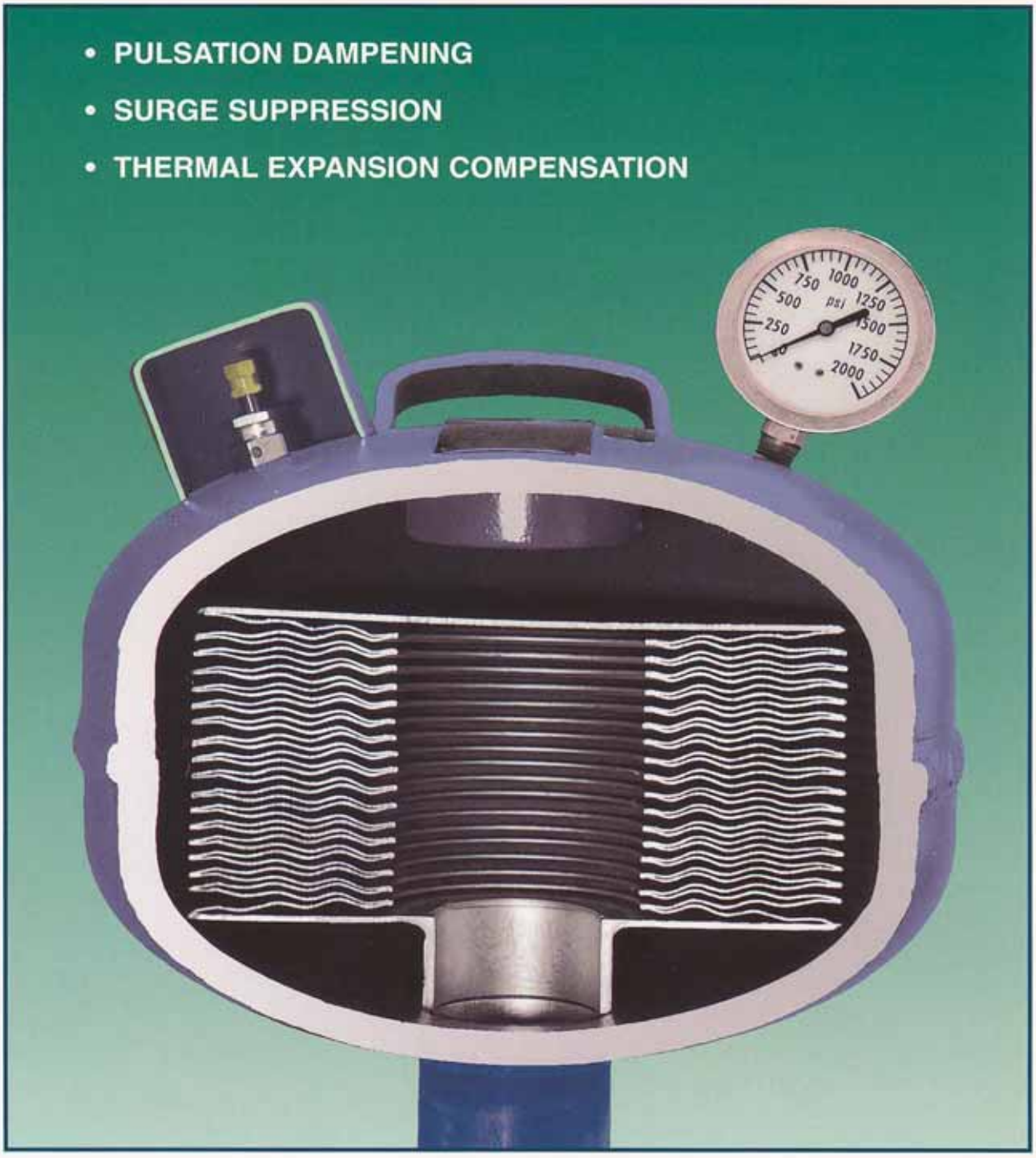
HYDROPAD

APPLICATION & DESIGN GUIDE

- PULSATION DAMPENING
- SURGE SUPPRESSION
- THERMAL EXPANSION COMPENSATION



FLEXICRAFT

2315 W. HUBBARD ST. • CHICAGO, IL 60612 • 800-533-1024 • 312-738-3588 • FAX 312-421-6327

The HYDROPAD

The Hydropad was developed to provide fluid control in process piping systems. The results are protection for piping systems from the destructive effects of water hammer produced by quick closing valves, pulsations from reciprocating pumps, and absorption of thermal fluid expansion. They have also found wide usage as accumulators in hydraulic systems.

The Hydropad acts as a shock absorber for fluid in motion. The cushion it provides absorbs kinetic energy, which provides the neccessary control of fluid dynamics. This is essential to many systems.

The use of all metal, all welded construction with the almost limitless range of bellows sizes provides unequaled flexibility of capacity for any system, maximum safety to personnel, no maintenance requirements and the widest possible range of temperature and pressure limits. The Hydropad provides the best performance possible.

How to Order

To insure proper design and sizing of Hydropads for your system, as complete information as possible on the system design and flowing liquid is needed. To make preparation of this material as simple as possible, forms F-801 (Surge Suppression Data Sheet), F-802 (Pulsation Dampener Data Sheet) and F-803 (Thermal Expansion Data Sheet) have been included with this catalog. They are useful in requesting engineering recommendations and quotations from Flexicraft Industries engineers, and also for submittal when purchase orders are issued.

If you prefer, you may use the calculations provided in this catalog to select Hydropads, or simply reference the calculations to better understand Hydropad applications and sizing.

Flexicraft has been supplying industry with quality piping products for over 40 years. Our reputation for superior products and technical support sets us apart from our competition.

In addition to Hydropads, **Flexicraft** is a supplier of metallic and non-metallic expansion joints, braided hose, expansion loops, and other specialty piping products using bellows technologies. For more information or to order,

Contact us at:

FLEXICRAFT INDUSTRIES

800-533-1024

(312) 738-3588 • (312) 421-6327 Fax

www.flexicraft.com

or contact the representative in your area - see back cover.

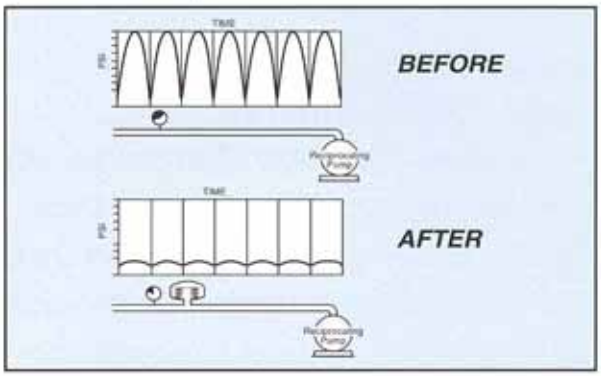
Applications

Pulsation Dampening

Systems that include positive displacement pumps must control the pulsations that result from pump's stroking action. The Hydropad is normally used on process lines to reduce the normal pressure and flow fluctuations.

Benefits

- *Provides steady flow in product and proportioning additives*
- *Provides steady application in spraying*
- *Ensures full suction stroke of pump cylinders*
- *Eliminates splashing and foaming*
- *Protects system components*

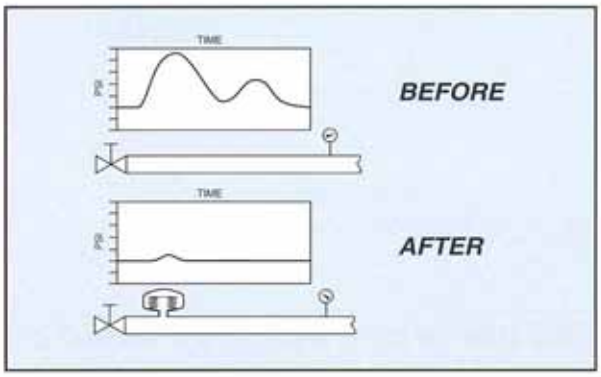


Surge Suppression

Pipeline surges are created by sudden changes in velocity of the liquid flowing in the system. This surging is often called "water hammer", and can result in pressures of six times normal operating pressure. It can be caused by quick closing valves, pump start up or shut down, back surge, and other system effects. Normal Hydropad selection is made to reduce this sudden pressure rise to below one and one-half times the operating pressure of the pipeline.

Benefits

- *Protects piping and fittings*
- *Protects valves*
- *Protects meters and instrumentation*

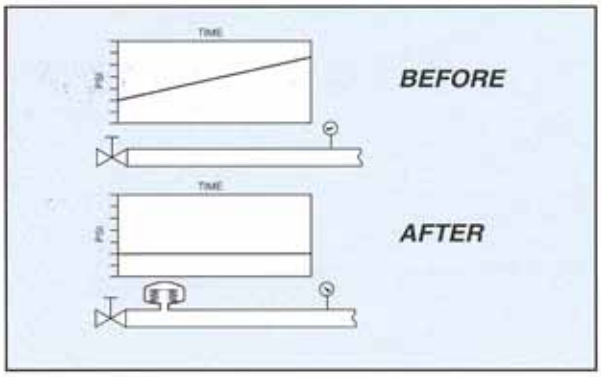


Thermal Expansion

When the fluid in a closed system experiences an increase in temperature, the thermal growth of the fluid manifests itself as an increase in pressure. Since the coefficient of thermal expansion for conduit/piping materials is usually an order of magnitude (or more) less than the coefficient for most fluids, conduit expansion is insufficient to absorb all the expansion of the fluid. Unfortunately, use of devices such as burst disks or pressure relief valves may cause other problems.

Benefits

- *Protects against ruptured piping and fittings from thermal expansion*
- *Prevents total loss of system pressure when using relief devices*
- *Prevents loss of process fluid when using relief devices*
- *Protects against contamination of the surrounding area when using relief devices*



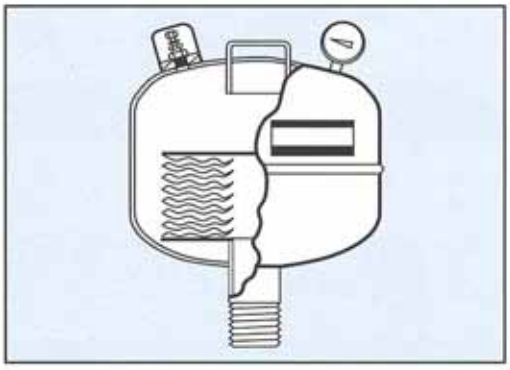
Construction Details

The Hydropad is a pressure vessel containing an inner expandable and collapsible bellows assembly. A suitable connection is provided to permit liquid displaced from the system to enter the inside of the bellows assembly. Inside the pressure vessel and surrounding the outside of the bellows assembly, a suitable gas, usually nitrogen, is sealed at a pressure equal to line pressure so that under normal flowing conditions the internal and external pressures on the bellows unit are equal. The housing is designed to allow for the expansion of the bellows within the shell as it absorbs surges from the main flow line, thus preventing excessive pressure and line shock.

All metal, all welded construction, using various steel and stainless steel alloys and other metals as needed to meet system requirements avoids the faults of units using rubber and other compounds in the flexible member. Standard Hydropads are suitable for almost any fluid such as: water, hydraulic fluids, all hydrocarbons having viscosities below 10,000 s.s.u., liquefied gases, and a large number of corrosive chemical solutions.

All Hydropads are designed and welded to meet ASME unfired pressure vessel codes. ASME code stamping and Canadian registration are available. The attention to design and fabrication details, together with the use of inert gas as the precharging medium, assures maximum safety, particularly in systems handling inflammable or explosive fluids.

Screwed, flanged or welded connections are available.



MATERIALS OF CONSTRUCTION

PART	HYDROPAD	ALL STAINLESS STEEL HYDROPAD
Bellows Assembly	Type 316L Stainless	Type 316L Stainless
Housing	Carbon Steel	Type 304 Stainless
Entrance Connection	Type 316L Stainless	Type 316L Stainless
Temperature Range	-20° F. to +650° F.	-325° F. to +1200° F.

Individual parts can be supplied with any weldable metal, including monel, iconel and others.

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Selection Charts

STANDARD SERIES HYDROPADS

200 PSI

MODEL NO.	NOMINAL GAS CAPACITY, C cu-in	FLUID DISPLACEMENT C_d (Max) cu-in	HOUSING		ENTRANCE CONNECTION* SIZE, NPS	APPROX. WT (LBS)
			DIA.	H		
11	100	60	10-1/2"	8"	2" Nipple	70
12	200	120	10-1/2"	10"	2" Nipple	80
13	500	300	16"	10-3/4"	2" Nipple	140
14	1,000	600	16"	14"	2" Nipple	150
15	2,000	1,200	24"	18"	3" Flange	300
16	5,000	3,000	24"	22-3/4"	3" Flange	350
17	10,000	6,000	36"	25"	4" Flange	570
175	25,000	15,000	42"	40"	6" Flange	2200
18	50,000	30,000	48"	47"	6" Flange	3000

500 PSI

MODEL NO.	NOMINAL GAS CAPACITY, C cu-in	FLUID DISPLACEMENT C_d (Max) cu-in	HOUSING		ENTRANCE CONNECTION* SIZE, NPS	APPROX. WT (LBS)
			DIA.	H		
21	100	60	10-3/4"	8"	2" Nipple	75
22	200	120	10-3/4"	10"	2" Nipple	85
23	500	300	16"	10-3/4"	2" Nipple	175
24	1,000	600	16"	14"	2" Nipple	185
25	2,000	1,200	24"	18"	3" Flange	450
26	5,000	3,000	24"	22-3/4"	3" Flange	500
27	10,000	6,000	36"	25"	4" Flange	900
275	25,000	15,000	42"	40"	6" Flange	2500
28	50,000	30,000	48"	47"	6" Flange	6000

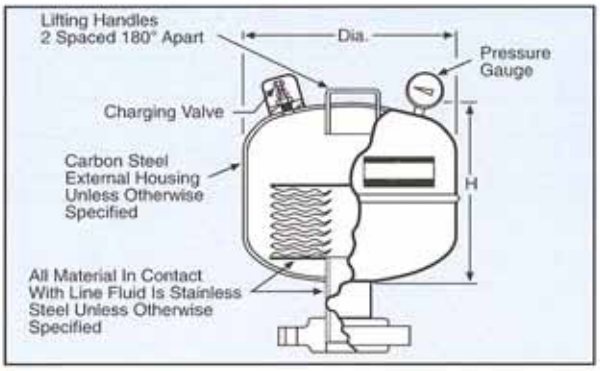
1000 PSI

MODEL NO.	NOMINAL GAS CAPACITY, C cu-in	FLUID DISPLACEMENT C_d (Max) cu-in	HOUSING		ENTRANCE CONNECTION* SIZE NPS	APPROX. WT (LBS)
			DIA.	H		
31	100	60	10-1/2"	9"	1" Flange	100
32	200	120	10-1/2"	10"	1" Flange	125
33	500	300	16"	12"	1" Flange	250
34	1,000	600	16"	14"	1" Flange	300
35	2,000	1,200	24"	18"	1" Flange	600
36	50,000	30,000	24"	29"	1" Flange	675

3000 PSI

MODEL NO.	NOMINAL GAS CAPACITY, C cu-in	FLUID DISPLACEMENT C_d (Max) cu-in	HOUSING		ENTRANCE CONNECTION* SIZE, NPS	APPROX. WT (LBS)
			DIA.	H		
41	100	60	10-3/4"	13"	1" Flange	200
42	200	120	10-3/4"	17"	1" Flange	275
43	500	300	16"	14-3/4"	1" Flange	700

* Other connection sizes and types (nipples, welding ends, flanges) available on request.



FLEXICRAFT

Selection Charts

MINIATURE SERIES HYDROPADS

500 PSI

MODEL NO.	NOMINAL GAS CAPACITY, C cu-in	FLUID DISPLACEMENT, C_d (Max) cu-in	HOUSING		APPROX. WT (LBS)
			DIA.	H	
160500	16	9.5	4-1/2"	2-7/8"	8
320500	32	19.0	4-1/2"	5"	13

1000 PSI

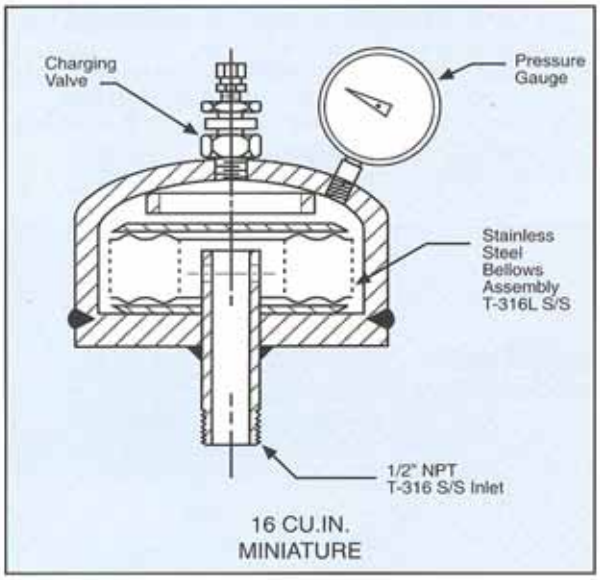
MODEL NO.	NOMINAL GAS CAPACITY, C cu-in	FLUID DISPLACEMENT, C_d (Max) cu-in	HOUSING		APPROX. WT (LBS)
			DIA.	H	
161000	16	9.5	4-1/2"	2-7/8"	9
321000	32	19.0	4-1/2"	5"	14

2000 PSI

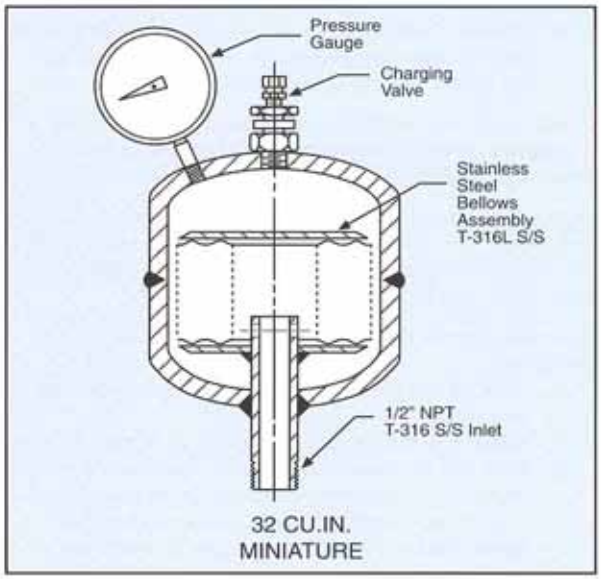
MODEL NO.	NOMINAL GAS CAPACITY, C cu-in	FLUID DISPLACEMENT, C_d (Max) cu-in	HOUSING		APPROX. WT (LBS)
			DIA.	H	
162000	16	9.5	5-9/16"	4-1/4"	15
322000	32	19.0	5-9/16"	7"	25

3000 PSI

MODEL NO.	NOMINAL GAS CAPACITY, C cu-in	FLUID DISPLACEMENT, C_d (Max) cu-in	HOUSING		APPROX. WT (LBS)
			DIA.	H	
163000	16	9.5	5-9/16"	5"	16
323000	32	19.0	5-9/16"	7"	26



16 CU.IN. MINIATURE



32 CU.IN. MINIATURE

Installation

Important features of the Hydropad are its ease of initial installation and lack of maintenance requirements. Once the means of connection to the systems have been provided, it is only necessary to connect the Hydropad by the screwed, flanged or weld end connection furnished, using accepted procedures.

The housing should be located above the point of connection and installed vertically. If horizontal or inverted vertical installation is necessary, additional instructions can be obtained from the factory.

Unless instructed otherwise, the Hydropad is pre-charged with nitrogen at the factory to the pressure specified by the customer, or as calculated from given system data. If the customer wishes to pre-charge after installation, the nitrogen gas pressure should be held to a value of 3 to 5 psi below flow pressure as measured at the point of installation for surge suppression, or between 80 and 90% of the mean pressure for pump pulsation dampening.

For assurance that the Hydropad has been properly precharged at the time of system start-up, follow these simple steps:

Surge Suppressor Applications

a. With Hydropad isolated from line pressure, note reading on Hydropad pressure gauge. Pressure should be 3-5 psi below line pressure.
b. Start up system.
c. Again note pressure on gauge. Indicated pressure should be 3 to 5 psi above that noted in (a).
d. If pressure does not increase, excessive precharge pressure is indicated. Charging valve should be opened and gas bled from the Hydropad housing. When precharge pressure equals flow pressure, gauge pressure will stop falling and charging valve should be closed. (This should be done with system on and valve(s) open).
e. Reseal charging valve and repeat steps (a) through (c) to assure that precharge pressure (a) is 3 to 5 psi below reading obtained in step (c).

Note: Under no circumstances should the bellows be exposed to pressure more than 5 psi greater than the precharge pressure at time of installation.

Note: If environmental temperature will be higher than installation temperature, initial precharge pressure must be adjusted to allow for the effect of increased temperature on the gas charge.

To precharge the Hydropad after installation, follow this procedure:

a. Shut off line pressure (isolate Hydropad from line pressure).
b. Attach gas charging chuck cc300 to charging valve.
c. Turn 3/4" hex swivel nut counter-clockwise a maximum of 3/4 turn after resistance is felt to open.
d. Charge with nitrogen gas to pressure shown on name plate or to system pressure (flowing) as measured at the point of installation. Use the latter pressure when system flow pressure has changed.
e. Turn 3/4" hex swivel nut clockwise and apply 50 to 70in. lb. torque to close.

Note: Charging gas pressure should be adjusted to allow for effect of a change in environmental temperature.

Pulsation Dampener Applications

Warning: Read all instructions carefully. Exposing the inlet side of an undercharged Hydropad to line pressure may damage unit. NEVER exceed the maximum operating pressure stamped on the nameplate of the vessel.

To ensure correct precharge, the Hydropad must be isolated from line pressure. The normal precharge pressure for pulsation dampeners is 80 to 90% of the mean pump output pressure. For a pump with a mean output pressure e of 100 psi, the precharge should be between 80 and 90 psi.

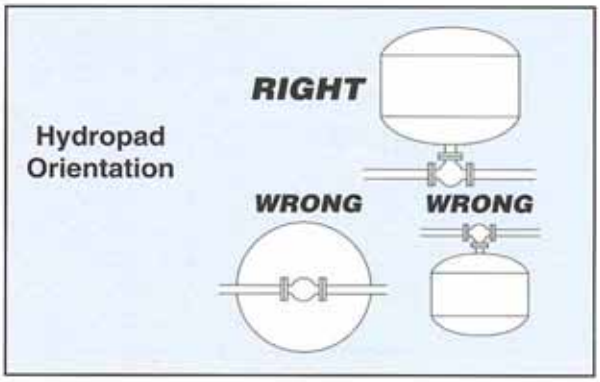
With correct precharge pressure, the unit may be exposed to line pressure. With the pump operating, the Hydropad pressure gauge should read the mean output pressure + / - the allowable variation in output pressure.

If the Hydropad is overcharged:

a. Isolate the unit from line pressure.
b. Slowly turn the 3/4" hex swivel nut counter-clockwise until nitrogen can be heard escaping and the gauge pressure begins to drop.
c. When the correct precharge pressure has been reached, turn the 3/4" hex swivel nut clockwise to close and apply 50-70 in. lb. torque.

If the Hydropad is undercharged:

a. Attach gas charging chuck cc300 to charging valve.
b. Attach nitrogen supply to charging chuck (1/8" tubing compression fitting).
c. Turn 3/4" hex swivel nut on charging valve 3/4 turn counter-clockwise to open valve.
d. Open valve on nitrogen bottle and increase Hydropad precharge pressure to required level.
e. Turn the 3/4" hex swivel nut clockwise to close and apply 50-70 in. lb. torque.
f. Disconnect nitrogen supply line and charging chuck.



Typical Specifications

Surge Suppression

Surge dampeners shall be installed upstream of all quick closing or solenoid operated valves as noted on drawings. Surge suppressors shall be Hydropads as manufactured by FLEXICRAFT or equal, and shall consist of a diaphragm-type stainless steel bellows unit enclosed by an outer steel shell. Bellows shall be of mutiple-type diaphragms, and heli-arc welded at the inner and outer peripheries. Bellows shall be exposed internally to line pressure and all material in contact with line fluid shall be stainless steel.

Unit shall have sufficient volume between bellows and outer steel shell to limit maximum surge pressure to 1-1/2 times normal line pressure or to value noted, whichever is lower. Unit shall be filled with nitrogen gas between bellows and steel shell. *Nitrogen gas pressure shall be 3 to 5 PSIG below the normal line pressure at point of installation* under normal flowing conditions. Hydropads should be as close to the valve as possible, and in no case further than 6 feet from the valve.

Pulsation Dampening

Pulsation dampeners shall be installed at outlet of pump or manifold as noted on drawing.

Pulsation dampeners shall be Hydropads as manufactured by FLEXICRAFT or equal, and shall consist of a diaphragm-type stainless steel bellows unit enclosed by an outer steel shell.

Bellows shall be exposed internally to line pressure and all material in contact with line fluid shall be stainless steel.

Unit shall have sufficient volume between bellows and outer steel shell to limit pulsation to values noted on drawings. *Unit shall be precharged with nitrogen gas.*

Thermal Expansion

Thermal Expansion Units shall be Hydropads as manufactured by FLEXICRAFT or equal, and shall consist of a diaphragm-type stainless steel bellows unit enclosed by an outer steel shell.

Bellows shall be exposed internally to line pressure and all material in contact with line fluid shall be stainless steel.

Unit shall have sufficient volume between bellows and outer steel shell to limit pulsation to values noted on drawings. *Unit shall be precharged with nitrogen gas.*

HYDROPAD
SURGE SUPPRESSOR FORM

Customer _____ Date _____

Street Address _____

City _____ State _____ Zip _____

Hydropad Surge Suppressors are designed to reduce the pressure rise or water hammer in a piping system caused by quick-closing valves. A value of one and one-half times the normal operating pressure of the system is used for design purposes unless a closer value is specified by the user.

1. Type of fluid in line: _____.

2. Pipe size _____ in. NPT; Type (Schedule 40, Standard, etc.) _____
   Length _____ ft.
   NOTE: If there is more than one pipe size in piping run, show pipe size and length of each section from valve to point of origin.

3. Discharge rate in gal./min. or velocity in ft./sec. at valve: _____ [gpm / ft./sec.]

*4. Flow pressure at point of installation of Hydropad: _____ psi.

5. Normal line pressure or static pressure at point of origin: _____ psi.

**6. Maximum allowable surge pressure: _____ psi.

7. Style of entrance connection: (Flanged ____) (Threaded ____) (Weld Nipple ____);
   Size: _____ in. NPT.

* If this not known, furnish a drawing showing length and size of pipe, indicating all changes in direction and rise and/or fall of piping, plus discharge pressure at point of origin.

** If not answered, a value of one and one-half times normal line pressure will be assumed.

Submitted by _____

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HYDROPAD
PULSATION DAMPENER FORM

Customer _____ Date _____

Street Address _____

City _____ State _____ Zip _____

Pulsation dampeners are normally used in processing lines to reduce the normal pressure and flow fluctuations associated with positive displacement pumps (piston types). Such fluctuations in many cases can be regulated to 1/2% above and below the mean operating pressure of the pump by installing properly sized Hydropads. More frequently a variation of ±10% is considered adequate, thus permitting the use of smaller Hydropads.

1. Type of pump (check one)

Simplex single-acting	( )	Simplex double-acting	( )
Duplex single-acting	( )	Duplex double-acting	( )
Triplex single-acting	( )	Triplex double-acting	( )
Quadruplex single-acting	( )	Quadruplex double-acting	( )

2. Type of fluid: _____

3. Fluid operating temperature _____ °F

*4. Bore of cylinder: _____ in.

*5. Stroke of piston: _____ in.

6. Design operating pump pressure _____ psi.

**7. Pressure fluctuation permissible: _____ % operating pressure or
(Maximum allowable pressure _____ psi). (Minimum allowable pressure _____ psi).

8. Style of entrance connection: (Flanged ____) (Threaded ____) (Weld Nipple ____);
Size: _____ in. NPT.

* If bore and stroke are not available, show discharge at pump _____ gpm at _____rpm.

** If not answered, we will design for ± 10% variation in operating pressure.

Submitted by _____

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HYDROPAD
THERMAL EXPANSION FORM

Customer _____ Date _____

Street Address _____

City _____ State _____ Zip _____

Please provide the following information for accurate sizing of HYDROPADS as thermal expansion compensation chambers. Note that although the English system of units is specified, any convenient system may be used provided the units of measure are specified.

1. Initial pressure when system is blocked off at initial temperature _____ psig.
2. Initial (lowest) temperature _____ °F.
3. Maximum anticipated system temperature _____ °F.
4. Maximum allowable system pressure _____ psig.
5. The net excess volume due to thermal expansion of the fluid _____ cu-in.**

** If not known, then provide the following information:

5a. Coefficient of cubical expansion of the fluid between the lowest and highest temperatures _____ / °F.

5b. Coefficient of linear expansion of the conduit material (if not known, then specify the type of conduit material) _____ / °F.

5c. Line size _____ in.

5d. Wall thickness of conduit or schedule number _____ in.

5e. Line length _____ ft.

6. If known, what is the bulk modulus of the liquid (for more accurate calculation) _____ psi.

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Calculations

2. SURGE SUPPRESSION

Exact calculations for pressure rise for any condition of fluid velocity, pipe length and time of closure are very complex. A conservative figure for such pressure rise may be obtained from this equation:

FORMULA (1)

$p_r = 60V_oG$

Where:

p_r = Rise above initial flowing pressure, psi.
V_o = Initial fluid velocity, fps
G = Specific gravity of flowing liquid (See Table II)

TABLE II
PROPERTIES OF LIQUIDS
(at Base Temperature of 60°F.)

Liquid	Specific Gravity, G
Ammonia (Saturated) at -28°F.	.67
Ethyl Alchohol (100%)	.79
Hydrazene (100%)	1.01
Nitric Acid (Red or White Fumming)	1.54
Nitrogen (Liquid) at -321° F.	.80
Oxygen (Liquid) at -298° F.	1.14
Sea Water	1.03
Fresh Water	1.00
Butane	.60
Gasoline, Grade (115-145)	.69
Gasoline	.76
Kerosene	.82
Fuel Oil	.90
JP-4	.80

The Hydropad provides a cushion of gas near the valve. The greater the velocity of the fluid, the larger the gas volume required to dissipate a sufficient amount of kinetic energy so that pressure rise is reduced to a safe value. From various gas laws we know that the gas volume required is a direct function of the energy absorbed.

The total kinetic energy to be absorbed due to a change in the velocity of the fluid from valve to origin may be found:

FORMULA (2)

$$K = \frac{62.4\ GALV_o^2}{2g} = .97\ GALV_o^2$$

Where:

K = Kinetic energy, ft. lbs.
g = Gravitational constant = 32.2 ft./sec²
A = Transverse area of pipe, sq. ft.
L = Length of pipe, ft.
V_o = Initial Fluid velocity, fps.
G = Specific gravity of flowing liquid (see Table II)

Note: Where there are combinations of different pipe sizes in a system, kinetic energy for each diameter must be calculated. Total energy to be absorbed is the sum of these. Knowing initial fluid velocity for line size at the valve, the velocity for other sizes of lines can be calculated as follows:

$$V_1 = (\frac{A_o}{A_1})V_o$$

Where:

A_o = Transverse area of pipe (sq. ft.) with velocity of fluid V_o
A_1 = Transverse area of new line, sq. ft.
V_1 = Velocity of fluid (fps) through line with area A_1.

Note: Transverse areas for pipe diameters can be found in Table VI, page 18.

FORMULA (3)

Calculations for Hydropad capacities involve pressure ratio factor Y which is read from Chart I, page 16. This ratio is determined as follows:

$$Y = f(\frac{P_m}{P_o})$$

Where:

p_o = The flow pressure at valve (no surge) with valve open and fluid flowing, psig.
P_o = The absolute pressure = p_o + 14.7, psia
p_m = The maximum surge pressure at valve. This will always be higher than normal line pressure. Unless a definite value is specified by the customer, a value of 1.5 times normal line pressure will be used, psig.
P_m = The absolute pressure = p_m + 14.7 psia

Note: Read Y from chart on page 16.
Alternately;

$$Y = 144\ (\frac{1}{n-1}[(\frac{P_m}{P_o})^{\frac{n-1}{n}} - 1] - [1 - (\frac{P_o}{P_m})^{\frac{1}{n}}])$$

n = 1.015 for nitrogen when calculating for surge suppressors.

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Calculations

2. SURGE SUPPRESSION (continued)

FORMULA (4)

The required capacity, C, of the Hydropad may be found as follows:

$$C = 1728 \frac{K}{P_o Y}, \text{ cu. in.}$$

The actual volume, C_a, of liquid entering the Hydropad must be less than the displacement capacity C_d noted for the Hydropad chosen, as listed in column 3, pages 4 and 5.

FORMULA (5)

The actual volume, C_a, of liquid entering the Hydropad may be computed as follows:

$$C_a = C \left(1 - \left(\frac{P_o}{P_m}\right)^{\frac{1}{n}}\right), \text{ cu. in.}$$

Example
Given: Assume instantaneous valve closure, atmospheric pressure = 14.7 psia.

Gasoline (G = 0.7) is being pumped at 7.7 feet per second through 8" standard weight steel pipe for a total of 1200 ft. If the initial pressure, p_o, is 100 psig at the valve, determine (1) maximum water hammer pressure, p, without a surge suppressor; (2) Hydropad capacity required to limit the maximum surge pressure, p_m, to 150 psig; and (3) the displaced liquid volume, C_a.

Solution:
From Formula (1)

$p_r = 60 V_o G = 60 \times 7.7 \times 0.7 = 323$ psig

$p = p_o + p_r = 100 + 323 = 423$ psig

From Formula (2)

$K = .97 GALV_o^2 = .97 \times .7 \times .347 \times 1200 (7.7)^2$

$= 16{,}763$ ft. lbs.

From Formula (3)

$$\frac{P_m}{P_o} = \frac{150 + 15}{100 + 15} = \frac{165}{115} = 1.43,$$

Read Y = 8 (from page 16).

From Formula (4)

$$C = 1728 \frac{K}{P_o Y} = \frac{1728 \times 16763}{115 \times 8} = 31485 \text{ cu. in.}$$

From Formula (5)

$$C_a = C \left[1 - \left(\frac{P_o}{P_m}\right)^{\frac{1}{n}}\right], \text{ cu. in.} = 31485 \left[1 - \left(\frac{115}{165}\right)^{\frac{1}{1.015}}\right]$$

Recommendation:
Use 200 psi Series, Model 18 (p_m = 150 psi)
Capacity 50,000 cu. in. (C = 31485 cu. in.)
Displacement 30,000 cu. in. (C_a = 9424 cu. in.)

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3. THERMAL EXPANSION COMPENSATION

FORMULA (1)

$$C_O = \frac{\Delta V}{1 - \left(\frac{P_o^*}{P_1^*}\right)^{\frac{1}{n}}} \text{ cu. in.}$$

Where:
- ΔV = The excess fluid volume which must be absorbed cu. in.
- P_o = The initial system pressure psig
- P_o^* = P_o + 14.7 psia
- P_1 = The maximum allowable system pressure psig
- P_1^* = P_1 + 14.7 psia
- n = Polytropic exponent of gas expansion
  = 1.4 for nitrogen

If the actual increase in fluid volume (ΔV) is unknown, it can be determined as follows:

FORMULA (2)

$$\Delta V = V_E - V_P \text{ cu. in.}$$

Where:
- V_E = The net excess volume of fluid which takes into account the expansion of the fluid and the conduit due to an increase in temperature.
- V_P = The amount of volume increase of the conduit due to the pressure increase from P_o to P_1.

In most cases, $V_P << V_E$ and V_P can be neglected without significant loss is accuracy.

Calculations

3. THERMAL EXPANSION COMPENSATION (continued)

FORMULA (3)

$$V_E = V_o\ (T_1 - T_o)\ (e_L - 3e_C)\ \text{cu. in.}$$

Where:

V_o = The initial fluid volume at temperature T_o and pressure P_o cu. in.
T_o = The initial fluid temperature °F
T_1 = The maximum expected fluid temperature °F
e_L = The effective coefficient of cubical expansion of the fluid / °F
e_C = The coefficient of linear expansion of the conduit material / °F

If the increase in volume of the conduit due to the pressure rise is to be considered, the following relation can be used:

FORMULA (4)

$$V_P = 432\pi L d^2 \left(\frac{1}{k} + \frac{d}{e\,E}\right)(P_1 - P_o)[1 - e_L(T_1 - T_o)]\ \text{cu. in.}$$

Where:

L = The conduit length Ft
d = The inside diameter of the conduit Ft
k = The bulk (volume) modulus of the liquid psi
e = The thickness of the conduit wall Ft
E = The elastic modulus of the conduit material psi

Example

Consider an 8" sch 20 type 304 stainless steel line 500 Ft long, which is holding gasoline at 75 psig and 60°F. It is expected that the line, when isolated, may experience temperatures up to 120°F and it is desired to limit the system pressure to 135 psig.

P_o = 75 psig P_o^* = 89.7 psia
P_1 = 135 psig P_1 = 149.7 psia
T_o = 60°F
T_1 = 120°F
L = 500 FT
d = 8.125/12 = 0.677 Ft
e = 0.25/12 = 0.021 Ft
e_C = 9.6×10^{-6}/°F (For T-304 S/S)
e_L = 0.0006/°F (For gasoline)
k = 96000. psi
= (For gasoline at temperature T1)
E = 30×10^6 psi (For T-304 S/S)

Using Formula 4:

$$V_P = 432\pi(500)(0.677)^2\left(\frac{1}{96000} + \frac{0.677}{(0.021)(30\times10^6)}\right)$$

$$V_P = (135\text{-}75)[1\text{-}0.0006(120\text{-}60)]$$

V_P = 207 cu. in.

(This is the volume that the pipe has expanded due to the pressure change.)

Using Formula 3:

$$V_o = AL = \pi\frac{d^2}{4}\,L\ \text{cu. ft.}$$

$$V_E = \pi\frac{(0.677)^2}{4} \times 500(120\text{-}60)$$

$$\times\ (0.0006\text{-}3\times9.6\times10^{-6}) \times 1728.$$

V_E = 10659 cu. in. (This is the excess volume of liquid which is not accounted for by the thermal expansion of the conduit.)

Using Formula 2:

ΔV = 10659-207
ΔV = 10452 cu. in.

Using Formula 1:

$$C_o = \frac{10452}{1 - \left(\frac{89.7}{149.7}\right)^{\frac{1}{1.4}}}\ \text{cu. in.}$$

C_o = 34114 cu. in.

Use a model 18 Hydropad precharged to 75 psig.

Note that the volume stored in the expanded pipe due to the pressure increase (V_p) is only 2% of the total excess volume. Thus, if V_p is neglected, the required Hydropad capacity would increase by only 2% for this application.

Reference

Useful Equivalents

1 Imperial Gallon	=	1.2 U.S. Gallon
1 U.S. Gallon of Water	=	8.34 Pounds
1 U.S. Gallon	=	231 Cubic Inches
1 Liter	=	.2641 U.S. Gallon
1 Cubic Foot of Water	=	62.4 Pounds
1 Cubic Meter	=	35.31 Cubic Feet
1 Pound per Square Inch	=	27.7 Inches of Water
1 Pound per Square Inch	=	2.042 Inches of Mercury
1 Cubic Foot of Air	=	.076 Pounds (Std. Pres. and Temp.)
1 Pound of Air	=	13.1 Cubic Feet (Std. Pres. and Temp.)
1 Cubic Ft. of Natural Gas	=	1000 BTU (Approx.)
1 Cubic Foot	=	7.48 U.S. Gallons

CHART I – PRESSURE RATIO FACTOR

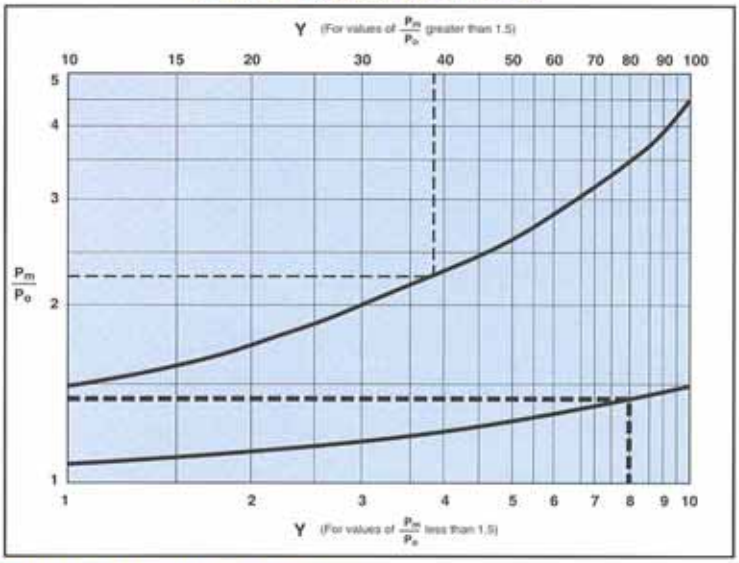


TABLE III – CONVERSION TABLE OF PRESSURE

Multiply known pressure units by factors given below to obtain the required pressure unit

KNOWN PRESSURE UNIT	REQUIRED PRESSURE UNIT							
	POUNDS PER SQ. IN.	OUNCES PER SQ. IN.	MILLIMETERS OF HG.	KILOGRAMS PER SQ. CM	INCHES OF WATER	INCHES OF HG	FEET OF WATER	CENTIMETERS OF WATER
Centimeters Head of Water	0.014209	0.22734	0.73691	0.00099902	0.39370	0.029012	0.32808	1
Feet Head of Water	0.43310	6.9296	22.461	0.030451	12.000	0.88430	1	30.480
Inches Head of Mercury	0.48977	7.8364	25.400	0.034434	13.570	1	1.1308	34.468
Inches Head of Water	0.036092	0.57747	1.8718	0.0025375	1	0.073692	0.083333	2.5400
Kilograms per Sq. Centimeter	14.223	227.57	737.63	1	394.09	29.041	32.840	1001.0
Milimeters Head of Hg.	0.019282	0.30852	1	0.0013557	0.53425	0.039370	0.044521	1.3570
Ounces per Sq. Inch	0.062500	1	3.2414	0.0043942	1.7317	0.12761	0.14431	4.3985
Pounds per Sq. Inch	1	16.000	51.862	0.070309	27.707	2.0418	2.3089	70.376

Table based on (Water at 60°F. – 62.367 lbs./cu. ft.)
(HG at 60°F. – 846.32 lbs./cu. ft.)
At Sea Level, Absolute Pressure = (Gauge Pressure psig) + 14.696

Temperature
1. To convert temperature in degrees Centigrade (°C) to degrees Fahrenheit (°F), use the following formula: °F = °C x 1.8 + 32
2. For steam, the degree of superheat is the difference between the actual temperature and the saturation steam temperature.

TABLE IV – FLOW CONVERSION

Multiply the known flow in the tabulation below by the factors listed to obtain flow in desired flow units

KNOWN FLOW	DESIRED FLOW UNITS							
	GPM	GALLONS PER HOUR	GALLONS PER DAY	CU. FT. PER MIN.	CU. FT. PER HOUR	BARRELS PER MIN.	BARRELS PER HOUR	BARRELS PER DAY
GPM	1.00	60	1440	0.1337	8.021	.0238	1.429	34.29
Gallons/Hour	.01667	1	24	.002228	0.1337	.000397	.0238	0.5714
Gallons/Day	.000694	.0417	1	.0000928	.00557	.00001653	.0009921	.0238
Cu. Ft./Min.	7.48	448.8	10771.2	1	60	0.1781	10.69	256.5
Cu. Ft./Hour	0.1247	7.48	179.5	.01667	1	.002968	0.1781	4.274
Barrels/Min.	42.00	2520	60480	5.615	336.9	1	60	1440
Barrels/Hour	0.7	42	1008	.0936	5.615	.01667	1	24
Barrels/Day	.02917	1.75	42	.003899	0.234	.000694	.0417	1

Note: The barrel in the above tabulation is equivalent to 42 U.S. gallons, which is standard for petroleum products.

Reference

TABLE V – FLOW OF WATER THROUGH SCHEDULE 40 STEEL PIPE

Discharge		Pressure Drop per 100 feet and Velocity in Schedule 40 Pipe for Water at 60° F															
		1/8"		1/4"		3/8"		1/2"		3/4"		1"		1 1/4"		1 1/2"	
Gallons per Minute	Cubic Ft. per Second	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.
.2	0.000446	1.13	1.86	0.616	0.359												
.3	0.000668	1.69	4.22	0.924	0.903	0.504	0.159	0.317	0.061								
.4	0.000891	2.26	6.98	1.23	1.61	0.672	0.345	0.422	0.086								
.5	0.00111	2.82	10.5	1.54	2.39	0.840	0.539	0.528	0.167	0.301	0.033						
.6	0.00134	3.39	14.7	1.85	3.29	1.01	0.751	0.633	0.240	0.361	0.041						
.8	0.00178	4.52	25.0	2.46	5.44	1.34	1.25	0.844	0.408	0.481	0.102						
1	0.00223	5.65	37.2	3.08	8.28	1.68	1.85	1.06	0.600	0.602	0.155	0.371	0.048				
2	0.00446	11.29	134.4	6.16	30.1	3.36	6.58	2.11	2.10	1.20	0.526	0.743	0.164	0.429	0.044		
3	0.00668			9.25	64.1	5.04	13.9	3.17	4.33	1.81	1.09	1.114	0.336	0.644	0.090	0.473	0.043
4	0.00891			12.33	111.2	6.72	23.9	4.22	7.42	2.41	1.83	1.49	0.568	0.858	0.150	0.630	0.071
5	0.01114		2"			8.40	36.7	5.28	11.2	3.01	2.75	1.86	0.835	1.073	0.223	0.788	0.104
6	0.01337	0.574	0.044		2 1/2"	10.08	51.9	6.33	15.8	3.61	3.84	2.23	1.17	1.29	0.309	0.946	0.145
8	0.01782	0.765	0.073			13.44	91.1	8.45	27.7	4.81	6.60	2.97	1.99	1.72	0.518	1.26	0.241
10	0.02228	0.956	0.108	0.670	0.046			10.56	42.4	6.02	9.99	3.71	2.99	2.15	0.774	1.58	0.361
15	0.03342	1.43	0.224	1.01	0.094		3"			9.03	21.6	5.57	6.36	3.22	1.63	2.37	0.755
20	0.04456	1.91	0.375	1.34	0.158	0.868	0.056		3 1/2"	12.03	37.8	7.43	10.9	4.29	2.78	3.16	1.28
25	0.05570	2.39	0.561	1.68	0.234	1.09	0.083	0.812	0.041		4"	9.28	16.7	5.37	4.22	3.94	1.93
30	0.06684	2.87	0.786	2.01	0.327	1.30	0.114	0.974	0.056			11.14	23.8	6.44	5.92	4.73	2.72
35	0.07798	3.35	1.05	2.35	0.436	1.52	0.151	1.14	0.704	0.882	0.041	12.99	32.2	7.51	7.90	5.52	3.64
40	0.08912	3.83	1.35	2.68	0.556	1.74	0.192	1.30	0.095	1.01	0.052	14.85	41.5	8.59	10.24	6.30	4.66
45	0.1003	4.30	1.67	3.02	0.668	1.95	0.239	1.46	0.117	1.13	0.064			9.67	12.80	7.09	5.85
50	0.1114	4.78	2.03	3.35	0.839	2.17	0.288	1.62	0.142	1.26	0.076		5"	10.74	15.66	7.88	7.15
60	0.1337	5.74	2.87	4.02	1.18	2.60	0.406	1.95	0.204	1.51	0.107			12.89	22.2	9.47	10.21
70	0.1560	6.70	3.84	4.69	1.59	3.04	0.540	2.27	0.261	1.76	0.143	1.12	0.047			11.05	13.71
80	0.1782	7.65	4.97	5.36	2.03	3.47	0.687	2.60	0.334	2.02	0.180	1.28	0.060		6"	12.62	17.59
90	0.2005	8.60	6.20	6.03	2.53	3.91	0.861	2.92	0.416	2.27	0.224	1.44	0.074			14.20	22.0
100	0.2228	9.56	7.59	6.70	3.09	4.34	1.05	3.25	0.509	2.52	0.272	1.60	0.090	1.11	0.036	15.78	26.9
125	0.2785	11.97	11.76	8.38	4.71	5.43	1.61	4.06	0.769	3.15	0.415	2.01	0.135	1.39	0.055	19.72	41.4
150	0.3342	14.36	16.78	10.05	6.69	6.51	2.24	4.87	1.08	3.78	0.580	2.41	0.190	1.67	0.077		
175	0.3899	16.75	22.3	11.73	8.97	7.60	3.00	5.68	1.44	4.41	0.774	2.81	0.253	1.94	0.102		8"
200	0.4456	19.14	28.8	13.42	11.68	8.68	3.87	6.49	1.85	5.04	0.985	3.21	0.323	2.22	0.130		
225	0.5013	...	...	15.09	14.63	9.77	4.83	7.30	2.32	5.67	1.23	3.61	0.401	2.50	0.162	1.44	0.043
250	0.557	...	...	...	...	10.85	5.93	8.12	2.84	6.30	1.46	4.01	0.495	2.78	0.195	1.60	0.051
275	0.6127	...	...	...	...	11.94	7.14	8.93	3.40	6.93	1.79	4.41	0.583	3.05	0.234	1.76	0.061
300	0.6684	...	...	...	...	13.00	8.36	9.74	4.02	7.56	2.11	4.81	0.683	3.33	0.278	1.92	0.072
325	0.7241	...	...	...	...	14.12	9.89	10.53	4.09	8.19	2.47	5.21	0.797	3.61	0.320	2.08	0.083
350	0.7798			...	...	...	...	11.36	5.41	8.82	2.84	5.62	0.919	3.89	0.367	2.24	0.095
375	0.8355			...	...	...	...	12.17	6.18	9.45	3.25	6.02	1.05	4.16	0.416	2.40	0.108
400	0.8912			...	...	...	...	12.98	7.03	10.08	3.68	6.42	1.19	4.44	0.471	2.56	0.121
425	0.9469			...	...	...	...	13.80	7.89	10.71	4.12	6.82	1.33	4.72	0.529	2.73	0.136
450	1.003		10"	...	...	...	...	14.61	8.80	11.34	4.60	7.22	1.48	5.00	0.590	2.89	0.151
475	1.059	1.91	0.054			...	...	...	...	11.97	5.12	7.62	1.64	5.27	0.653	3.04	0.166
500	1.114	2.01	0.059			...	...	...	...	12.60	5.65	8.02	1.81	5.55	0.720	3.21	0.182
550	1.225	2.24	0.071			...	...	...	...	13.85	6.79	8.82	2.17	6.11	0.861	3.53	0.219
600	1.337	2.44	0.083			...	...	...	...	15.12	8.04	9.63	2.55	6.66	1.02	3.85	0.258
650	1.448	2.64	0.097		12"	...	...	...	...	...	...	10.43	2.98	7.22	1.18	4.17	0.301
700	1.560	2.85	0.112	2.01	0.047							11.23	3.43	7.78	1.35	4.49	0.343
750	1.671	3.05	0.127	2.15	0.054		14"					12.03	3.92	8.33	1.55	4.81	0.392
800	1.782	3.25	0.143	2.29	0.061							12.83	4.43	8.88	1.75	5.13	0.443
850	1.894	3.46	0.160	2.44	0.068	2.02	0.042					13.64	5.00	9.44	1.96	5.45	0.497
900	2.005	3.66	0.179	2.58	0.075	2.13	0.047					14.44	5.58	9.99	2.18	5.77	0.554
950	2.117	3.86	0.198	2.72	0.083	2.25	0.052					15.24	6.21	10.55	2.42	6.09	0.613
1 000	2.228	4.07	0.218	2.87	0.091	2.37	0.057		16"			16.04	6.84	11.10	2.68	6.41	0.675
1 100	2.451	4.48	0.260	3.15	0.110	2.61	0.068					17.65	8.23	12.22	3.22	7.05	0.807
1 200	2.674	4.88	0.306	3.44	0.128	2.85	0.080	2.18	0.042			...	...	13.33	3.81	7.70	0.948
1 300	2.896	5.29	0.355	3.73	0.150	3.08	0.093	2.36	0.048			...	...	14.43	4.45	8.33	1.11
1 400	3.119	5.70	0.409	4.01	0.171	3.32	0.107	2.54	0.055					15.55	5.13	8.98	1.28
1 500	3.342	6.10	0.466	4.30	0.195	3.56	0.122	2.72	0.063		18"			16.66	5.85	9.62	1.46
1 600	3.565	6.51	0.527	4.59	0.219	3.79	0.138	2.90	0.071					17.77	6.61	10.26	1.65
1 800	4.010	7.32	0.663	5.16	0.276	4.27	0.172	3.27	0.088	2.58	0.050			19.99	8.37	11.54	2.08
2 000	4.456	8.14	0.808	5.73	0.339	4.74	0.209	3.63	0.107	2.87	0.060			22.21	10.3	12.82	2.55
2 500	5.570	10.17	1.24	7.17	0.515	5.93	0.321	4.54	0.163	3.59	0.091		20"			16.01	3.94
3 000	6.684	12.20	1.76	8.60	0.731	7.11	0.451	5.45	0.232	4.30	0.129	3.46	0.075		24"	19.24	5.59
3 500	7.798	14.24	2.38	10.01	0.982	8.30	0.607	6.35	0.312	5.02	0.173	4.04	0.101			22.44	7.56
4 000	8.912	16.27	3.08	11.47	1.27	9.48	0.787	7.26	0.401	5.74	0.222	4.62	0.129	3.19	0.052	25.65	9.80
4 500	10.03	18.31	3.87	12.90	1.60	10.67	0.990	8.17	0.503	6.46	0.280	5.20	0.162	3.59	0.065	28.87	12.2
5 000	11.14	20.35	4.71	14.33	1.95	11.85	1.21	9.08	0.617	7.17	0.340	5.77	0.199	3.99	0.079	...	...
6 000	13.37	24.41	6.74	17.20	2.77	14.23	1.71	10.89	0.877	8.61	0.483	6.93	0.280	4.79	0.111	...	...
7 000	15.60	28.49	9.11	20.07	3.74	16.60	2.31	12.71	1.18	10.04	0.652	8.08	0.376	5.59	0.150	...	...
8 000	17.82	...	...	22.93	4.84	18.96	2.99	14.52	1.51	11.47	0.839	9.23	0.488	6.38	0.192	...	...
9 000	20.05	...	...	25.79	6.09	21.34	3.76	16.34	1.90	12.91	1.05	10.39	0.608	7.18	0.242	...	...
10 000	22.28	...	...	28.66	7.46	23.71	4.61	18.15	2.34	14.34	1.28	11.54	0.739	7.98	0.294	...	...
12 000	26.74	...	...	34.40	10.7	28.45	6.59	21.79	3.33	17.21	1.83	13.85	1.06	9.58	0.416	...	...
14 000	31.19	...	...	...	...	33.19	8.89	25.42	4.49	20.08	2.45	16.16	1.43	11.17	0.562	...	...
16 000	35.65	...	...	...	...	...	...	29.05	5.83	22.95	3.18	18.47	1.85	12.77	0.723	...	...
18 000	40.10	...	...	...	...	...	...	32.68	7.31	25.82	4.03	20.77	2.32	14.36	0.907	...	...
20 000	44.56	...	...	...	...	...	...	36.31	9.03	28.69	4.93	23.08	2.86	15.96	1.12	...	...

For pipe lengths other than 100 feet, the pressure drop is proportional to the length. Thus, for 50 feet of pipe, the pressure drop is approximately one-half the value given in the table . . . for 300 feet, three times the given value, etc.

Velocity is a function of the cross sectional flow area; thus, it is constant for a given flow rate and is independent of pipe length. *Chart Courtesy of Crane Company*

TABLE VI – TRANSVERSE AREA IN SQUARE FEET FOR STEEL & STAINLESS STEEL PIPE

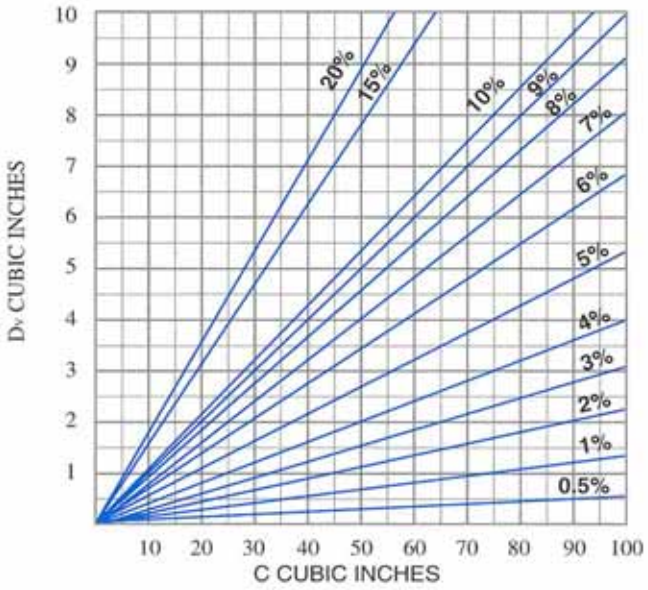
Nominal Pipe Size, NPT	SCHEDULE NUMBER		Weight Designation	Outside Diameter, Inches	Inside Diameter, Inches	Wall Thickness, Inches	Transverse Area, Square Feet	Transverse Area, Square Inches	Nominal Pipe Size, NPT
	Carbon & Alloy Steel	Stainless Steels							
⅛	40 80	10S 40S 80S	Std. X-Stg.	.405 .405 .405	.307 .269 .215	.049 .068 .095	.0003 .0004 .0003	.0740 .0568 .0364	⅛
¼	40 80	10S 40S 80S	Std. X-Stg.	.540 .540 .540	.410 .364 .302	.065 .088 .119	.0009 .0007 .0001	.1320 .1041 .0716	¼
⅜	40 80	10S 40S 80S	Std. X-Stg.	.675 .675 .675	.545 .493 .423	.065 .091 .126	.0016 .0013 .001	.2333 .1910 .1405	⅜
½	40 80	10S 40S 80S	Std. X-Stg.	.840 .840 .840	.670 .622 .546	.083 .109 .147	.003 .002 .002	.3568 .3040 .2340	½
¾	40 80	10S 40S 80S	Std. X-Stg.	1.050 1.050 1.050	.884 .824 .742	.083 .113 .154	.004 .004 .003	.6138 .5330 .4330	¾
1	40 80	10S 40S 80S	Std. X-Stg.	1.315 1.315 1.315	1.097 1.049 .957	.109 .133 .179	.007 .006 .005	.9448 .8640 .7190	1
1¼	40 80	10S 40S 80S	Std. X-Stg.	1.660 1.660 1.660	1.442 1.380 1.278	.109 .140 .191	.011 .010 .008	1.633 1.495 1.283	1¼
1½	40 80	10S 40S 80S	Std. X-Stg.	1.900 1.900 1.900	1.682 1.610 1.500	.109 .145 .200	.015 .014 .012	2.221 2.036 1.767	1½
2	40 80	10S 40S 80S	Std. X-Stg.	2.375 2.375 2.375	2.157 2.067 1.939	.109 .154 .218	.021 .023 .021	3.654 3.355 2.953	2
2½	40 80	10S 40S 80S	Std. X-Stg.	2.875 2.875 2.875	2.635 2.469 2.323	.120 .203 .276	.038 .033 .029	5.453 4.788 4.238	2½
3	40 80	10S 40S 80S	Std. X-Stg.	3.500 3.500 3.500	3.260 3.068 2.900	.120 .216 .300	.058 .051 .046	8.346 7.393 6.605	3
3½	40 80	10S 40S 80S	Std. X-Stg.	4.000 4.000 4.000	3.760 3.548 3.364	.120 .226 .318	.077 .069 .062	11.10 9.89 8.89	3½
4	40 80	10S 40S 80S	Std. X-Stg.	4.500 4.500 4.500	4.260 4.026 3.826	.120 .237 .337	.099 .088 .080	14.25 12.73 11.50	4
5	40 80	10S 40S 80S	Std. X-Stg.	5.563 5.563 5.563	5.295 5.047 4.813	.134 .258 .375	.153 .139 .126	22.02 20.01 18.19	5
6	40 80	10S 40S 80S	Std. X-Stg.	6.625 6.625 6.625	6.357 6.065 5.761	.134 .280 .432	.220 .201 .181	31.75 28.99 26.07	6
8	20 30 40 60 80	10S 40S 80S	Std. X-Stg.	8.625 8.625 8.625 8.625 8.625 8.625	8.329 8.125 8.071 7.981 7.813 7.625	.148 .250 .277 .322 .406 .500	.378 .360 .356 .347 .333 .317	54.5 51.8 51.2 50.0 47.9 45.6	8
10	20 30 40 60 80	10S 40S 80S	Std. X-Stg.	10.750 10.750 10.750 10.750 10.750 10.750	10.420 10.250 10.136 10.020 9.750 9.564	.165 .250 .307 .365 .500 .593	.592 .574 .560 .548 .519 .499	85.3 82.6 80.7 78.9 74.7 71.8	10
12	20 30 40 60 80	10S 40S 80S	Std. X-Stg.	12.750 12.750 12.750 12.750 12.750 12.750 12.750 12.750	12.390 12.250 12.090 12.000 11.938 11.750 11.626 11.376	.180 .250 .330 .375 .406 .500 .562 .687	.838 .819 .797 .785 .777 .753 .738 .706	120.6 118.0 114.8 113.1 111.9 108.4 106.2 101.6	12
14	10 20 30		Std.	14.000 14.000 14.000	13.500 13.375 13.250	.250 .312 .375	.993 .976 .958	143 140.5 137.9	14
16	10 20 30		Std.	16.000 16.000 16.000	15.500 15.375 15.250	.250 .312 .375	1.313 1.289 1.268	189 185.6 182.6	16
18	10 20		Std.	18.000 18.000 18.000	17.500 17.375 17.250	.250 .312 .375	1.674 1.647 1.623	241.0 237.1 233.7	18
20	10 20		Std.	20.000 20.000	19.500 19.250	.250 .375	2.076 2.022	299.0 291.1	20
24	10 20		Std.	24.000 24.000	23.500 23.250	.250 .375	3.031 2.949	435.0 424.6	24

Reference

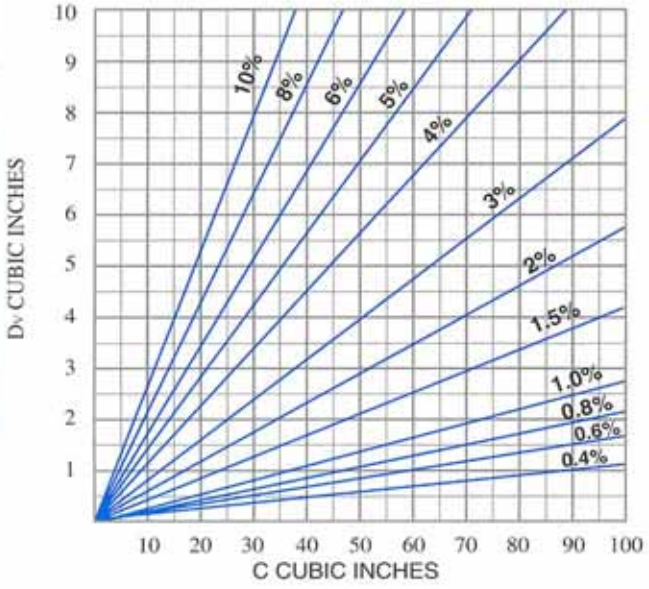
MINIMUM AIR VOLUME C FOR PULSATION DAMPENING
DIAGONAL LINES ON ALL CHARTS SHOW % VARIATION ABOVE AND BELOW MEAN DISCHARGE PRESSURE

D_V = volume displaced by one cylinder = 0.7854 b^2s cu. in.
b = bore of cylinder, in.
s = stroke, in.
The values of the graphs may be increased or decreased by factors of 10. Be sure that both the values of DV and C are changed accordingly.

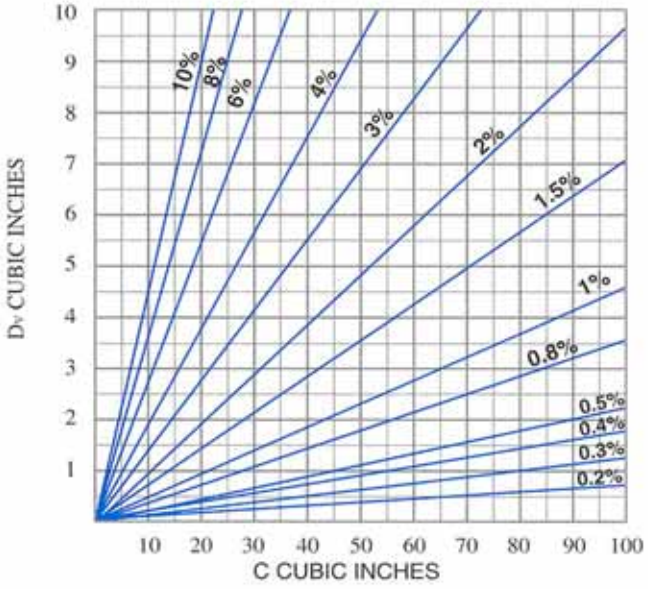
GRAPH 1
SIMPLEX SINGLE-ACTING PUMPS



GRAPH 2
SIMPLEX DOUBLE-ACTING &
DUPLEX SINGLE-ACTING PUMPS



GRAPH 3
DUPLEX DOUBLE-ACTING PUMPS



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No prices may be made up from information other than that shown in the tables.

2. All prices are F.O.B. factory, Chicago, Illinois, are are quoted exclusive of any taxes.

Shipments boxed for trans-ocean export add 10% to total trade price.

Terms: Net 30 days from date of invoice.

3. Cancellation or alteration of an order or return of any product by Buyer may not be made without advance written consent of manufacturer and shall be subjected to a cancellation charge.

A 35% minimum restocking charge shall be placed on any returned goods.

4. We will not be responsible for delays in shipping due to conditions beyond our control such as strikes, fires, or accidents.

5. Any claims for shortages or damaged products must be made in writing within 10 days after receipt of shipment.

6. Prices subject to change without notice.

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