HYDRAULIC ACCUMULATOR
DIMENSIONING

OSP 050

Principles

The accumulator dimensioning method is based on the status change of the gas contained in the accumulator. The same changes occur with oil.

While dimensioning hydraulic accumulators, the following two elements have to be accounted for:

- the principle wants that the accumulator filling gas (nitrogen) behaves as an ideal gas, which in practice is not the case at high pressures and low temperatures
- as the temperature exchange process is unknown, isothermal or adiabatic changes can only be assumed.

The ideal and real gas

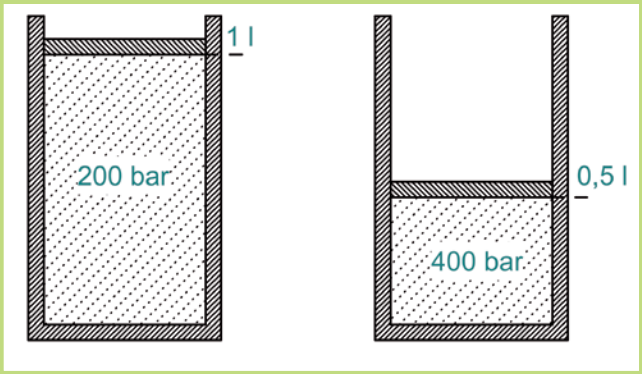
Ideal gas: this gas does not exist

Real gas: all known gases are real. The more they move away from their condensation point (the point where a gas changes to liquid), the more the gas features get closer to those of an ideal gas.
Nitrogen condensation point: -196 °C

Assuming that we have to deal with an ideal gas, the accumulator filling gas behaves as described hereafter.

Equation for an ideal gas

At constant temperature and isothermal state change:



Boyle-Mariotte's Law

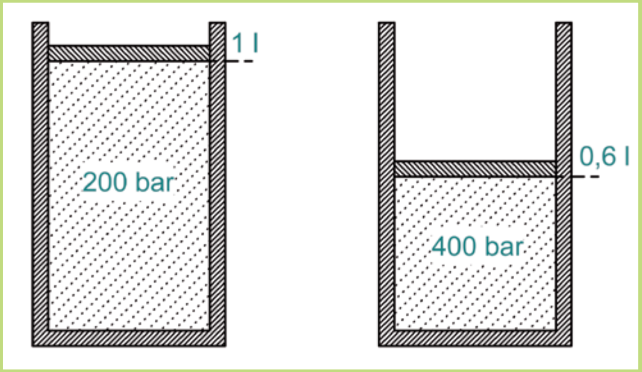
At constant temperature, the product of pressure and volume of the gas contained in a vessel is always constant.

$$p \bullet V = constant$$

As, however, no ideal gas is available, one must take the behaviour of the real gas into consideration.

Equation for an real gas

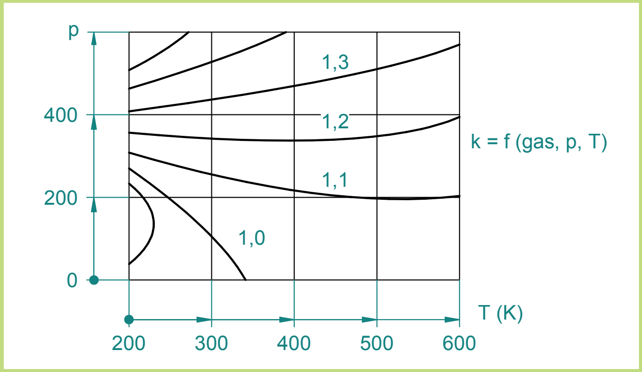
At constant temperature and isothermal state change:



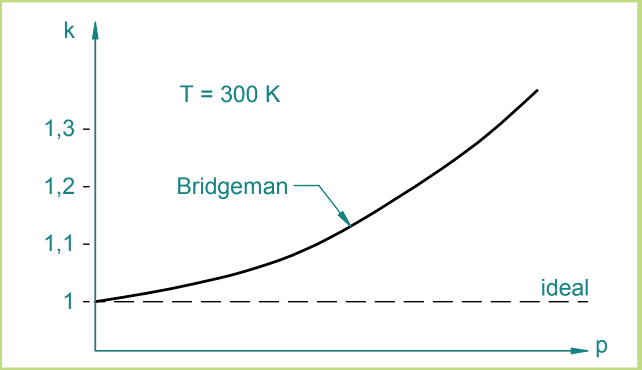
It is obvious, that the state equation p • V = constant does not describe the real behaviour of a gas, specially at high pressures and low temperatures.

The compressibility factor "k" makes it possible to take account of and describe the behavioural differences between the real and ideal gas.

p - T - diagram for constant "k" values in case of nitrogen



By integrating the Beattie Bridgeman equation into our computer program, we are able to take account of the above mentioned behavioural differences of the gas.



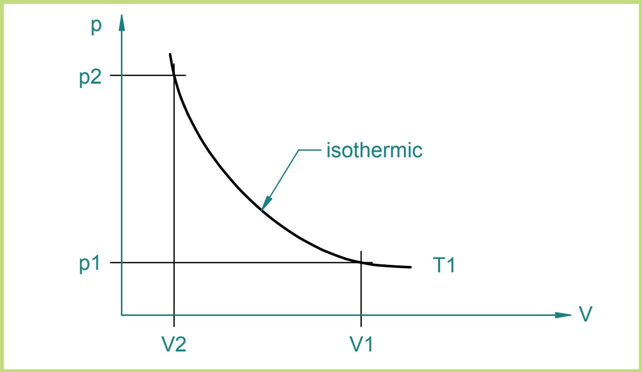
State changes of ideal gases

The state of a gas is defined by three factors: **pressure, volume and temperature**, also called state variables. A state change refers to the change of two or all state variables. Filling or emptying a hydraulic accumulator leads to an exchange of work at accumulator gas level. A gas temperature differing from the ambient temperature leads to a thermal exchange. Processes affecting the accumulator gas and linked to the work and thermal exchanges can be described by means of an isobaric (constant pressure), isothermic (constant temperature), isochore (constant volume), adiabatic (without heat transfer) or polytropic (between isothermic and adiabatic) change of state.

The following processes include volume variations:

Isothermic changes of state

One refers to isothermic changes of state for a hydraulic accumulator when charging and discharging happen over a long period allowing for a full thermal exchange with the environment. During such a state change, the gas exchanges work and heat with the environment.



Relationship between p, V and T

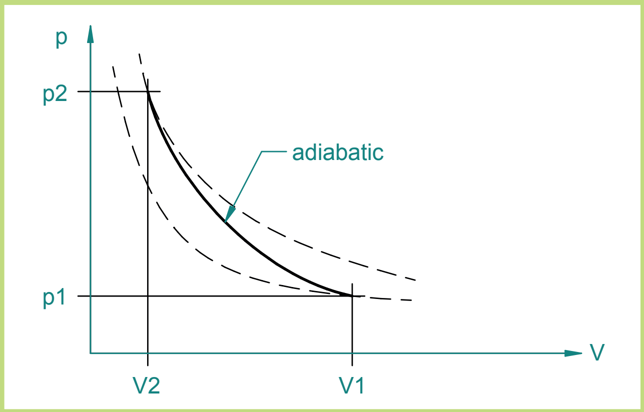
Boyle-Mariotte governs following relationship:

$$p \bullet V = constant$$

T = constant

Adiabatic changes of state

One refers to adiabatic changes of state for a hydraulic accumulator when charging and discharging happen in such a short space of time, that apart from an exchange of work no heat exchange may take place with the environment.



Relationship between p, V and T

The following rule governs this relationship:

$$p \bullet V^{\chi} = constant$$

with χ = adiabatic exponent

$\chi = f(p, T, gas)$

$$\chi = \frac{c_p}{c_v}$$

c_p = specific heat capacity at constant pressure
c_v = specific heat capacity at constant volume

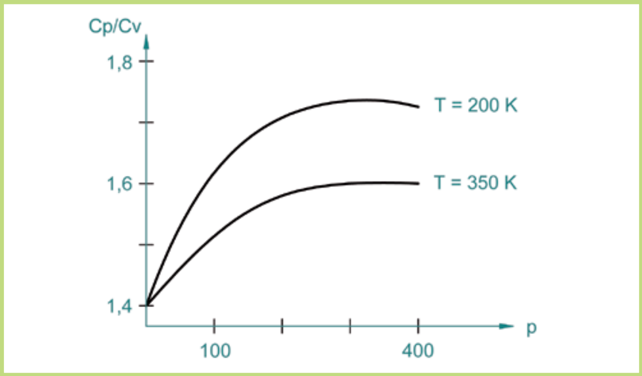
Based on an ideal gas, the adiabatic exponent depends on the number of gas atoms of the gas.

$\chi = 1{,}67$	gas with 1 atom	at 0 °C and 1 bar
$\chi = 1{,}4$	gas with 2 atoms	
$\chi = 1{,}3$	gas with 3 atoms	

The higher the number of atoms, the closer to 1 χ will be. The adiabatic exponent of nitrogen is 1,4.

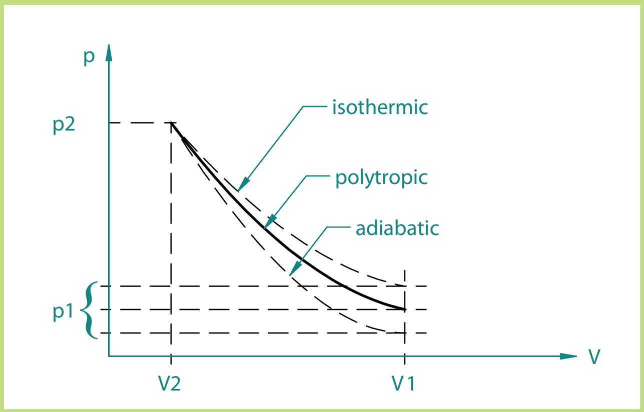
As mentioned earlier, the adiabatic exponents does not only depend on the gas, but also on pressure and temperature.

This adiabatic exponent can also exceed the value of 1,4.



Polytropic changes of state

While charging and discharging the accumulator, the change of state rarely occurs fully isothermically or fully adiabatically. The gas contained in the accumulator exchanges some of its heat. This change is called polytropic and characterised by a mix of exchange of work and to a bigger or smaller extent of heat.



Relation between p, V and T

The following rule governs this relation:

$$p \cdot V^n = constant$$

n = polytropic exponent

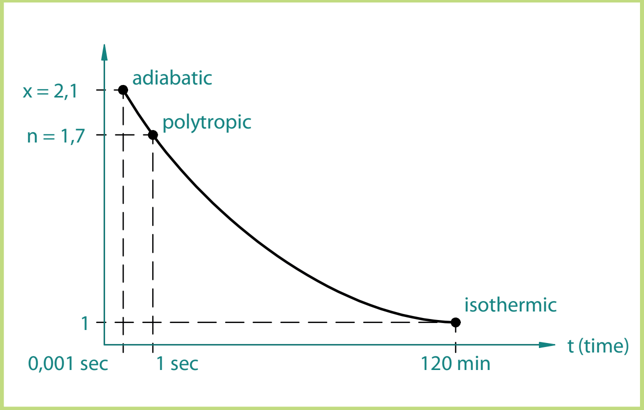
$n = f(p_1, p_2, p_0, V_0, T_{oil}, T_{gas}, t, \text{accumulator shape})$

By getting closer to the isothermic state "n" tends to 1 and to the adiabatic state "n"tends to the adiabatic exponent "χ" .

$$1 < n < \chi$$

Relation between the adiabatic exponent "χ" and the polytropic exponent "n"

Example of a type EHV 50-330 hydraulic accumulator at an operating pressure of 300 bar and an operating temperature of 10 °C:



χ represents the highest value on the curve.
The polytropic exponent "n" is located between the adiabatic and isothermic exponent and depends on t, p_1, p_2, p_0, V_0, T_{oil}, T_{gas} and the accumulator shape.

All these formulas and explanations clearly show that it is not possible to accurately dimension hydraulic accumulators by means of diagrams and simple formulas.
One really needs a program running on a powerful computer taking all the above mentioned factors into account.

OLAER owns this program!

Challenge us.

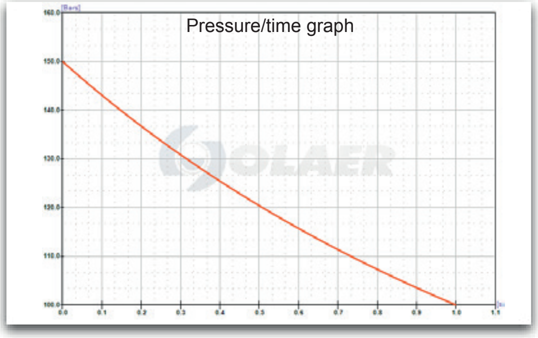
The following examples illustrate the information contained in the hard copies printed by the computer.

Hard copy 1 - Technical features at 20 °C

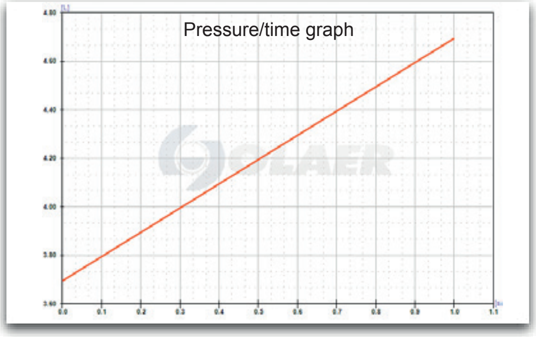
OLAER Accu 2.1

Simulation als Energiespeicher

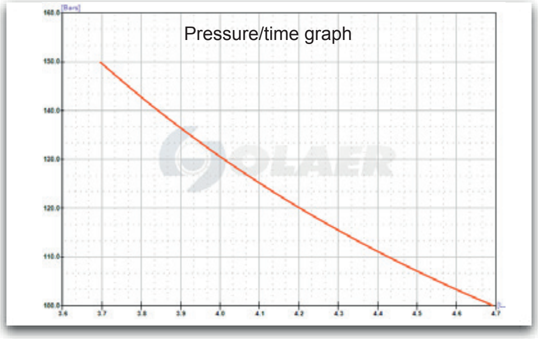
Hard copy 2 - p - t diagram



Hard copy 3 - V - t diagram



Hard copy 4 - p - V diagram



Approximate accumulator calculation

Parameters and abbreviations

p_0 =	precharge pressure (bar)	usually at 20 °C
p_1 =	minimum operating pressure (bar)	admissible minimum operating overpressure
p_2 =	maximum operating pressure (bar)	admissible maximum operating overpressure
ΔV =	returned volume (l) (V_1 - V_2)	volume of the accumulated or returned liquid
T_1 =	minimum operating temperature (°C)	minimum ambient or liquid temperature
T_2 =	maximum operating temperature (°C)	maximum ambient or liquid temperature
t =	charge time / discharge time (s)	necessary liquid accumulation or return time
V_0 =	actual accumulator volume (l)	corresponds to the term "Capacity" in the data sheets
V_1 =	capacity at pressure p_1 (l)	accumulated gas volume at pressure p_1
V_2 =	capacity at pressure p_2 (l)	accumulated gas volume at pressure p_2
n =	polytropic exponent	coefficient taking the thermal exchange into account
p_m =	average operating (bar)	used to dimension pulsation dampers

$$\frac{p_2 + p_1}{2} = p_m$$

**For all accumulator dimensioning calculations absolute pressures (relative pressures + 1 bar) will be used.
The temperatures T1 and T2 are in ° Kelvin (T + 273).**

Power buffer dimensioning:

Formula used to determine the capacity V_0 :

$$V_0 = \frac{\Delta V \bullet \frac{p_1}{p_0}}{1 - \left(\frac{p_1}{p_2}\right)^{\frac{1}{n}}}$$

Formula used to determine the returned volume ΔV :

$$\Delta V = V_0 . p_0 \frac{1 - \left(\frac{p_1}{p_2}\right)^{\frac{1}{n}}}{p_1}$$

Temperature influence

The above formulas may be used only at approximately stable temperatures. When the system is subject to important temperature variation a correction must be applied (also true in case of approximative calculations).

The Gay-Lussac law is used here:

$$V'_0 = V_0 \bullet \frac{T_2}{T_1}$$

Gas filling pressure

As a general rule, the pressures p_1 and p_2 are defined by the hydraulic system. The gas filling pressure must be chosen from case to case and according to the accumulator shape.

The gas filling pressure is always set for the maximum operating temperature (T_2). Gas filling is usually carried out at a temperature of 20 °C. All indications concerning gas filling pressures issued by OLAER apply for 20 °C.

In general, the following formulas are used:

Energy buffering / security reserve applications

$$p_0 = 0{,}9 \bullet p_1$$

at temperature T_2

Limits : p_0 min. ≥ 0,2 x p_2
p_0 max. = p_1
(contact OLAER; according to operating conditions)

Weight balancing applications

$$p_0 = 0{,}9 \bullet p_1$$

at temperature T_2

Pulsation damping applications

$$p_0 = 0{,}6 \bullet p_m$$

at temperature T_2

Accumulator applications with additional gas bottles

Bladder accumulator

$$p_0 = (0{,}95 \div 0{,}97) \bullet p_1$$

at temperature T_2

Piston accumulator

$$p_0 = p_1 - (2 \div 5\ bar)$$

at temperature T_2

Gas filling pressure formula p_0 at 20 °C

$$p_0 \text{ at } 20\,°\mathrm{C} = p_0 \text{ at } T_2 \ \frac{273 + 20}{T_2}$$

Dimensioning example:

Known values:

Operating pressure p_2 max.	190 bar
Operating pressure p_1 min.	100 bar
Returned volume ΔV	2 l
Discharge time	1 s
Operating temperature T_1 min.	25 °C
Operating temperature T_2 min.	45 °C
Polytropic exponent n	at 25 °C = 1,638
(according to our PC program)	at 45 °C = 1,617

Values sought:

Hydraulic accumulator capacity V_0

Solution:

a) Calculation of the gas filling pressure p_0 at the maximum operating temperature

$$p_0 = 0{,}9 \bullet 101 = 91\ bar = 90 \text{ relative bar}$$

b) Calculation of the capacity V_0

$$V_0 = \frac{\Delta V \bullet \dfrac{p_1}{p_0}}{1 - \left(\dfrac{p_1}{p_2}\right)^{\frac{1}{n}}} = \frac{2 \bullet \dfrac{101}{91}}{1 - \left(\dfrac{101}{191}\right)^{\frac{1}{1{,}6}}} = 6{,}8\ litre$$

c) Calculation of the capacity V'_0

$$V'_0 = V_0 \bullet \frac{T_2}{T_1} = 6{,}8 \bullet \frac{318}{298} = 7{,}3\ litre$$

d) Calculation of the gas filling pressure p_0 at20 °C

$$p_0 \text{ at } 20\,°\mathrm{C} = 0{,}9 \bullet p_1 \bullet \frac{273 + 20}{T_2} =$$

$$0{,}9 \bullet 101 \bullet \frac{273 + 20}{318} =$$

$$84 \text{ bar} = 83 \text{ relative bar}$$

The data sheets allow one to select the desired accumulator in the requested pressure range with the capacity of $V_0 > 7{,}3$ l.

In our example, the accumulator type EHV 10 - 210 - K or EHV 10 - 210 - L will do the job (according to the desired accumulatorshape).

Our computer calculation gives a ΔV of 2,06 l at 25 °C and 2,26 l at 45 °C.

Warning!

In the theoretical part of the present document we have mentioned the important influence of the temperature when dimensioning accumulators. At -10 °C for instance, a 10 l accumulator will only return 1,71 l oil.