Basic Accumulator Terms

p_0 = gas precharge pressure

p_1 = minimum working pressure

p_2 = maximum working pressure

V_0 = effective gas volume of the accumulator *(this an internal net volume)*

V_1 = gas volume at p1

V_2 = gas volume at p2

T_0 = temperature at precharging

T_1 = minimum ambient temperature

T_2 = maximum ambient temperature

$p_0@T_0$ = gas precharge pressure at precharge ambient temperature

$p_0@T_1$ = gas precharge pressure at minimum ambient temperature

$p_0@T_2$ = gas precharge pressure at maximum ambient temperature

Accumulator Operational Sequence Steps

Bladder

1 The bladder accumulator is precharged with nitrogen to system design specified precharge pressure prior to accumulator installation.

- The expanded, pressurized bladder causes the fluid port poppet to close, preventing the bladder from extruding into the fluid port.
- No fluid is inside the accumulator at this step until the accumulator is installed in the hydraulic system and the system pressure becomes greater than the precharge pressure, P_0.
- Once the system working fluid pressure becomes greater than P_0, the poppet will open and the bladder will begin to compress.

2 The accumulator is installed in the hydraulic system and the fluid is increased to the maximum working system pressure, P_2. This is often called “charging” the accumulator.

- At P_2, the gas volume in the bladder accumulator is V_2.
- At this step the maximum amount of fluid possible for a particular system pressure range is inside the accumulator and the fluid is compressing the bladder and nitrogen gas to smallest gas volume.

3 During operation, the minimum working system pressure, P_1, is reached and the gas volume is now V_1. This is often called “discharging” the accumulator.

- V_1 is the maximum gas volume during hydraulic system operation and correlates to the smallest possible fluid volume inside the accumulator during system operation.
- The amount of fluid that is expelled, or supplied, to the hydraulic system is ΔV, where $\Delta V = V_1 - V_2$
- A small amount of fluid should remain inside the accumulator at P_1, in order to prevent the bladder from rubbing or chaffing against the fluid port poppet which will cause bladder damage.
- Therefore the precharge pressure, P_0, should always be slightly lower than the minimum working system pressure, P_1.

Diaphragm

1 The diaphragm accumulator is precharged with nitrogen to system design specified precharge pressure prior to accumulator installation.

- The expanded, pressurized diaphragm causes the integral poppet in the diaphragm to close over the fluid port opening, preventing the diaphragm from extruding into the fluid port.
- No fluid is inside the accumulator at this step until the accumulator is installed in the hydraulic system and the system pressure becomes greater than the precharge pressure, P_0.
- Once the system working fluid pressure becomes greater than P_0, the diaphragm with an integrated poppet, will begin to compress and cause the integral poppet to move away from the fluid port opening.

2 The accumulator is installed in the hydraulic system and the fluid is increased to the maximum working system pressure, P_2. This is often called “charging” the accumulator.

- At P_2, the gas volume in the diaphragm accumulator is V_2.
- At this step the maximum amount of fluid possible for a particular system pressure range is inside the accumulator and the fluid is compressing the diaphragm and nitrogen gas to smallest gas volume.

3 During operation, the minimum working system pressure, P_1, is reached and the gas volume is now V_1. This is often called “discharging” the accumulator.

- P_1 is the maximum gas volume during hydraulic system operation and correlates to the smallest possible fluid volume inside the accumulator during system operation.
- The amount of fluid that is expelled, or supplied, to the hydraulic system is ΔV, where $\Delta V = V_1 - V_2$
- A small amount of fluid should remain inside the accumulator at P_1, in order to prevent the diaphragm from rubbing or chaffing against the shell which will cause diaphragm damage.
- Therefore the precharge pressure, P_0, should always be slightly lower than the minimum working system pressure, P_1.

Piston

1 The Piston accumulator is precharged with nitrogen to system design specified precharge pressure prior to accumulator installation.

- The pressurized nitrogen will cause the piston to move completely over to the fluid port side.
- No fluid is inside the accumulator at this step until the accumulator is installed in the hydraulic system and the system pressure becomes greater than the precharge pressure, P_0.
- Once the system working fluid pressure becomes greater than P_0, the fluid pressure will begin to compress the gas by overcoming the precharge pressure, and cause piston to move away from the fluid port opening.

2 The accumulator is installed in the hydraulic system and the fluid is increased to the maximum working system pressure, P_2. This is often called “charging” the accumulator.

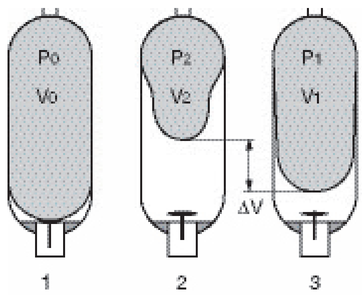
- At P_2, the gas volume in the piston accumulator is V_2.
- At this step the maximum amount of fluid possible for a particular system pressure range is inside the accumulator and the fluid is exerting force on the piston and compressing nitrogen gas to the smallest gas volume.

3 During operation, the minimum working system pressure, P_1, is reached and the gas volume is now V_1. This is often called “discharging” the accumulator.

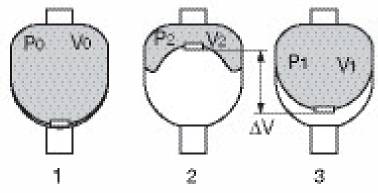
- P_1 is the maximum gas volume during hydraulic system operation and correlates to the smallest possible fluid volume inside the accumulator during system operation.
- The amount of fluid that is expelled, or supplied, to the hydraulic system is ΔV, where $\Delta V = V_1 - V_2$
- A small amount of fluid should remain inside the accumulator at P1, in order to prevent the piston from impacting the end cap for any system cycle.
- Therefore the precharge pressure, P_0, should always be slightly lower than the minimum working system pressure, P_1.

Accumulators

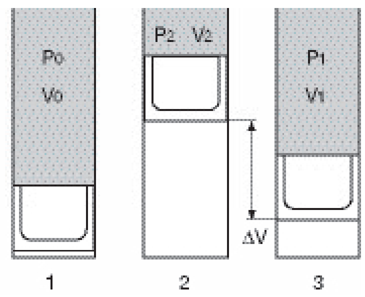
Bladder



Diaphragm



Piston



Precharge Recommendations

For energy storage:

$p_0 = 0.9 \times p_1$

p_1 = minimum working pressure

For shock absorption:

$p_0 = (0.6 \text{ to } 0.9) \times p_m$

p_m = median working pressure at free flow

For pulsation dampening:

$p_0 = (0.6 \text{ to } 0.8) \times p_m$

p_m = median working pressure

Temperature Effect

Due to the Ideal Gas Laws, the precharge pressure of an accumulator is affected by the ambient temperature of the accumulator's operating environment. Given the constant volume of an accumulator shell when the temperature rises, the gas pressure will increase and conversely as the temperature goes lower, the gas pressure decreases. This temperature effect on precharge gas pressure will affect operation of the accumulator in a hydraulic fluid system. Therefore it is critical to consider the precharge pressure at T_2, maximum ambient temperature, and T_1, the minimum ambient temperature, when sizing an accumulator to ensure that the accumulator is sized large enough to operate properly over the entire operating ambient temperature range. The formula below describes the ambient temperature and precharge pressure relationship to any temperature. Refer to the sizing example on page 95 to see how the formula is applied in the sizing calculation process.

Fahrenheit

$$p_0@T_0 = p_0@T_x \times \left(\frac{T_0 + 460}{T_x + 460}\right)$$

T_0 = precharge temperature in °F

T_x = actual ambient operating temperature in °F, where T_x is $T_1 \le T_x \le T_2$

$p_0@T_0$ = gas precharge pressure at precharge ambient temperature

$p_0@T_x$ = gas precharge pressure at maximum ambient operating temperature, where T_x is $T_1 \le T_x \le T_2$

Celsius

$$p_0@T_0 = p_0@T_x \times \left(\frac{T_0 + 273}{T_x + 273}\right)$$

T_0 = precharge temperature in °C

T_x = maximum operating temperature in °C, where T_x is $T_1 \le T_x \le T_2$

$p_0@T_0$ = gas precharge pressure at precharge ambient temperature

$p_0@T_2$ = gas precharge pressure at maximum ambient operating temperature, where T_x is $T_1 \le T_x \le T_2$

Gas Behavior

The compression and expansion processes taking place in hydro-pneumatic accumulators are governed by the general gas laws.
The following applies for ideal gases:

$$p_0 \times V_0^n = p_1 \times V_1^n = p_2 \times V_2^n$$

where the time related change of state is represented by the polytropic exponent "n". For slow gas expansion and compression processes which occur almost isothermically, the polytropic exponent can be assumed to be n = 1.

For rapid processes, the adiabatic change of state can be calculated using n = k = 1.4 (for nitrogen as a diatomic gas)

For pressures above 3000 psi the real gas behavior deviates considerably from the ideal one, which reduces the effective fluid volume ΔV. In such cases a correction is made which takes into account an adiabatic exponent (k) even greater than 1.4; n = k > 1.4. By using the following formulas, the required gas volume V_0 can be calculated for various calculations.

For low pressure applications of less than 150 psi absolute gas pressures must always be used in the formulas.

Calculation Formulas

polytropic:

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

isothermal:
(n=1)

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

adiabatic:
(n = k = 1.4)

$$V_0 = \frac{\Delta V}{\left(\frac{p_0}{p_1}\right)^{0.714} - \left(\frac{p_0}{p_2}\right)^{0.714}}$$

Correction factors to take into account the real gas behavior(2

For isothermal change of condition:

$V_{0,real} = C_i \times V_{0,ideal}$ or

$$\Delta V_{0,real} = \frac{\Delta V_{ideal}}{C_i}$$

for adiabatic change of condition:

$V_{0,real} = C_a \times V_{0,ideal}$ or

$$\Delta V_{real} = \frac{\Delta V_{0,ideal}}{C_a}$$

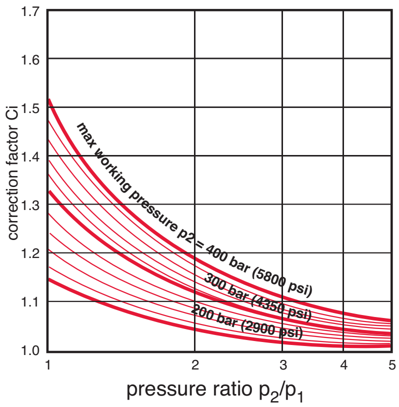
The C_i and C_a can be determined from the following Correction factor graphs.

Calculate the ratio of Max/Min pressure, p_2/p_1.

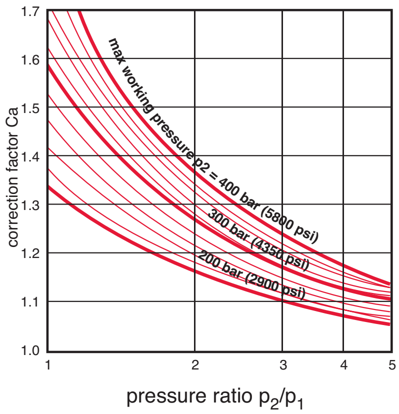
On the graph find the intersection of p_2/p_1 and the maximum working system pressure p_2, which is shown as a curve on the graphs for either an isothermal or adiabatic change of condition.

Project the intersection point to the Y-axis to determine the appropriate correction factor, C_i or C_a.

Correction factor C_i Isothermal change of condition



Correction factor C_a Adiabatic change of condition



Sizing Example

An additional operation is to be added to an existing machine which requires 1.35 gallons of oil in 2.5 seconds for optimal operation. The system must operate between 3000 psi and 1500 psi. The operating ambient temperature range is 75 to 120°F. The machine's hydraulic fluid pump is sufficient to fully recharge the accumulator in the 8 second machine dwell time. Total machine cycle time = 10.5s.

Given:

maximum system working pressure
p_2 = 3000 psi

minimum system working pressure
p_1 = 1500 psi

required fluid volume of the system
ΔV = 1.35 gallons

maximum ambient operating temperature
T_2 = 120°F

minimum ambient operating temperature
T_1 = 75°F

Determine the following:

Necessary accumulator size, taking into account the real gas behavior by using correction factors

Calculate gas precharge pressure p_0 at 68°F (T_0)

Select accumulator size and type

Solution:

Since it is a rapid process, the change of condition of the gas can be assumed to be adiabatic.

1. Calculation for the required ideal gas volume:

a) gas precharge pressure at T_2:

$p_0@T_2 = 0.9 \times p_1 = 0.9 \times 1500 = 1350$ psi

b) gas precharge pressure at T_1:

$$p_0@_{T1} = p_{0\,@}\,T_2 \times \left(\frac{T_1 + 460}{T_2 + 460}\right)$$

$$p_0@_{T1} = 1350 \text{ psi} \times \left(\frac{75 + 460}{120 + 460}\right) = 1245 \text{ psi}$$

c) ideal gas volume:

$$V_{0\,ideal} = \frac{\Delta V}{\left(\frac{p_{0'}(T_1)}{p_1}\right)^{0.714} - \left(\frac{p_{0'}(T_1)}{p_2}\right)^{0.714}}$$

$$V_{0\,ideal} = \frac{1.35}{\left(\frac{1245}{1500}\right)^{0.714} - \left(\frac{1245}{3000}\right)^{0.714}} = 3.95 \textit{ gals.}$$

2. Calculation for the required real gas volume:

a) Determine the adiabatic correction factor, C_a

$$\frac{p_2}{p_1} = \frac{3000\text{psi}}{1500\text{psi}} = 2$$

From the correction factor for adiabatic change condition graph, using the 3000psi curve:

$C_a \approx 1.16$

b) Real gas volume:

$V_{0,\,real} = C_a \times V_{0,\,ideal} = 1.16 \times 3.95$ gal.
= 4.6 gal.

3. Select actual accumulator size by rounding up to nearest nominal size accumulator listed in catalog:

Selected size: 5 Gallon = 20 Liter

4. Calculation of gas precharge pressure p_0 at 68°F:

$$p_0@\,T_0 = p_0@\,T_2 \times \left(\frac{T_0 + 460}{T_2 + 460}\right)$$
= 1350 psi x $\left(\frac{T_0 + 460}{T_2 + 460}\right)$
= 1230 psi

3. Selected: Size 20 (5 gallon)

Recommended Model: SB330-20A1/112S-210C, Precharged to 1230 psi at 68°F

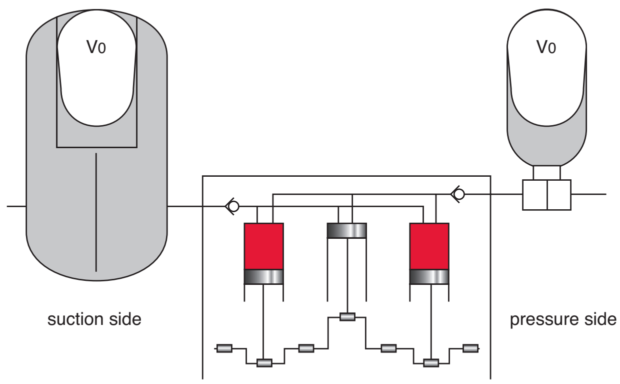
Pulsation Dampeners & Suction Flow Stabilizers

On the suction and pressure side of piston pumps almost identical conditions regarding non-uniformity of the flow rate occur. Therefore the same formulas for determining the effective gas volume are used for calculating the dampener size. That in the end two totally different dampener types are used is due to the different acceleration and pressure ratios on the two sides.

Not only is the gas volume V_0 a decisive factor but also the connection size of the pump has to be taken into account when selecting the pulsation dampener. In order to avoid additional cross section changes which represent reflection points for vibrations, and also to keep pressure drops to a reasonable level, the connection cross section of the dampener has to be the same as the pipe line.

The gas volume V_0 of the dampener is determined with the aid of the formula for adiabatic changes of state.

A simulation of the pressure performance can be carried out by means of a computer program for real pipe line conditions.



Formulas

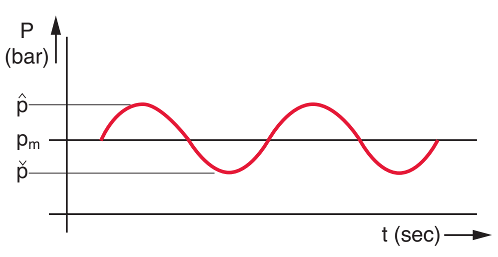
$$V_0\,(l) = \frac{\Delta V}{0.695 \times \left[1 - \left(\frac{100}{100 + x}\right)^{0.714}\right]}$$

$$X\,(\pm\%) = \frac{100}{\left(1 - \frac{V}{0.695 \times V_0}\right)^{1.4}} - 100$$

$$\Delta V\,(l) = k\,q$$

$$X\,(\pm\%) = \frac{\hat{p} - p_m}{p_m} \times 100 = \frac{\check{p} - p_m}{p_m} \times 100$$

V_0 = required gas volume
ΔV = fluctuating fluid volume
q(l) = stroke volume per cylinder
$\hat{p} - p_m = \check{p} - p_m$ = amplitude of pressure fluctuations
X = residual pulsations
$\hat{p}$ = max. working pressure
$\check{p}$ = min. working pressure
pm = pump flow rate or pressure in the suction line
= Coefficient of cyclic variation of the pump
z = No. of compressions / effective cylinders per revolution factors for other types, i.e. gear, axial, and radial piston pumps on request



Types of Pump	z	k
Gear Pump	7 - 14	0.1 - 0.3
Piston Pump	1 - 11	0.01 - 0.6
e.g.	1	0.6
	2	0.25
	3	0.13
	4	0.12
	5	0.05
	6	0.13
	7	0.02
	9	0.01

Calculation Example

Parameters:

Single acting 3-plunger pump

piston diameter	2.36 inches	(60 mm)
piston stroke	3.15	(80 mm)
rpm	370	
flow rate	64.44 gpm	(244 l/min.)
operating temp.	68°F	(20°C)
operating pressure		
pressure side	3625 psi	(250 bar)
suction side	58 psi	(4 bar)

Required:

- Suction flow stabilizer for a residual pulsation of ± 2.5%
- Pulsation dampener for a residual pulsation of 0.5%

Solution:

a) Determination of required suction flow stabilizer

$$V_0\,(in^3) = \frac{0.13 \cdot \left(\frac{2.36^2 \times \pi}{4}\right) \cdot 3.15}{0.695 \left[1 - \left(\frac{100}{100 + 2.5}\right)^{0.714}\right]}$$

Selected: SB 330-4 *(see table on page 13)*

b) Determination of required pulsation dampener

$$V_0\,(in^3) = \frac{0.13 \cdot \left(\frac{2.36^2 \times \pi}{4}\right) \cdot 3.15}{0.695 \left[1 - \left(\frac{100}{100 + 0.5}\right)^{0.714}\right]}$$

Selected: SB 330 P-20 *(see table on page 61)*

For assistance in sizing pulsation dampeners, shock absorbers, and suction stabilizers, please contact the HYDAC Accumulator Group at 1-877-GO HYDAC.

Energy Storage Form

Name ______________________ Title ______________________

Company ______________________ E-mail ______________________

Address ____

Phone ______________________ State ____________ Zip ____________

Phone ______________________ Fax ______________________

Please attach any special requirements or drawings to the fax or e-mail.

Operation of Pump

☐ Continuous Operation

☐ Emergency Operation

Maximum Operating Pressure	(P2)		PSI
Minimum Operating Pressure	(P1)		PSI
Precharge Pressure at 68˚F (20˚C)	(P0)		PSI
Temperature Range of Environment	(T)		˚F
Temperature Range of Fluid or System	(TF)		˚F
Pump Flow Rate	(QP)		GPM
Total Cycle Time of System	(TE)		Sec.
Number of Actuators *(cylinders, etc.)*	(NV)		

Actuator Time Schedule and Flow

QVi = Required Actuator Flow (GPM) **Ei** = Actuator Start Time **Ai** = Actuator Shut Down Time

(i = 1 for first actuator, i = 2 for second actuator, etc. up to NV)

QV1 =	E1 =	A1 =
QV2 =	E2 =	A2 =
QV3 =	E3 =	A3 =
QV4 =	E4 =	A4 =
QV5 =	E5 =	A5 =

Fluid

Required Mounting Orientation

Country of Final Installation *(for country codes please see page 2)*

Required Quantity

Annual Usage ____________ Target Price ____________ Competitor ____________ Quantity ____________

Additional Remarks

Shock Applications Form

Name ______________________ Title ______________________

Company ______________________ E-mail ______________________

Address ____

Phone ______________________ State __________ Zip __________

Phone ______________________ Fax ______________________

Please attach any special requirements or drawings to the fax or e-mail.

What is the source of the shock? *(i.e. valve closing, pump start, or other - please describe)*

At the instance the shock occurs what is the...

Flow rate: ___________ GPM

Normal Operating Pressure: ___________ PSI ; Maximum Spike Pressure: ___________ PSI

The system's maximum allowable design pressure: ___________ PSI

Information is required on all piping from the shock source to the anticipated location of the shock absorber *(accumulator)*.
Please continue to answer the following:

Total Number of pipes: ___________ *(up to 10 pipes)*

Starting at the shock source, please answer the following:

Pipe	Inner Diameter (inches)	Length (feet)	Pipe	Inner Diameter (inches)	Length (feet)
1			6		
2			7		
3			8		
4			9		
5			10		

If the vertical height from the shock source to the anticipated location of the shock absorber is greater than 10 feet please state this distance.

Vertical Height: _________________feet

Fluid

Required Mounting Orientation

Country of Final Installation *(for country codes please see page 2)*

Required Quantity

Annual Usage ______________ Target Price ______________ Competitor ______________ Quantity ____________

Additional Remarks

Pulsation Dampening Form

Name ______________________ Title ______________________

Company ______________________ E-mail ______________________

Address ____

Phone ______________________ State ____________ Zip ____________

Phone ______________________ Fax ______________________

Please attach any special requirements or drawings to the fax or e-mail.

What type of pump is causing the pulsation?

Please name or describe *(ie piston pump, gear pump, etc.)*

What is the...

Flow rate: ___________ GPM

Pump: ___________ RPM

Pump Piston Diameter: ___________ *(inches)*

Pump Piston Stoke: ___________ *(inches)*

Number of Rotating Elements: ___________ *(3 piston, 13 tooth gear, etc)*

Operating Pressure: ___________ psi

The system's maximum allowable pressure: ___________ psi

Line Size where pulsation dampener will be fitted into: ______________________

(The I.D. of the line is what is really required)

Note: A pulsation dampener should be always be installed as close to the pulsation source as possible to optimize its performance. A pulsation dampener should never be placed greater than 10 ft away from the pulsation source.

Fluid

Required Mounting Orientation

Country of Final Installation *(for country codes please see page 2)*

Required Quantity

Annual Usage ___________ Target Price ___________ Competitor ___________ Quantity ___________

Additional Remarks

PN#02068195 / 04.13 / ACU1102-1326