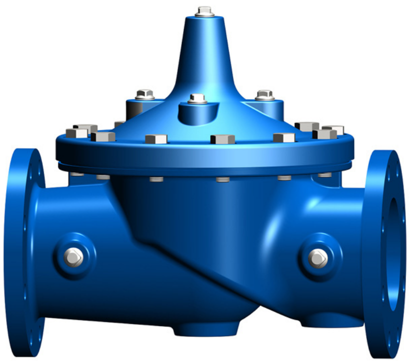
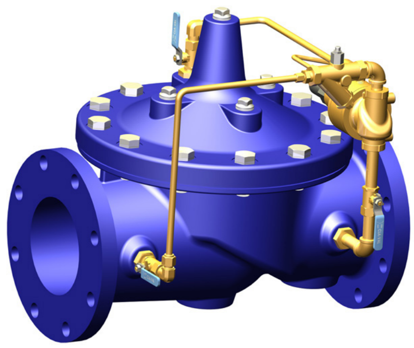
Cla-Val

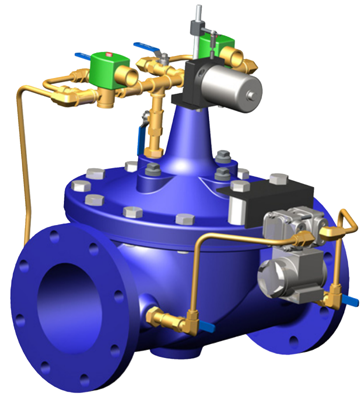
Service Training Manual

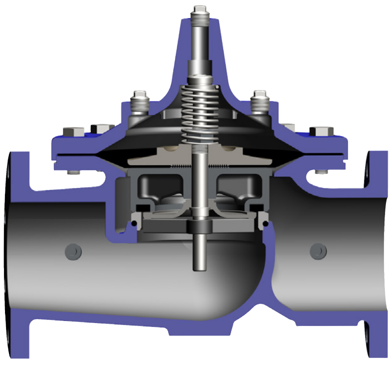
Section # 6

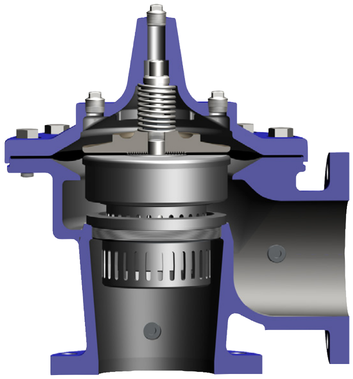
Technical Support

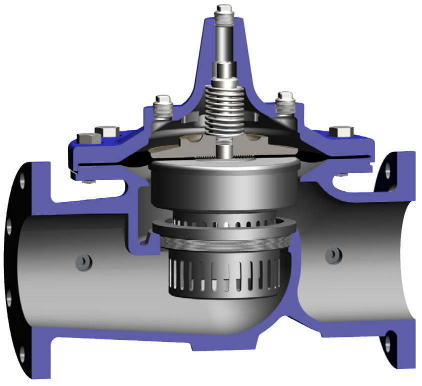












“Simple solutions plus learning with a purpose”

Section 6

Technical Support

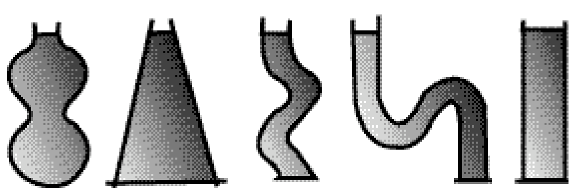
AN INTRODUCTION TO THE SCIENCE OF HYDRAULICS AND ITS APPLICATION IN CLA-VAL VALVES

SECTION I DEFINITIONS

HYDRAULICS:
The word hydraulics has its origin from two Greek words meaning water and pipe. When first used, it referred only to that branch of science which treats liquids in motion. The word is now used to include the scientific study of all fluids, both in motion (dynamic) and at rest (hydrostatic).

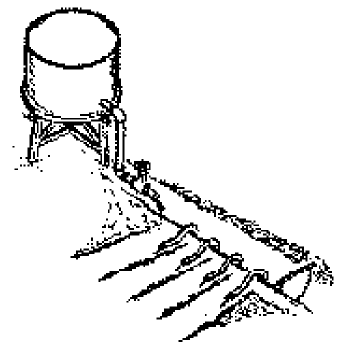
SCIENCE OF HYDRAULICS:
The science of hydraulics involves the study and application of the manner in which fluids act in containers such as tanks, valves and pipes and the study of the properties of fluids and the utilization of these properties. It also includes the laws of floating bodies, the treatment of flow under various conditions and the ways of directing this flow to useful ends.

PHYSICAL PROPERTIES OF FLUIDS:
Fluids are substances such as water, oil or air which are capable of changing their shapes and flow--as contrasted to solids. Fluids are divided into two classes: liquids and gases. Liquids do not substantially change in volume when subjected to pressure and are less compressible than solids. When a force is applied to a confined liquid, that liquid is substantially as rigid as a solid. Gases fill all parts of a containing vessel and they are far more compressible than liquids.



Fluids conform to the shape of their container.

All fluids have **weight** (density). The molecules which make up these fluids resist movement; this resistance is known as **viscosity.**



Because of their nature, liquids flow through open channels, as well as through closed conduits (pipe), by the force of gravity or by other applied forces.

When considering the control of flow or pressure of a fluid, it is important to know the **specific gravity, viscosity, and temperature** of the fluid (In the case of gases, other characteristics must be known).

SPECIFIC GRAVITY:
The specific gravity of a substance is the ratio of the weight density of a unit volume of that substance to the weight density of a similar unit volume of a standard substance. Water is the standard substance for liquids and solids. Air is the standard substance for gases. Both water and air are designated as having a specific gravity of 1.0 under standard conditions.

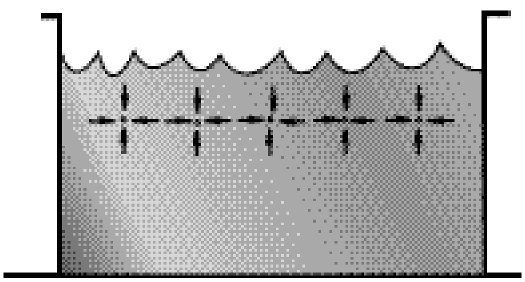
WEIGHT DENSITY: The number of units of mass of a substance which is contained in a unit of volume is called the weight density of that substance (ie. the weight density of water is 62.4 pounds mass per cubic foot of volume).

VISCOSITY: Resistance to movement in fluids is called viscosity. Fluids differ greatly in mobility (viscosity) due to the differences in their resistance to the movement in the molecules of different fluids. Viscosity is expressed in many ways; for example: Seconds Saybolt Universal (SSU), Kinematic, Viscosity-Centistoke, etc. SSU is most commonly used to express the degree of viscosity.

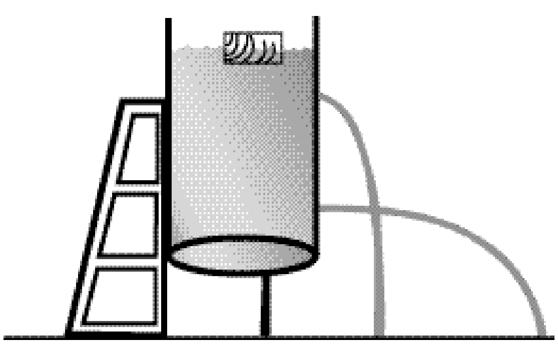
TEMPERATURE: Temperature affects the weight density and viscosity of fluids to a greater or lesser degree, depending upon the fluid concerned. Temperature is commonly expressed as degrees Fahrenheit or degrees Centigrade. Standard temperature for water is 60^{o} F.

SECTION II

FLUIDS EXERT PRESSURE: At any point in a fluid at rest, the pressure is the same in every direction.



Therefore, in a fluid at rest, the pressure is the same at all points at the same level.

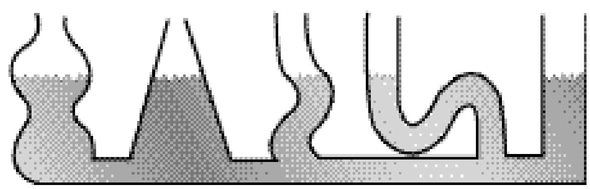


FOR EXAMPLE:

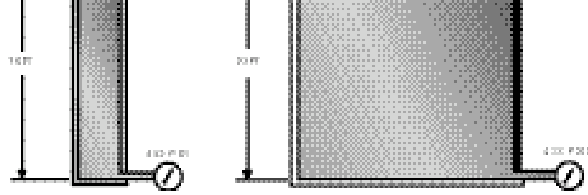
If a hole were to be bored in the bottom of a wooden tank full of water, the water would flow out; this would prove that fluids push downward. If a hole were to be bored in the side of the tank, the water would flow out; this would prove that fluids also exert pressure in a sideways direction. If a piece of wood were pushed down into the water, it would rise to the surface as soon as it was released. The upward push which liquids exert upon objects submerged in them makes them to seem to lose weight. From these examples, it must be concluded that fluids exert pressure in all directions.

LIQUID PRESSURE AND CONTAINERS:

Since fluid pressure is measured in unit area and is exerted equally in all directions, the shape of a container or vessel has no effect upon the amount of pressure exerted by the contained liquid. For example, the area of the liquid surface inside the body of a teakettle is much greater than the area of the liquid in the spout, but the pressure per unit area at the same depth is the same in both cases. If the pressure increased with the area, water would always flow out of the spout. The depth of the liquid in the container would determine the pressure exerted at any point, regardless of the shape or size of the container.

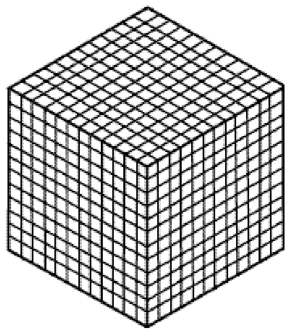


A liquid will come to rest at the same height in open vessels that are interconnected regardless of the shape of the area in these vessels. Simply stated, water seeks its own level.



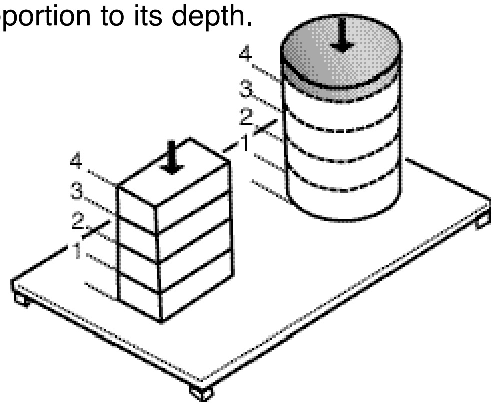
Hydrostatic paradox describes a condition when the force exerted on the bottom of a vessel is greater than the weight of all the liquid in that vessel.

In our study of liquids, water is most commonly used for illustration purposes. The weight density of water varies; but, for the purpose of standard measurement, its weight is considered to be 62.4 pounds per cubic foot.



If the bottom area of a straight-sided container is one square foot and the water which it contains is one foot deep, the pressure exerted would be 62.4 pounds per square foot at its base [or 62.4 divided by 144 equals 0.433 pounds per square inch (psi)].

Fluid pressure is proportional to the depth of the fluid, just the same as a brick lying on a table exerts force on pressure upon the table. When several bricks are piled one upon another, the downward pressure is increased. Likewise, each layer of fluid sustains the weight of the layer or layers above it; hence, the pressure of the fluid increases in direct proportion to its depth.



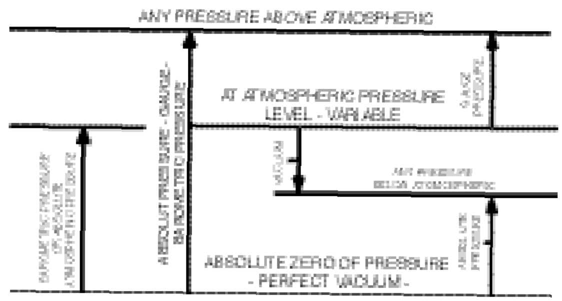
Because pressure exerted by any liquid is governed by its weight density as well as by its depth, the pressure in psi exerted by any liquid at any depth is determined as follows: multiply the depth of the liquid in feet by 0.433 and multiply that result by the specific gravity of the liquid (If the liquid is water, omit multiplying by specific gravity).

Example: To find the psi exerted at the base of a column of gasoline 18 feet in depth (specific gravity 0.7):

$$18 \times 0.433 = 7.794$$

$$7.794 \times 0.7 = 5.4558 \text{ or } 5.46 \text{ psi}$$

MEASUREMENT OF PRESSURE: There are several types of pressure: absolute, barometric, gauge and vacuum.



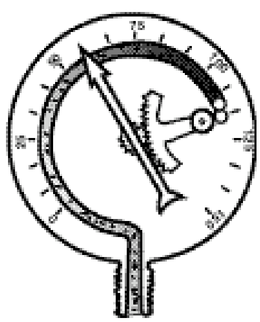
Perfect vacuum cannot exist on the surface of the earth, but it nevertheless makes a convenient starting point or datum for the measurement of pressure. Barometric pressure is the level of atmospheric pressure above perfect vacuum. Standard atmospheric pressure is 14.695 (14.7) pounds per square inch or 760 millimeters of mercury. Gauge pressure (psi) is measured above atmospheric pressure, while absolute pressure (psia) always refers to perfect vacuum as a base. Vacuum, usually expressed in inches of mercury, is the depression of pressure below the atmospheric level.

6 — 1

POUNDS PER SQUARE INCH GAUGE (PSIG): Normally, in an hydraulic system's equipment, the atmosphere has access to both ends (top and bottom) or actually surrounds the system. Consequently, in everyday engineering, the local atmospheric pressure is taken as zero. Almost all gauges are calibrated to read zero when exposed to local atmospheric pressure. When we see the term psig used, this means that the design engineer wishes no mistake made as to his reference point.

FEET OF HEAD: Pressure can also be referred to in these terms: head (in feet) or head (in inches). When using these terms, the type of fluid concerned must be stated (ie: head in feet of water or head in inches of mercury). Pressure instruments in one type of units can be converted to another type of units mathematically. Pressure of one foot of head is equal to pressure of .433 pounds per sq. inch. Also, 1 psi equals 2.31 of head

There are different instruments which measure pressure. The most common instrument for measuring pressure is the Bourdon tube type of pressure gauge. The Bourdon tube is fixed at the open end and free at the closed end. The closed end is attached to a lever gear and pinion system which rotates a pointer when the free end of the Bourdon tube moves. The dial in the Bourdon tube is usually calibrated in pounds per square inch.



Pressure applied to the open end of the tube tends to straighten out the curved tube, causing the free end to move.

By transmitting this movement through the linkage, gears and pointer, the magnitude of the pressure applied is indicated.

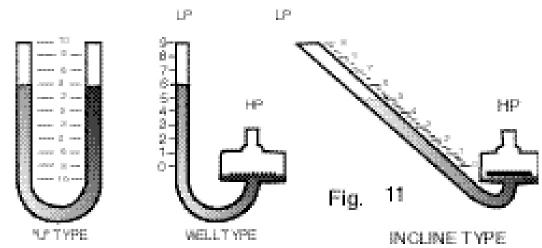


Fig. 11

The manometer is another instrument used for measuring pressure. It comes in several forms: Well type, U type and Incline type. It utilizes various liquids as the gauging medium. Because of its relatively heavy weight, low congealing point and high surface tension which prevents adherence to the gauge walls, mercury is the most commonly used gauging medium (A column of mercury one inch high is the equivalent of 0.49 pounds per square inch).

SECTION III

FORCE AND PRESSURE: In order to determine answers to hydraulic problems, the terms force and pressure are commonly used and must be clearly defined. Force may be defined as a push or a pull. If we push against a wall, we are using force; if we pull on a rope, we are using force.

FORCE: Force is the total amount of pressure exerted on any given surface or area. Force is most commonly expressed in pounds (lb.).

PRESSURE: Pressure is the amount of force applied to a unit area and is generally expressed in pounds per square inch (psi).

FORCE, PRESSURE AND HEAD RELATIONSHIP: In dealing with liquids, forces are practically always considered in relation to the area over which they are applied; thus, a force acting over a unit area is a pressure.

Pressures can alternatively be stated either in that form (pounds per square inch), or in terms of head which is the vertical height (feet) of the column of liquids whose weight would produce that pressure.

MATHEMATICALLY RELATED:

$$F = P \times A, \quad P = \frac{F}{A} \quad A = \frac{F}{P}$$

Where: F = Force in pounds

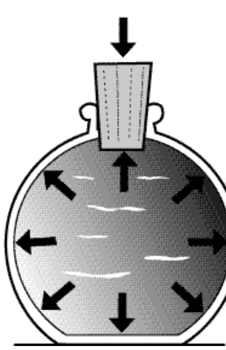
P = Pressure in psi

A = Area in square inches

PASCAL'S PRINCIPLE: Although the modern development of hydraulics is comparatively recent, ancient civilizations were familiar with many hydraulic principles and their application. About three or four hundred years ago, the physical sciences, as we now know them began to flourish. It was in this period that one of the fundamental laws underlying the whole science of hydraulics was discovered and was stated by Blaise Pascal in the year 1653.

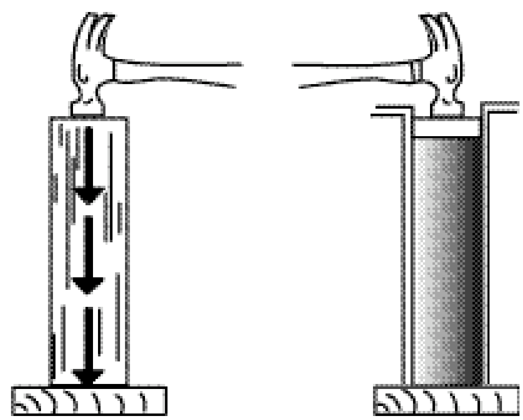
Pascal's principle is that pressure is transmitted equally in all directions throughout a mass of fluid at rest; therefore, if pressure of a confined fluid is increase at any point, pressure is increased everywhere throughout the fluid mass by that same amount.

In a simple example, a farm hand went to a well, filled a jug with water and inserted a stopper. He hit the stopper a sharp blow with the palm of his hand; and, much to his astonishment, the bottom fell out of the jug. What happened?



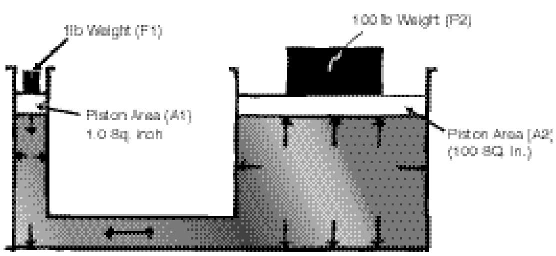
As the stopper was driven into the jug by the force of the blow, its pressure upon the confined liquid was transmitted equally in all directions. For convenience, assume that the neck of the jug had an area of exactly one square inch and that a ten-pound force was used in driving the stopper into the jug. That means that every square inch of the inside surface was subjected to a pressure of ten pounds in addition to the pressure of its weight. If the bottom of the jug had an area of forty square inches, the total force acting upon it must have reached a total of four hundred pounds. The bottom of the jug was not strong enough to withstand so great a force.

TRANSMISSION OF FORCES: When the end of a solid column is struck, the force of that blow is carried straight through the solid in the direction of the blow only. If the end of a column of a confined fluid is struck, the force is transmitted not only to the opposite end, but is transmitted equally in all directions through the column causing the container to literally be filled with pressure.



Forces can be transmitted through fluids (up or down and around corners or curves) with great efficiency. Although fluids are not rigid, the laws of fluids permit them to be used like levers. A small force can be used to balance a larger force.

Let us consider a hydraulic system filled with liquid which consists of two interconnected cylinders; one with a piston area of one square inch and the other with a piston area of one hundred square inches. Disregarding friction, a downward force of one pound on the small piston would create a pressure of one pound per square inch in the liquid. This pressure would be transmitted, undiminished, in all directions throughout the system and would act at right angles against all internal surfaces. Thus, the upward force on the one hundred square inch piston would support a weight of one hundred pounds (1 psi x 100 sq. in.) The basic formula is pressure = Force/Area. For equilibrium in the below examples F1/A1 = F2/A2 or 1/1 = 100/100.

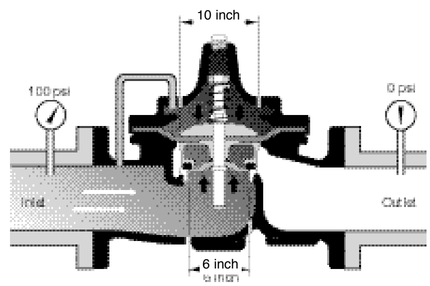


SECTION IV

PRESSURE, FORCE AND THE OPERATION OF CLA-VAL VALVES:

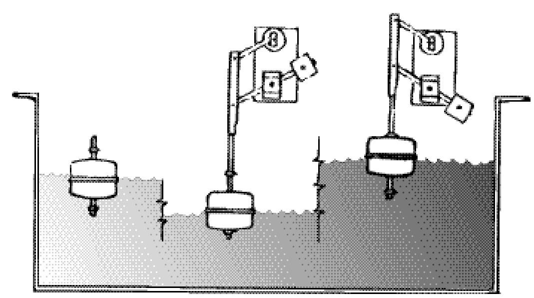
The CLA-VAL Hytrol main valve employs a flexible diaphragm instead of a piston for its operation. The diaphragm assembly of the main valve has an effective area. Assuming that the effective area is 10 square inches for the diaphragm and 6 square inches for the seat opening of the valve, a pressure of 100 psi at the valve inlet would create a force of 600 pounds (100 psi x 6 sq. in.) acting upward, which would push the disc away from the seat tending to open the valve.

By being connected to the valve inlet through a pilot system, the cover chamber also contains a pressure 100 psi. This pressure on the effective area of the diaphragm would create a force 1000 pounds (100 psi x 10 sq. in), acting downward to push the disc toward the seat. The net difference between the two opposed forces would be a force of 400 pounds, acting downward. This force would hold the disc closed against the seat to prevent flow through the valve. By using simple pilot controls in the pilot system, the pressure in the valve cover chamber can be easily changed. This will cause the operating force to move the disc to any point desired between drip-tight closed and wide open.

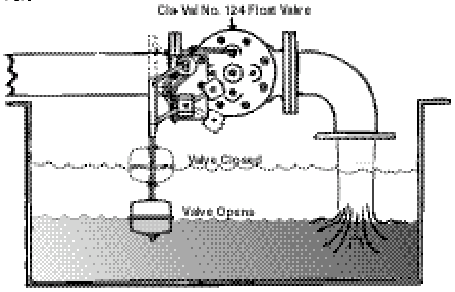


SECTION V

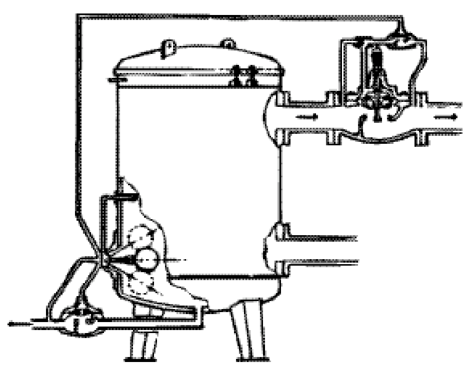
BUOYANCY: The lifting force of a liquid upon a body immersed in it is called buoyancy. The law of buoyancy discovered by Archimedes at about 420 B.C is: a body immersed in a liquid is buoyed up by a force equal to the weight of the liquid displaced by it.



It follows that when a body floats on a liquid with a portion protruding above the surface of the liquid, the weight of the liquid displaced is equal to the weight of the floating body. A float is a body designed to float in liquids in order to perform useful tasks. If a float is constructed so that its total weight is one pound and the liquid displace by one half of its volume is also one pound, the float will rest on a liquid with one half submerged. This float will have a thrust or upward lift which is equal to one pound.



A float must be designed for the liquid in which it floats. A float can be used to control the level of liquid in reservoirs or tanks. By utilizing mechanical and hydraulic linkages, the float will control the opening and closing of a CLA-VAL valve which allows the valve to automatically control the liquid level in the tank.



If a quantity of gasoline (specific gravity of 0.7) and water (specific gravity of 1.0) is poured into a container and is thoroughly mixed and then allowed to settle, it will be noted that the two liquids will quickly separate and the gasoline will float on top of the water. When completely at rest, the two liquids will be separated by a clear-cut line. The two liquids are said to be immiscible. Immiscible liquids can be defined as liquids that will not remain in solution when mixed together but will tend to separate (as with oil and water).

The line of separation is called the interface. The liquid on the top will be lighter than the liquid at the bottom. If two immiscible liquids are contained in the same vessel, a float can be constructed in such a manner that it will come to rest at the interface of two immiscible liquids with one half of its volume above the interface and one half of its volume below the interface. With such a float and with the proper mechanical and hydraulic linkage (as can be accomplished by a CLA-VAL valve), the volume of either liquid in the vessel can be controlled.

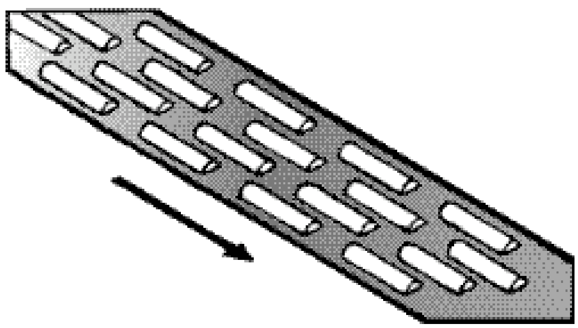
FLUIDS IN MOTION: In order to understand hydraulic systems and the flow of fluids through valves, it is necessary to become acquainted with some of the characteristics of fluids in motion and their definition.

VOLUME OF FLOW: Volume of flow, or flow rate, means the quantity of liquid that will pass a given point in a system in a unit of time. The unit of measure for volume of flow is stated in many different ways: cubic feet per second, barrels per hour, acre feet, gallons per minute and others. Gallons per minute is the most commonly used measure of volume of flow.

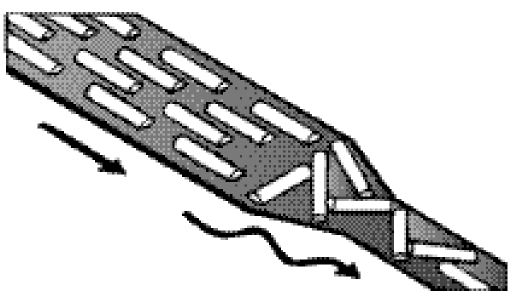
VELOCITY OF FLOW: Velocity of flow means the rate of speed of the liquid flowing past a given point in a system. There are several units of measure for velocity. The usual method of stating velocity is in feet per second. Volume of flow and velocity of flow are interrelated since volume can be determined by multiplying the area of a pipe (in sq. ft.) by the velocity in feet per second, resulting in volume in cubic feet per second.

STEADY AND UNSTEADY FLOW: Few hydraulic systems have uniformly steady flow rates. Changes in demand and pressure usually alter the flow rate in most systems.

LAMINAR AND TURBULENT FLOW: Flowing liquid tends to flow in a Laminar streamline manner in small diameter pipes and at low velocities. Streamline means that the particles of liquid will follow one another and move alongside each other without bumping into each other.



When flow velocities are increased and/or pipe diameters are enlarged, liquid particles tend to tumble and jostle each other and the flow becomes turbulent.
Flow through valves is generally accepted as being turbulent. Some valve designs are less inclined to cause turbulence than others.



In a pipe or channel, the liquid lying next to the wall of a conduit or pipe will have very little velocity. The closer to the center, the greater the velocity; the more turbulent the flow, the less difference in velocity (wall to center). Velocities, when stated, are the average of velocities across a cross section of pipe.

REYNOLDS NUMBER: Experiments which were conducted by Osborne Reynolds revealed that the nature of flow (turbulent or laminar) could be given a numerical value. This value is determined by the internal diameter of the pipe, the roughness factor, the average velocity of flow, the weight density of the fluid and the absolute viscosity in pounds mass per foot second. These calculations are not within the scope of this report. For those who wish to pursue the subject further, excellent study material can be found in any library.

FIVE FACTORS OF HYDRAULIC ACTION: There are just five physical factors which can act upon a liquid to affect its behavior. All of the physical actions of liquids in all possible systems are determined by the relationships of these five factors to each other. These five factors are:

• **Gravity -** acts at all times upon all bodies regardless of all other forces.

• **Atmospheric Pressure -** acts whenever any part of a system is exposed to the open air.

• **Specific Applied Forces -** May or may not be present; but which, in any event, are entirely independent of the presence or absence of motion.

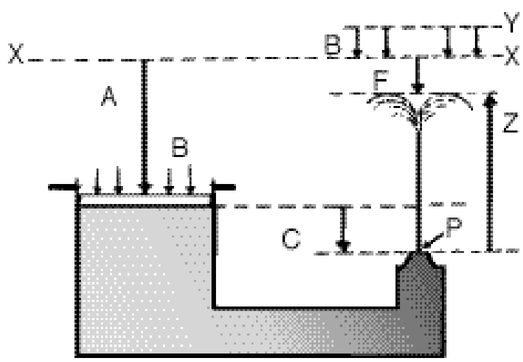
• **Inertia -** Comes into play whenever there is a change from rest to motion (or vice versa), or whenever there is a change in direction or in rate of motion.

• **Friction -** is always preset whenever there is motion.

INERTIA: Inertia is used by scientists to describe the ability of all forms of matter to resist being moved if it is at rest and likewise resist any change in its rate of motion if it is moving. This is simply saying, in more scientific terms, what everyone has learned by experience--that one must push on an object to get it moving and push in the opposite direction (or offer an opposing force) in order to stop it.

INERTIA AND FORCE: In order to overcome the tendency of an object to resist any change in its state of rest or motion, some force which is not otherwise canceled or balanced must act upon the object.

Some unbalanced force must be applied whenever liquids are set in motion or speeded up. Conversely, forces are made available to do work elsewhere whenever liquids in motion are retarded or stopped.
There is a direct relationship between the magnitude of the force exerted and the inertia against which it acts. This force is dependent upon two factors: on the mass of the subject (which is proportional to its weight), and on the rate at which the velocity of the object is changed. While the mathematical relationship between inertia and force is outside the scope of this report, it is included here for completeness and for those who may be interested. The rule is that the force in pounds required to overcome inertia is equal to the weight of the object, multiplied by the change in velocity measured in feet per second, and divided by 32.2 times the time in seconds required to accomplish the change. Thus, the rate of change in the velocity of an object is directly proportionate to the force applied. The number 32.2 appears because it is the conversion factor between weight and mass.



The figure above diagrams a possible relationship between the five factors (gravity, atmosphere, pressure, specific applied forces, inertia and friction) with respect to a particle of liquid P in a system. The different forces are shown in terms of head; or, in other words, in terms of the vertical columns of liquid required to produce the forces. At the particular moment under consideration, a particle of water P is being acted upon by an applied force equivalent to a head of A, by atmospheric pressure equivalent to a head of B and by gravity head C produced by the weight of the liquid standing over it. The particle possesses sufficient inertia or velocity head to rise to a level **Z**, since head equivalent to **F** was lost in friction as **P** passed through the system. Since atmospheric pressure **B** acts downward on the system on both sides, what was gained on one side was lost on the other.

If all the pressure acting on **P** to force it through the nozzle could be recovered in the form of elevation head, it would rise to level **Y**; or, if account is taken of the balance in atmospheric pressure, in a frictionless system it would rise to level **X** or precisely as high as the sum of gravity head and the head equivalent to the applied force.

KINETIC ENERGY: As pointed out above, a force must be applied to an object in order to impart velocity to it or to increase the velocity it already has. Of necessity, the force must act while the object is moving over some distance. Since a force acting over a distance is work and that work and all forms into which it can be changed are classified as energy, then energy is obviously required to give an object velocity. The greater the energy used, the greater the velocity. Likewise, for an object to be brought to rest (disregarding friction) or if its motion is to be slowed down, an opposing force to its motion must be applied.

This force also acts over some distance. In this way, energy is given up by the object and is delivered in some form to whatever opposes its continued motion. The moving object is, therefore, a means of receiving energy at one place (where it is speeded up) and delivering it to another point (where it is stopped or retarded). While it is in motion, it is said to contain this energy as energy of motion or **kinetic energy.**

For those who may be interested, the mathematical relationship for kinetic energy is equal to the force in pounds which created it, multiplied by the distance through which it was supplied; or, kinetic energy in foot pounds is equal to the weight of the moving object in pounds, multiplied by the square of its velocity in feet per second, divided by 64.3.

FACTORS IN FLOWING LIQUIDS:
All five of the factors which control the actions of liquids can be expressed either as forces or in terms of alternative or equivalent pressure or in heads. In each situation, however, the different factors are commonly referred to in the same terms (or units), since on this common basis it is possible to add to and subtract from them and also study their relationship to each other.

Some terms in general use should be explained.

• **Gravity head -** when it is of sufficient importance to be considered, is sometimes known simply as head.

• **Atmospheric Pressure** - the effect of atmospheric pressure is frequently, and improperly, referred to as suction.

• **Velocity Head** - inertia effect, because it is always directly related to velocity, is usually called velocity head.

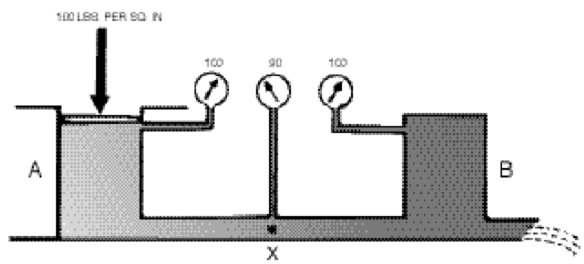
• **Friction Head** - friction is usually referred to as friction head because it represents a loss of pressure or head.

STATIC AND DYNAMIC FACTORS:
Gravity, applied forces and atmospheric pressure (static factors) apply equally to liquids at rest or in motion, while inertia and friction (dynamic factors) apply only to liquids in motion. The arithmetic sum of the first three (gravity, applied forces and atmospheric pressure) is the static pressure obtained at any one point in a liquid at a given time. Static pressure exists in addition to any dynamic factors which may also be present at the same point and time.

Pascal's Law states that a pressure set up in a liquid acts equally in all directions and at right angles to its containing surfaces. This covers the situation only for liquids at rest, or practically at rest. It is true only for the factors making up static head. it is for this reason that most problems involving fluids at rest disregard friction completely.

When velocity becomes a factor, it must obviously have a direction; and, as already explained, the force related to the velocity must also have a direction. So, Pascal's Law alone does not apply to the dynamic factors of liquid flow.

RELATION BETWEEN STATIC AND DYNAMIC FACTORS:
In one sense, however, the dynamic factors of inertia and friction are related to static factors. Velocity head and friction head are obtained at the expense of static head. On the other hand, at least a portion of velocity head can always be reconverted to static head. Force, which can be produced by pressure or head when we are dealing with liquids, is necessary to start a body moving if it is at rest, and is always present in some form when the motion of the body is arrested. In other words, whenever a liquid is given velocity, some part of its original static head is used to impart this velocity, which then exists as velocity head.

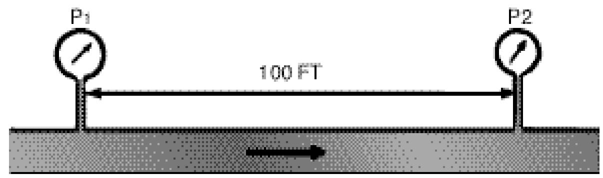


The relationship of static and dynamic factors can be illustrated in a system which consists of chamber A (under pressure), connected by a tube to chamber B which is also under pressure. The pressure in chamber A will be a wholly static pressure of, say, 100 pounds per square inch. The pressure at some point, X, along the connecting tube will consist of a velocity pressure of, say, 10 pounds per square inch exerted in a direction parallel to the line flow, plus the unused static pressure of 90 pounds per square inch which still obeys Pascal's Law and operates equally in all directions. As the liquid enters chamber B, it is slowed down. In so doing, its velocity head is changed back into pressure head. In other words, force is required to get the liquid moving in the first place so that the static pressure in chamber B will again be equal to that in chamber A, although it was lower at an intermediate point.

This example disregards friction and does not represent actual practice. Friction also requires force or head to overcome it; but, contrary to the inertia affect, this force cannot be recovered again, although the energy represented still exists somewhere as heat. In an actual system, therefore, the pressure in chamber B would be less than that in chamber A by the amount of pressure used in overcoming friction along the way.

BERNOULLI'S THEOREM: At all points in a system, therefore, the static pressure will always be the original static pressure less any velocity head at the point in question, and less the friction head consumed in reaching that point. Since both velocity head and friction head represent energy which comes from the original static head; and, since energy cannot be destroyed, the sum of the static head, velocity head and friction head at any point in a system must add up to the original static head. This general truth is known as Bernoulli's Theorem and is another important basic law of hydraulics. it governs the relationship between static and dynamic factors, while Pascal's Law states the manner in which the static factors behave when taken by themselves.

FLOW THROUGH PIPE:
Flow requires energy and the energy used is reflected in loss of static head. For example, if ordinary Bourdon tube-type pressure gauges were installed in a pipe at 100 foot intervals and flow was occurring through the pipe, the gauge downstream would show a lower pressure than the upstream gauge. The amount of pressure would depend of the velocity of the flow.



The loss of static head or the pressure different (P) in psi between P1 and P2 can be expressed mathematically as:

$$\Delta P = \frac{p\, fLV^2}{144\ D2g}$$

where:

ΔP = Pressure Differential (in psi)

p (Rho) = weight (density) of the fluid in pounds per cubic feet

f = friction factor (determined experimentally)

L = length of pipe in feet through which flow occurs

V = velocity of flow in feet per second

D = inside diameter of pipe in feet

g = acceleration due to gravity (32.2)

The above equation is a form of the Darcy formula which is generally used for determining pressure loss.

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SECTION VII

FLOW THROUGH VALVES: The preceding has been devoted to the flow of fluids, in general, in order to explain the causes and results of the flow of fluids. When a fluid is flowing steadily through a long straight pipe of uniform diameter, the flow pattern of the velocity-head distribution across the pipe diameter will assume a certain characteristic form. Any impediment in the pipe which changes the direction of the whole stream, or even part of it, will alter the characteristic flow pattern which will create turbulence and cause an energy loss greater than that normally accompanying flow in a straight pipe. Because valves and fittings in a pipeline disturb the blow pattern, they produce an additional pressure drop.

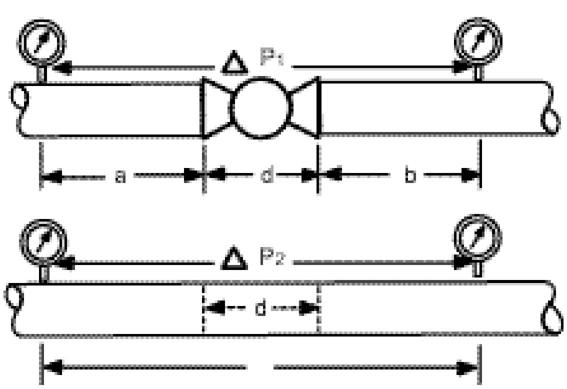
The loss of pressure produced by a valve consists of the following:

• The pressure drop within the valve itself.

• The pressure drop in the upstream piping in excess of that which would normally occur if there were no valve in the line. This effect is small.

• The pressure drop in the downstream piping in excess of that which would normally occur if there were no valve in the line. This effect may be comparatively large.

From an experimental point of view, it is difficult to measure the three items separately. However, their combined effect is the desired quantity and can be accurately measure by well-known methods.



The illustration shows two sections of pipeline of the same diameter and length. The upper section contains a globe valve. If the pressure drops ΔP1 and ΔP2 were measured between the points indicated, it would be found that ΔP1 is greater than ΔP2.

Many experiments have shown that pressure loss due to valves is proportional to a constant power of the velocity. For all practical purposes, it can be assumed that pressure (or head) loss due to the flow of fluids in the turbulent range varies as to the square of the velocity (V2).

When the pressure loss caused by a valve has been determined experimentally at several rates of flow, the losses can be plotted, and losses at all flow rates can then be predicted. The plot is usually illustrated on logarithmic coordinates and the curve is, therefore, a straight line.

Pressure loss through valves is normally given for a wide-open valve. Not all valves are wide open during flow. The pressure (head) loss caused by valves can be expressed in several different terms, each having its specific value to engineers in their work. These terms are:

• Differential pressure in psi (ΔP)

• Equivalent length in pipe diameters L/D

• Resistance coefficient K

• Flow coefficient C_v

DIFFERENTIAL PRESSURE ΔP:
Directly expresses (in pounds per square inch) the loss in static head caused by the valve (valve inlet pressure minus outlet pressure) at the specified rate of flow.

EQUIVALENT LENGTH IN PIPE:
The L/D factor is the equivalent length, in pipe diameters, of a straight pipe which will cause the same pressure loss as a valve (wide open) at the same flow rate.

Generally, the L/D factor is converted to length of pipe (of equivalent sizes in feet). EXAMPLE: Let us assume that a 6-inch valve flowing 600 gpm of water has a pressure loss of 2.02 psi (determined experimentally). From pressure loss tables, we find that the pressure loss at 600 gpm through 100 feet of 6-inch schedule 40 pipe is 2.34 feet of head or (2.34 x 0.433 x 1.0) 1.01 psi or 0.0101 psi per foot of pipe. Therefore the number of feet 6-inch schedule 40 pipe that would cause the same loss as the valve at 600 gpm would be the valve loss (2.02) divided by the loss per foot of pipe (0.0101) or 200 feet of pipe.

RESISTANCE COEFFICIENT:
Since velocity in a pipe is obtained at the expense of static head and the loss of head through a valve is also at the expense of static head, this reduction of static head can be expressed in terms of velocity heads. Most head-loss charts on pipe also give the velocity head loss at various flow rates.

EXAMPLE:
If a flow of 100 gpm through a pipe causes a loss in static head of 1 psi due to velocity head loss and a valve of the same size as the pipe causes a loss of 8 psi in static head at 100 gpm flow, it can be stated that the valve has a resistance coefficient K of 8. Thus, if at another flow rate through the pipe the velocity head loss was 1.2 psi, the loss through the valve at that flow rate would be 8 x 1.2 or 9.6 psi.

FLOW COEFFICIENT C_V:
It is often convenient to express the flow characteristics of a valve in terms of the number of gpm of water that will flow through the valve with a pressure loss across the valve of 1 psi. EXAMPLE: If a wide-open valve will flow 80 gpm at a pressure loss of 1 psi across the valve, the valve has a Cv factor of 80. With the Cv factor known, we can calculate: 1) ΔP (pressure differential of pressure loss) at any flow rate; or 2) the flow rate in gpm at any pressure loss. This can be expressed mathematically as:

$$C_V = \frac{Q}{\sqrt{\Delta P}}$$

Where: Q = rate of flow in gpm

P = pressure differential in psi

C_V = flow coefficient

Pressure loss charts on CLA-VAL valves are determined from laboratory test data and are for the flow of water. Problems involving other liquids should be referred to CLA-VAL

HYDRAULIC GRADIENT (OR HYDRAULIC GRADE LINE): If open-water columns were installed at intervals along a pipeline in which water is flowing, the water in these columns would rise to a height equal to the pressure head at each point. The imaginary line connecting the points to which the water would rise in these columns is called the hydraulic grade line or hydraulic gradient.

WATER HAMMER: This is the series of shocks, like hammer blows, produced by suddenly checking or stopping the flow of fluid (usually water) in a pipe. If a valve, turbine gate or faucet is suddenly closed, the kinetic energy of the arrested column of water is expended in compressing the water and in stretching the pipe walls if no relief devices have been provided. Starting at the suddenly closed valve, a wave of increased pressure is transmitted back through the pipe with constant velocity and intensity. The shock pressure is not concentrated at the valve; but if a bursting pressure is produced, it may show its effects near the valve simply because it acts there first.

The velocity of the pressure wave for an ordinary cast-iron pipe, 2 to 6-inches in diameter, is about 4200 feet per second; and for a 24-inch pipe, it is about 3300 feet per second. It depends on the elasticity of the metal and upon the ratio of its thickness to the diameter of the pipe. If the pipe were perfectly rigid, the velocity would be that of sound through water of about 4700 feet per second.

The increase of pressure is proportional to the destroyed velocity of flow and to the speed of propagation of the pressure wave. This increase is about 60 pounds per square inch for each foot per second of extinguished velocity for 2 to 6-inch pipes, and about 45 pounds per square inch for each foot per second for 24-inch cast-iron pipe. These increase of pressure will be attained only in case the valve is closed in less time than one round trip of the pressure wave.

When the pressure wave has traveled upstream to the end of the pipe where there is a reservoir or a larger main (the whole pipe then being under increased pressure with checked flow throughout), the elasticity of the compressed water and that of the distended pipe reverse the flow at that tend of the pipe and a wave of normal pressure (that of the reservoir or main) travels downstream, the flow being progressively reversed as the compressed water expands.

When this wave of normal pressure reaches the valve, the kinetic energy of the column of water with reversed flow tends to create a vacuum at the valve. There the reversed flow is checked and the checking proceeds progressively upstream accompanied by a wave of subnormal pressure. When this wave reaches the upstream end (the whole pipe then being under subnormal pressure), the greater normal pressure in the reservoir or large main starts flow into the pipe; and a wave of normal pressure and forward flow travels downstream. When this wave reaches the valve, there is forward flow throughout the pipe (the conditions being the same as when the valve was suddenly closed) and a wave of increased pressure and of checked flow again starts upstream.

A complete cycle of pressure waves and reversal of flow occupies the time required for two round trips. The amplitude of the pressure vibrations becomes less with succeeding cycles because of friction, but the time interval remains constant.

If a high-pressure wave in its travel through the pipe enters a branch pipe with a closed of dead end, there will be almost a doubling in the increase of pressure when the wave strikes the closed end. In some pipe systems, dangerous water-hammer pressures are built up if the back wave from a branch pipe with a dead end has access to another branch, the high pressure may receive further augmentation.

As the intensity of the excess pressure in the water-hammer wave is dependent upon the amount of extinguished velocity, the same excess pressure can be produced by suddenly reducing the velocity from 7 to 4 feet per second the same as by entirely stopping a velocity of 3 feet per second. If the flow is not checked rapidly so that the wave from the first movement of the valve has time to travel upstream to the end and back again several times while the checking is in progress, the excess pressure is very much reduced. Hence, the wisdom of using slow-closing valves on long pipe lines is derived.

SURGE: Much work has been done concerning the study of water-hammer surge pressures created by quick-closing valves; however, very little has been published on water-hammer surge pressure caused when pumps stop under power-failure conditions. It is generally acknowledge that an analysis of just what happens hydraulically is quite difficult, and very little experimental data is available to determine what will happen under various conditions. it can be assumed that the surge wave will be similar to the surge wave created by a quick-closing valve. The surge pressure would, however, be started in a different manner than when the surge pressure is caused by a quick closure of the valve. When a pump stops, the fluid continues to flow upstream with diminishing velocity until the energy provided by the pump is expended. The extent of the low-pressure wave thus created is very difficult to predict. It can become a minor subnormal pressure, or the pressure can go to below atmospheric and might cause the water column in the conduit to actually separate. The magnitude of a low-pressure wave will depend upon the initial flow velocity, the length of transmission line (to the first abrupt change), the hydraulic gradient of the transmission line, the abruptness with which the pump will stop and also the inlet pressure conditions at the pump.

The extent of the subnormal pressure created and the distance that the flow moves away from the pump will determine the velocity of the return flow. The velocity of the return flow when it reaches the closed check valve will generate a surge pressure wave in a similar manner to that of a quick closure of a valve.

Power-failure pump stops, or a pump stop without pump control valves, can cause damaging surge pressure waves to be generated in the intake of a booster pump when the supply line to the pump is relatively long and velocities are fairly high. These surge pressure are generated in the same manner as by a quick-closing valve. Should the high-pressure surge in the inlet line and the high-pressure surge in the discharge line meet at the pump, considerable stress will be imposed upon the pump and serious damage could result.

SURGE CONTROL: Several means of protection from, and elimination of, the surge pressures due to an electrical power outage and pump stopping are available through the use of proper surge relief valves. Inlet or suction line surges can be prevented by the use of quick-opening, slow-closing relief valves such as the CLA-VAL 50-Series Relief Valve installed at the pump and discharging to atmosphere.

Discharge line surges being generated by the sudden stopping of return flow can be successfully eliminated by installing (downstream of the check valve) a surge control valve discharging to atmosphere. This valve begins opening upon power failure and subsequent low-pressure conditions, so that it is open when the returning flow reaches the check valve and then slowly closes and gradually stops the surge reverse flow. The CLA-VAL 52-03 surge-anticipator control valve offers this type of operation and will successfully prevent surge pressure by eliminating the cause.

Contact Your Cla-Val Factory Representative For More Information

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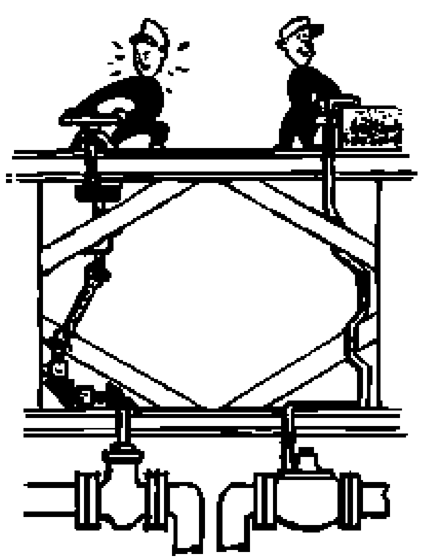


- Factory- Newport Beach ,Ca.
  1-800-942-6326
- Western Region- Riverside,Ca.
  1-800-247-9090
- Southern Region-Houston, Tx.-
  1-800-336-7171
- Northern Region-Elgin,Il.-
  1-800-238-7070
- Eastern Region-Alexandria,Va.-
  1-800-451-3030

Section
6-2 Simple Conversion Formulas

MULTIPLY	BY	TO OBTAIN
Atmosphere	14.5	PSI (G)
Atmosphere	1.0133	Bar
Bar	14.5	PSI (G)
Centimeters	.03281	Feet
Cubic centimeters	.06102	Cubic inches
Cubic centimeters	.0002642	Gallons (liquid)
Cubic feet	7.4805	Gallons (liquid)
Cubic feet	.1728	Cubic inches
Cubic feet / sec (CFS)	448.831	GPM
Cubic feet / sec (CFS)	.646317	Millions gallons / day
Cubic feet / min.	.4720	Liters / sec.
Cubic feet / min.	28317	Cubic meters / min.
Cubic inches	.004329	Gallons
Cubic inches	16.387	Cubic cm.
Cubic inches	.0005787	Cubic feet
Cubic meters	264.17	Gallons (liquid)
Cubic meters	35.31	Cubic feet
Cubic meters / min.	.00026	GPM
Feet	30.48006	Centimeters
Feet	.3048006	Meters
Feet of water	.4335	PSI (G)
Feet of water	.8826	Inches of Mercury
Feet / sec	.305	Meters per sec.
Gallons	3,785.43	Cubic Centimeters
Gallons	231	Cubic inches
Gallons	.83268	Gallons (Imperial)
Gallons	.13368	Cubic feet
Gallons	8.345	Lbs of water
Gallons	.003785	Cubic meter
Gallons / min. (GPM)	2228	Cubic Ft / sec.
Gallons / min. (GPM)	.0000630902	Cubic meter / sec.
Gallons / min. (GPM)	3.785	Liters / min.
Gallons / min. (GPM)	.06308	Liters / sec.
Inches	25.40	Millimeters (mm)
Inches of Mercury	1.133	Feet of water
Kilograms / sq. cm.	14.2233	PSI (G)
Liters	.264178	Gallons
Liters / min.	.0005886	Cubic Ft / sec.
Meters	3.2808	Feet
Pounds / sq. in. (psi)	2.036	Inches of Mercury
Pounds / sq. in. (psi)	2.31	Feet of water
Pounds / sq. in. (psi)	6895	Pascal (Pa)
Pounds / sq. in. (psi)	.0689	Bar
Square inches	6.4516	Square cm.

NOTE: 1 cubic foot = .028317 cubic meter
NOTE: 1 Atmosphere (U.S.) = 14.7 psi = 1.033 bar = 1.033 kgs / Sq. cm.

CONTROL VALVE CAVITATION CAUSES & PREVENTION

By Harold W. Ensign, Vice President Engineering
Cla-Val Newport Beach, California

PREFACE

This paper is intended to serve as a reference on cavitation in valves, its causes, and effects and how to use the Cla-Val Cavitation Program. The cavitation program is a guide to determining if there is damage cavitation in the Hytrol main valve, at what flow rate it occurs and how to minimize or eliminate the damage caused by cavitation.

Studies to determine the flow characteristics, incipient, critical and incipient damage cavitation have been performed on the Cla-Val 100-01 and 100-20 series valves at the Utah Water Research Laboratory, Utah State University Foundation. These tests were divided into four basic parts: 1) development of techniques for detecting cavitation damage on the interior surfaces of the valve body, 2) evaluating the location where damage first occurs at various valve openings, 3) evaluating the magnitude of the cavitation index corresponding to incipient cavitation damage, and 4) a study of the influence of pressure on the onset of cavitation damage. The studies were conducted under the direction of Dr. J. Paul Tullis, Professor of Civil and Environmental Engineering at Utah State University.

CAVITATION

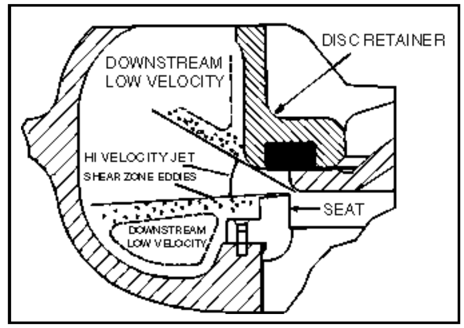
Cavitation prevention and protection is an important consideration in the design and operation of valves used in water distribution systems. One should be able to determine if cavitation exists, and if so its intensity and effects on the system. Cavitation in valves is a destructive condition that seriously affects the operation and service of the valve and occurs when fluid passing through the valve lowers to the vapor pressure of the fluid causing vapor cavities (bubbles) to form. When the fluid passes out of the low pressure area into a higher pressure area, the vapor cavity becomes unstable and collapses. This collapse is what can sometimes be heard or seen and is the reason we must be concerned about its presence in pipeline systems. The collapse can be violent and is accompanied by noise, vibrations, and possible erosion damage to the valve or surrounding pipeline.

ORIGIN OF CAVITATION

There are three fundamental requirements for cavitation to occur. First, there must be gas bubbles (nuclei) or voids in the fluid that serves as a basis for vaporization to occur. Second, the internal pressure in the fluid must drop to or below vapor pressure. Third, the pressure surrounding the vapor bubble must be greater than the vapor pressure in order for it to collapse. For cavitation to occur, there must be nuclei present. If the water was completely deaerated and there were no contaminant's, voids or entrapped air, either in the water or in the boundary of the valve, the water could sustain tension and would not cavitate when the pressure dropped to the normal vapor pressure. Therefore, nuclei is one of the primary requirements for cavitation to occur. The primary sources of nuclei are from free air bubbles and air bubbles trapped in crevasses of suspended material and crevasses in the valve body material (boundary).

SOURCES OF LOW PRESSURE

The mean pressure at the inlet to a valve is equal to the static head or pump pressure, minus the dynamic head. The local pressure in a valve is the sum of the mean pressure, which is uniform over a certain flow range and the dynamic pressure which depends on fluid motion which causes friction losses and local accelerations due to changes in the cross sectional flow area and on the formation and dissipation of eddies and vortices in turbulent shear zones. Flow at the inlet to a valve for example, has a relatively low velocity and high pressure. As the flow approaches the partially open valve, the velocity has to increase in order to maintain the same flow rate and this causes the pressure to drop. When the high velocity jet



enters the larger downstream area of the valve, a shear layer is created along the boundary of the high velocity jet and the lower velocity in the larger downstream area. The high velocity gradients created along this shear area creates eddies is considerably less than the already lower pressure of the high velocity jet. If nuclei is entrapped inside these eddies and the pressure drops to vapor pressure, it will begin to grow. If the pressure remains at vapor pressure long enough for the nuclei to reach a critical diameter, it then begins to grow rapidly vaporization. As the size of the vapor pressure cavity increases, the strength of the eddy is rapidly destroyed, the rotational speed reduces, and the pressure is no longer vapor pressure.

Since surrounding pressure is above vapor pressure, the cavity becomes unstable and collapses inward. The time that a nucleus is subjected to low pressure inside the eddy is important. If the time is so short the bubble cannot reach its critical diameter, it will not become cavitation event.

PRESSURE RECOVERY

In the third phase of cavitation there must be a pressure in the cavitation zone greater than vapor pressure in order for the cavity to collapse. If the bubble collapses before reaching the boundary areas there will be no cavitation damage, only noise, vibrations and possible reduction of flow.

DAMAGE

If the vapor cavities are carried to the solid boundary of the valve before they collapse, erosion damage will occur. Prior research has indicated that the collapse must occur approximately one bubble diameter from the boundary in order to cause erosion damage. Since the bubbles are generally small, this indicates that only collapses near or on the surface of the boundary will cause erosion damage. High pressure shock waves are generated by the collapse of the vapor cavities and in severe cases have been estimated to be over 1,000,000 psi. No material can withstand this type of beating very long. Once a system reaches a point where erosion damage occurs, damage increases very rapidly as the velocity of the system is increased. Because of this it is important that when selecting conditions corresponding to the onset of erosion or cavitation damage, one should be conservative because a slight increase in velocity could cause a large increase in the damage rate.

EFFECTS OF CAVITATION

There are five basic problems associated with cavitation: noise, vibrations, pressure fluctuations, erosion damage and loss of flow capacity. The type and intensity of noise in a valve usually depends on the size of the valve. Cavitation in a small valve is usually identified as a hissing or a light crackling sound. In large valves, the noise may sound more like small explosions and can vary with the design of the valve. The shock waves generated by the collapsing vapor cavities can produce pressure fluctuations and system vibration. As the intensity of the cavitation increases, the magnitude of the vibration increases many times over and can cause serious damage to mounting bolts, pipe fitting and structural failure. If the vapor cavities collapse close to a boundary inside the valve, erosion damage can occur. In many cases cavitation damage has eroded holes through the side of valve bodies and in some cases has eroded holes in the bridgewall and valve seat areas. This is one of the most common types of failure.

During advanced stages of cavitation, large vapor cavities form, which can alter the flow characteristics of the valve and drastically reduce the efficiency. This is referred to as Choking cavitation and represents the condition at which the flow coefficient (Cv) is drastically reduced because of the large vapor cavities. Just prior to choking cavitation, erosion damage, noise and vibration are at their maximum, then will start to drop off rapidly. Once the valve fully chokes, the vapor cavity will extend out beyond the discharge of the valve and into the downstream piping where the collapsing vapor cavities can cause major damage to the downstream piping and fittings.

DESIGN PARAMETERS

If we understand cavitation, its causes and effects, we can probably think of several ways to prevent damage to the valve. One easy method would be to limit operation of the system to a level that would not produce enough energy to carry the vapor cavity to the boundary of the valve and there would be no cavitation damage. Another method would be to change the internal geometry of the valve to remove the boundary out of the immediate damage cavitation zone. We made use of the data obtained from 25 years of studying cavitation and associated problems. We changed the internal geometry of the valve and by doing this we are able to increase the operating differentials of the valve tremendously without causing cavitation damage.

DETERMINING CAVITATION LIMITS

There is no analytical solution for determining the cavitation characteristics of a valve. Every valve design has its own "footprint" so to speak and for this reason the only way to properly evaluate the cavitation parameters is by laboratory experimentation. Once these parameters are obtained for a specific valve geometry then it is possible to develop empirical relationships for predicting the various levels of cavitation. If the internal geometry is changed then new experimental data must be obtained to develop new empirical relationships. For this reason the empirical data developed for one company's products cannot be transferred to another manufacturer's products.

Most any laboratory instrument that can detect noise, pressure fluctuations, vibrations, pitting or loss of efficiency can be used to detect cavitation. An important factor in determining the cavitation parameters is to do the experimentation in a laboratory that is relatively free from other noises such as pumps, control valves and vibrations that could effect the data obtained. Probably the most common instrument used to detect cavitation is the accelerometer because it is easy to use and is sensitive to the lightest and heaviest levels of cavitation. To obtain the flow conditions for incipient damage, polished soft aluminum plates were installed flush with the inside surfaces of the valve, in the proper locations to record the pitting.

Nearly all of the experimental data taken in the laboratory is taken at reduced pressures and flows from actual applications and for this reason just scaling the experimental data up to actual conditions in the field will not give true cavitation data. Therefore pressure scale effects for a given valve geometry have to be determined in the laboratory.

CLA-VAL CAVITATION STUDIES

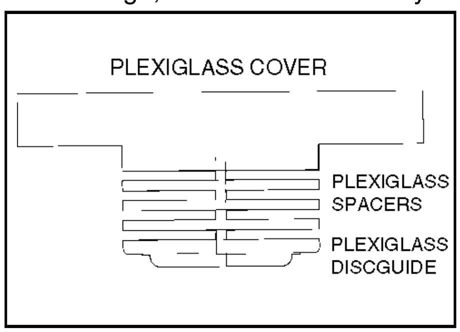
In the summer of 1970, Dr. J. Paul Tullis, Assistant Professor of Civil Engineering at Colorado State University, in Fort Collins, Colorado, sponsored a seminar on "Control of Flow in Closed Conduits". There were several well known authors who presented papers at this seminar on subjects ranging from flow in closed conduits to determining when cavitation will occur. After attending this program it became obvious that to assist in making the right valve selection for critical applications, Cla-Val should embark on a program to have the Hytrol main valves tested for the onset of cavitation. The tests were started at Colorado State University and later transferred to Utah State University when Dr. Tullis transferred to Utah State and became Professor of Civil and Environmental Engineering. When the tests were completed on various selected sizes, we had a world of information for the onset of cavitation (Critical Cavitation). With the data obtained from these tests we were able to develop a computer program to aid in selecting valves to operate in what we hoped would be a cavitation free condition. Unfortunately we soon found that in nearly all applications there was some degree of cavitation and we did not know to what degree of cavitation the valve could operate without damage. As a result, the program was of little value as far as determining the maximum safe operating conditions with regard to cavitation damage.

CAVITATION DAMAGE STUDIES

At Cla-Val we felt that if we knew the conditions at which cavitation damage started we would be able to develop a program that would allow us to determine the maximum operating limits without incurring cavitation damage. It was decided to have Dr. Tullis conduct further testing on the hytrol main valves to determine the conditions of incipient cavitation damage. Several sizes and types of valves were sent to Utah State University where Dr. Tullis and Stephen L. Barfus conducted tests to determine the flow conditions where cavitation noise first begins (Critical Cavitation), the pressure scale effects on critical cavitation, the flow conditions where cavitation damage begins, (Incipient Damage) and the flow conditions where choking cavitation begin to occur.

A dimensionless cavitation parameter sigma was used to quantify the intensity of cavitation at different flow conditions. The most common formula for determining sigma is (= (Pd - Pvg)/Pu - Pd) where Pd is the downstream pressure, Pvg is the gage vapor pressure and Pu is the valve inlet pressure. Data were collected at every 10 percent of opening to provide a valve opening versus Cv curve. The intensity of cavitation at critical level consists of steady light popping sounds. This level of cavitation does not cause erosion damage or reduce the service life of the valve and for most applications is recommended for what could be termed “cavitation free operation". The critical cavitation levels were determined by ear during these tests.

To determine the sigma value at incipient damage, it was first necessary to



determine the location inside the valve where actual cavitation was occurring. This was done by making a valve cover and valve disc from Lucite with spacers for each 10 percent of valve opening. When installed, one could actually observe where inside the valve, cavitation occurred when operated at various percentages of opening. Polished soft aluminum plugs were then inserted through the walls of the valve body and positioned flush with the inside wall in the locations where cavitation was observed. Plates were also fastened flush with the bridgewall boundary inside the valve. The internals were then re-installed in the valves and the valves operated at each 10 percent opening at various differentials and flow rates until pitting was observed on the soft aluminum plates. This was a very time consuming test because the valve had to be operated at a known condition for 10 to 20 minutes, then disassembled and the plates examined to see if there were any pits in the soft aluminum plates. If there were no pits the valve was reassembled and the process repeated at a lower sigma value until the proper number of pits were obtained. Incipient damage for these tests was taken as one pit per square inch per minute on the soft aluminum plates. This procedure was then repeated at each 10 percent of valve opening.

At the conclusion of the cavitation damage studies, the cavitation program was modified to include the condition of incipient damage and we found that some body designs would tolerate a much higher degree of cavitation than others before the onset of cavitation damage.

Over the years different series of valves have been developed and much of the information obtained from the cavitation studies is incorporated in the design. When designing a valve with a reduced seat diameter to eliminate the need for reducing flanges that are required in many installations, it gave us the opportunity to design a valve that had improved cavitation characteristics. As a result, the 100-20 series of valves was developed and tested by Dr. Tullis for incipient damage. The results were far better than expected. This series of valves will operate at much greater velocities without experiencing cavitation damage. All new designs, including our new 24 inch 100-01 Hytrol, utilize our many years of experience from operation and testing.

Valves that operate intermittently such as some relief applications may be able to operate at a higher degree of cavitation. In this type of service, erosion damage may not be the deciding factor. If the system is designed to withstand the vibration and noise the valve may be able to operate at choke flows. The intensity of cavitation, noise, vibration and erosion damage is usually at their maximum just before the valve chokes and the flow may be very unstable. The cavitation program shows the occurrence of choking cavitation.

VALVE APPLICATION

When specifying a valve, the Cla-Val Cavitation Program can be used to determine the cavitation characteristics of the valve for the specific application. As in **example 1**, lets say we have a 4 inch 100-01 Hytrol, located at the end of a long pipeline flowing from 400 to 700 gpm. The long supply pipeline has a pressure loss of 50 psi at 700 gpm. The static inlet pressure is 120 psi, the outlet pressure is 20 psi and the valve is at 800 feet elevation. The cavitation program shows cavitation damage over the entire range of flow. Now that we know there will be cavitation damage, what can we do about it? One method of combating cavitation damage is to add back pressure to the valve. This is done in the cavitation program by entering a value for the back pressure, which must be greater than the normal outlet pressure. As the flow rate increases, the pressure at the outlet of the valve increases causing the valve to open further which reduces the velocity of the jet through the partially open valve and increases the outlet pressure which may raise the internal pressure above vapor pressure.

CLA-VAL NEWPORT BEACH
100-01/100-20 HYTROL
Cavitation Characteristics

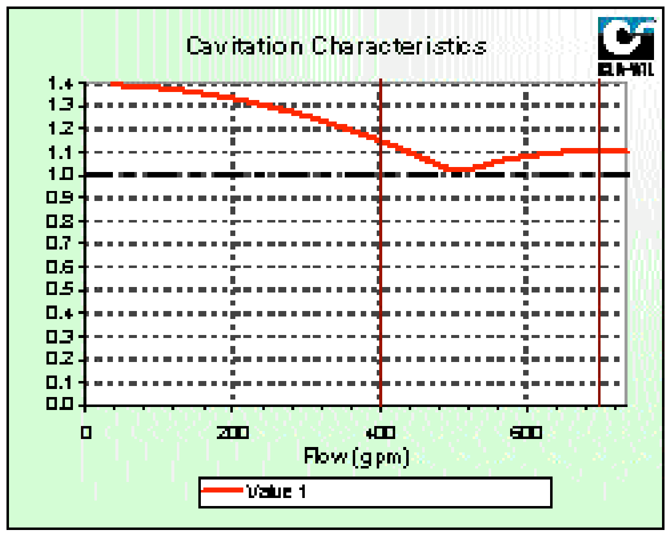
Cla-Val Cavitation Analysis - EXAMPLE 1 Project -

Valve 1		
Valve size	4" 100-01	
Maximum flow rate	700	gpm
Minimum flow rate	400	gpm
Static inlet pressure	120	psi
Static outlet pressure	20	psi
Elevation above S.L.	800	ft
Water temperature	60	deg F
Dynam. inlet pressure	70.0	psi
Dynam outlet pressure	20.0	psi
Backpressure orifice	None	
Orifice backpressure	0	
Orifice discharge to	Downstream piping	

Valve operation

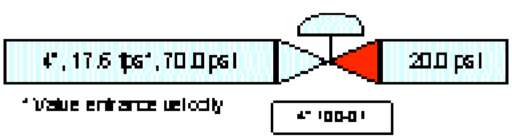
Continuous (>50%)

Avoid operation near (within 10%) cavitation damage level of 1.0.



If the lines go above 1.0 there will be cavitation damage

No damage
Caution - near damage
Damaging cavitation



* Valve entrance velocity

Valve 1 Flow Rate GPM	Inlet (psi)	Outlet (psi)	% Open	Pipe Vel. (fps)	Cav Damage
35	119.9	20.0	6.6	0.9	Yes
175	116.9	20.0	20.6	4.4	Yes
350	107.5	20.0	28.5	8.8	Yes
525	91.9	20.0	36.8	13.2	Yes
700	70.0	20.0	48.1	17.6	Yes

In **example 2**, a back pressure of 44 psi at a maximum flow was added and the cavitation damage was completely eliminated. Adding back pressure to a valve can be accomplished by adding an orifice plate downstream of the valve. In a pressure reducing valve application, the pressure regulating pilot must sense the pressure downstream of the orifice plate. If there is considerable resistance in the discharge line of the valve, then the back pressure on the valve will automatically increase as the flow increases and this must be taken into consideration when entering the data. If the discharge line is long and the valve is anything but a pressure reducing valve, then the discharge pipe Cv must be entered which will automatically raise the outlet pressure as the flow increases. This should be done before entering back pressure to eliminate damage cavitation.

Still another method of reducing cavitation damage in a valve installation is to use two or more valves in series or add KO trim to the valve. Using the cavitation program, one can determine the maximum pressure conditions for each valve that will permit them to operate free of cavitation damage.

CLA-VAL NEWPORT BEACH
100-01/100-20 HYTROL
Cavitation Characteristics

Cla-Val Cavitation Analysis - EXAMPLE 2

Project -

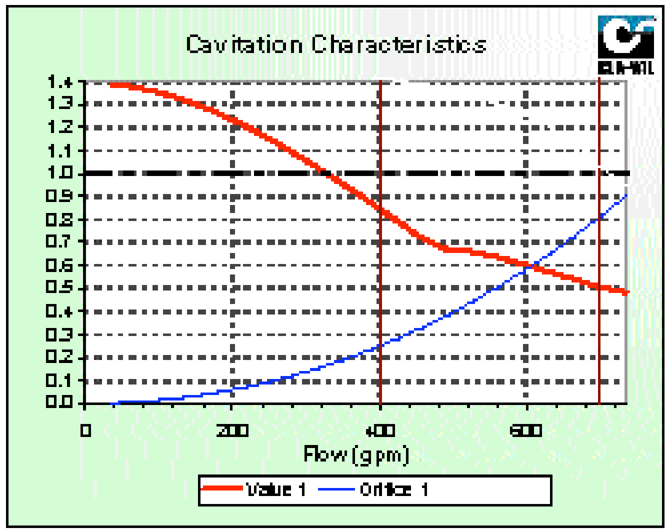
Valve 1

Valve size	4" 100-01	
Maximum flow rate	700	gpm
Minimum flow rate	400	gpm
Static inlet pressure	120	psi
Static outlet pressure	20	psi
Elevation above S.L.	800	ft
Water temperature	60	deg F
Dynam. inlet pressure	70.0	psi
Dynam outlet pressure	20.0	psi
Backpressure orifice	Single	
Orifice backpressure	44.2	psi
Orifice discharge to	Downstream piping	

Valve operation

Continuous (>50%)

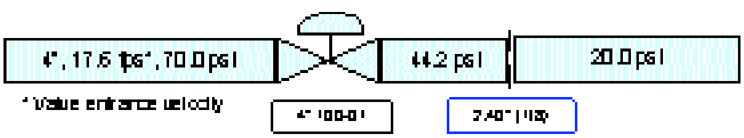
Avoid operation near (within 10%) cavitation damage level of 1.0.



If the lines go above 1.0 there will be cavitation damage

No damage
Caution - near damage
Damaging cavitation

Valve damage occurs < 15 psi.



Valve 1 Flow Rate GPM	Inlet (psi)	Outlet (psi)	% Open	Pipe Vel. (fps)	Cav Damage
35	119.9	20.1	6.6	0.9	Yes
175	116.9	21.5	20.6	4.4	Yes
350	107.5	26.1	29.0	8.8	Near
525	91.9	33.6	38.9	13.2	No
700	70.0	44.2	59.4	17.6	No

CONCLUSION

Cla-Val has over twenty-five years of time proven experience in understanding, identifying, minimizing and eliminating cavitation damage associated with our control valves in water distribution systems. We offer free of charge, assistance in proper selection and sizing of valves to engineers, suppliers or end users in their quest for a more trouble free system. Cla-Val has the experience, the products, solution and trained technical assistance to deal with cavitation.

Data for portions of this paper was taken by permission from "Hydraulics of Pipelines" by J. Paul Tullis, Professor of Civil and Environmental Engineering at Utah State University, Logan, Utah.