Figure 4, the Flownex® model may also be used to determine the PSV relief flow reaction forces. With a vertical outlet as shown in Figure 4, high velocity gas discharged to the atmosphere will cause a vertical, downward reaction force on the outlet piping. Since PSVs typically “pop” open, design standards often call for a dynamic load factor (multiplier) to account for the initial impulse. A typical dynamic load factor of 2 is often used in the oil and gas industry and would simply double the calculated net force value.

PSV installations are often in the geometrical form shown in Figure 4 where the PSV outlet is initially horizontal and then turns vertical with the release to atmosphere high enough to satisfy OH&S requirements. A force applied at the PSV outlet therefore causes a bending moment at the PSV connections (flanges) and therefore supports may be required.

The simplest method to calculate PSV reaction forces may be to place the elbow at the exit to atmosphere and utilise the elbow component’s built-in force results. These elbow force results are shown in Figure 4. The disadvantage of this method is that the elbow component does not allow the specification of an exit loss coefficient which is taken as 1.0. This may be the cause of significant inaccuracies as relief velocities are often sonic. Therefore, the model shown in Figure 4 places the actual vertical length of pipe and an exit loss component downstream of the elbow.

A simple script is then used to calculate the momentum and pressure forces from first principles as well as the API 520 force calculation. If needed, the PSV and piping masses may also be specified which will add another force component to the vertical. The script reads the gas mass flow, static pressure, pipe cross sectional area, gas heat capacity (Cp), gas constant (R) and gas temperature at the point between the pipe and the exit loss element. It also reads the gas static pressure and gas velocity at the point of discharge from the exit loss element. Figure 7 shows how the simple script then calculates the z-forces for momentum, pressure and weight as well as the implementation of the API 520 equation. Note that the net force calculated from first principles and the force calculated by the API 520 method are practically identical. Also note that the dynamic load factor is yet to be applied to these results.

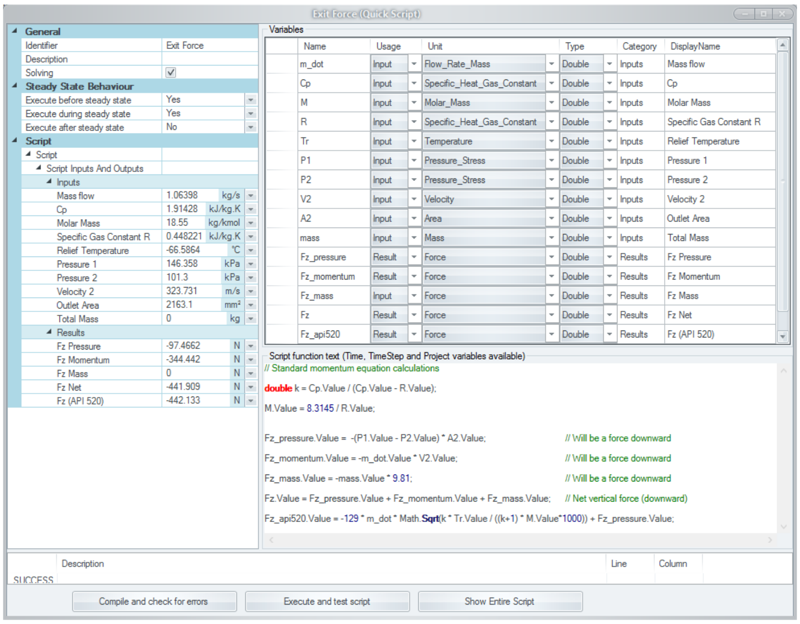

Figure 7: Force Calculation Script

Summary

Using a very simple Flownex® model, a pressure control valve may be sized to perform properly at the high and low valve opening cases. A matching full flow pressure safety valve may then be sized to ensure vessel or piping pressures do not exceed design limits. At the same time, pressure drop limits, temperature limits and PSV reaction forces are also checked for compliance with design specifications. Apart from a simple script, Flownex® has the ability out-of-the-box to perform the complete sizing and code compliance checks for pressure control valves with their matching full-flow pressure safety valves. The further ability to model a dynamic relief situation in real time is almost unheard of in this industry.