6.5.3 Calculation of the Reaction Force

When the safety device is closed, the loads resulting from the system pressure at the inlet and (if existing) superimposed back pressure are static and already taken into account when designing the pipe work and selecting the safety device.

Reaction forces are forces generated when the safety valve is blowing. When the safety valve is open, the reaction forces are generated by the impulse of the flow and by built-up back pressure. At the inlet, the change of the forces is small. At the outlet, the reaction forces need to be considered, particularly for gaseous fluids, due to the high flow velocity and the increase of outlet pressure.

NOTE: In many installations, the flow in the outlet is critical with speed of sound at a considerably higher back pressure than in the case of the closed valve.

When the safety valve is installed without a discharge pipe, the reaction force acts radial to the inlet axis. At steady flow, many forces will balance each other out. It should be noted that this balancing needs a certain time, depending on the opening time of the valve and the pressure wave propagation time. The transient forces can be reduced by minimizing the length of piping.

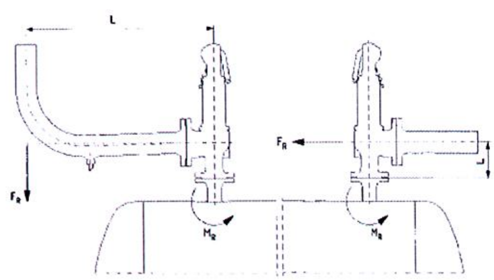

Figure 6.5.3-1: Reaction Force

LESER offers the possibility to calculate the reaction forces in three different ways:

1. ISO 4126-9
2. API 520 Part 2
3. AD 2000-Merkblatt A2

Reaction force calculation with VALVESTAR®
An easy and user-optimized calculation of the reaction force can be done with the LESER sizing program VALVESTAR®. It is possible to choose between the three standards. VALVESTAR® is available online at www.valvestar.com.

6.5.3.1 Calculation of the Reaction Force According to ISO 4126-9

Used Symbols	Designation	Units
F	Reaction force	N
Q_m	Mass flow	kg/h
u	Velocity of the fluid in the outlet pipe	m/s
P_b	Back pressure	MPa abs
P_u	Superimposed back pressure	MPa abs
A_A	Flow area of the outlet pipe	mm²

Table 6.5.3.1-1: Symbols ISO 4126-9

At steady flow, the reaction force, F, expressed in N, can be calculated, taking into account the conditions at the end of the piping, by the following equation:

$$F = \frac{Q_m x\ u}{3600} + (P_b - P_u)\frac{A_A}{10} \quad (6.5.3.1\text{-}1)$$

6.5.3.2 Calculation of the Reaction Force According to API 520 Part II

Used Symbols	Designation	Units	
F	Reaction force at the point of discharge to the atmosphere	N	lbf
W	Flow of any gas or vapour	kg/s	lbm/hr
k	Ratio of specific heats (Cp/ Cv) at the outlet conditions	-	
C_p	Specific heat at constant pressure	-	
C_v	Specific heat at constant volume	-	
T	Temperature at the outlet	°K	°R
M	Molecular weight of the process fluid	-	
A	Area of the outlet at the point of discharge	mm²	in²
P	Static pressure within the outlet at the point of discharge	barg	psig

Table 6.5.3.2-1: Symbols API 520 Part II

Determining Reaction Forces in an Open Discharge System
The following formula is based on a condition of critical steady-state flow of a compressible fluid that discharges to the atmosphere through an elbow and a vertical discharge pipe. The reaction force (F) includes the effects of both momentum and static pressure; thus, for any gas, vapour, or steam.
In U.S. customary units

$$F = \frac{W}{366} \cdot \sqrt{\frac{kT}{(k+1)M}} + (AP) \quad (6.5.3.2\text{-}1)$$

In metric units

$$F = 129W \cdot \sqrt{\frac{kT}{(k+1)M}} + 0{,}1 \cdot (AP) \quad (6.5.3.2\text{-}2)$$

Determining Reaction Forces in a Closed Discharge System
Pressure-relief devices that relieve under steady-state flow conditions into a closed system usually do not transfer large forces and bending moments to the inlet system, since changes in pressure and velocity within the closed system components are small.
Only at points of sudden expansion in the discharge piping will there be any significant inlet piping reaction forces to be calculated. Closed discharge systems, however, do not lend themselves to simplified analytical techniques. A complex time history analysis of the piping system may be required to obtain the reaction forces and associated moments that are transferred to the inlet piping system.

6.5.3.3 Calculation of the Reaction Force According to AD 2000-Merkblatt A2

Used Symbols	Designation	Units
F_R	Reaction force at the blow-out opening	N
q_m	Mass flow to be drawn off	kg/h
p_n	Absolute final pressure in the blow-out line	bar
p_{a0}	Absolute imposed backpressure	bar
p_{ns}	Absolute final pressure in the blow-out line at sound velocity, i.e. Mn = 1	bar
A_n	Clear cross-sectional area at blow-out end of line	mm²
M_n	Mach number at the end of the pipe (Mn ≤ 1)	-
k	Isentropic exponent of the medium in the pressure chamber	-
T_0	Absolute temperature within the pressure vessel in the quiescent condition	K
v_n	Velocity at the end of the pipe of the blow-out opening	m/s
v_s	Sound velocity	m/s
ρ_n	Density of the fliud in the blow-out opening at the end of the pipe	kg/m³

Table 6.5.3.3-1: Symbols AD 2000-A2

The reaction force due to the outflow FR ($N=kgm/s^2$) is determined according to the general momentum theory.

$$F_R = \frac{q_m}{3600} \cdot v_n \qquad (6.5.3.3\text{-}1)$$

In this case, v_n is the velocity in the blow-out opening.

$$v_n = \frac{q_m}{3600} \cdot \frac{10^6}{\rho_n \cdot A_n} \qquad (6.5.3.3\text{-}2)$$

For gases, v_n is less than/equal to the sound velocity. If M_n is known, v_n can be calculated according to the following formula:

$$v_n = M_n \cdot \sqrt{\frac{2k}{k+1} \cdot \frac{p_n \cdot 10^5}{\rho_n(p_n, T_0)}} \leq \cdot \sqrt{k \cdot \frac{p_n \cdot 10^5}{\rho_n}} = v_s \qquad (6.5.3.3\text{-}3)$$

Furthermore, for gases a pressure term is added to the momentum term, if for the throughput of the mass flow at sound velocity the pressure is $p_n = p_{ns} > p_{a0}$.

$$F_R = \frac{q_m}{3600} \cdot v_s + A_n \cdot (p_n - p_{a0}) \cdot \frac{1}{10} \qquad (6.5.3.3\text{-}4)$$

LESER Note: Explanation of the formula:

Formula 6.5.3.3-1: General formula for the reaction force. It is valid for gases and liquids.

Formula 6.5.3.3-2: General formula for the velocity at the end of the pipe of the blow-out opening. It is valid for gases and liquids.

Formula 6.5.3.3-3: The velocity at the end of the pipe of the blow-out opening can be calculated with this formula, when the Mach number at the end of the pipe is known and the medium is gas.

Formula 6.5.3.3-4: This formula can be taken, if the medium is gas, the velocity is sound velocity and the outlet is ending into a blowdown system.