# Fluid Flow Through Small Calibrated Orifices

Many variables enter into the calculations of fluid flow through orifices. These variables influence flow rates of gases differently than flow rates of liquids. The flow rate of any gas or liquid can be predicted, regardless of conditions, if the orifice has been flow calibrated under a controlled and known set of conditions. An orifice flow calibrated with a known gas and a known set of conditions can be used to control the flow of any other gas with known set conditions. Liquid flow calibrated orifices have the same relationship. However, a constant relationship between gas and liquid flow rates does not exist. A variation of + /- 5 % is encountered relative to an average constant.

Many variables affect the flow through orifices. One variable is the hole diameter. Flow varies directly with the area of the hole or is a function of the hole diameter squared. Other variables affecting the flow through a hole of a fixed diameter include the shape of the entrance and the depth of the hole relative to its diameter. Some of these variables affect gases different than liquids.

Most flow variables are eliminated when making calculations using a flow diameter instead of a diameter measured at the throat of the hole. The diameter varies by as much as a few percent from the actual diameter and can be used in calculations to determine the flow of different gases and different flow conditions.

The following formula can be used to determine a flow diameter and to calculate flows of other gases and other conditions after an orifice has been flow calibrated.

Gases:

$$Flow = .01749 \times \frac{P_1}{29.7} \times \sqrt{\frac{29}{M.W.Gas}} \times Factor\#3 \times \sqrt{\frac{528}{Temp\,^\circ R}} \times d_1^2$$

$$d_1 = \sqrt{\frac{Flow}{.01749 \times \frac{P_1}{29.7} \times \sqrt{\frac{29}{M.W.Gas}} \times Factor\#3 \times \sqrt{\frac{528}{Temp\,^\circ R}}}}$$

Liquid flow can be predicted the same as gas thru flow calibrated orifices. However, liquid is not compressible and different formula are required for calculations. A $d_1$ is used to designate flow diameters for gas flow and $d_2$ is used to designate flow diameters for liquid flow.

$$Flow = .0001423 \times \sqrt{\frac{\Delta P}{\rho}} \times d_2^2$$

For the preceding formulae the following units apply:

Flow = Cubic centimeters / minute
$P_1$ = Inlet pressure in pounds / inch$^2$ absolute

$$d_2 = \sqrt{\frac{Flow}{.0001423 \times \sqrt{\frac{\Delta P}{\rho}}}}$$

$P_2$ = Outlet pressure in pounds / inch$^2$ absolute
$\Delta P = P_1 - P_2$ in pounds / inch$^2$
$d_1$ = Micrometers (for gases) $d_2$ (for liquid)
.01749 = Constant in gas flow calculations
.0001423 = Constant in liquid flow calculations
$\rho$ = Liquid density relative to water
Factor#3 = A factor used to calculate gas flow when $\Delta P/P_1$ is less than 0.5
M.W. = Molecular weight of gas or gas mixture

In using the preceding formulae, proportional factors are used to solve for flow rates for different basic changes such as inlet pressure, outlet pressure, temperature, molecular weight of gases, density of liquids, etc. When $\Delta P/P_1$ is more than 1/2, gas velocity through an orifice is at the speed of sound and the standard flow rate is directly proportional to the absolute pressure. When $DP/P_1$ is less than 1/2, the flow curve is empirical and cannot be satisfied with an equation. Many points on this curve have been found by testing and are found on the $\Delta P/P_1$ vs. Factor#3 sheet. For good results, extrapolate between points.

Since air is the gas used for our standard in flow calibrating orifices, the flow of other gases is proportional to air by the ratio of $(M.W.Air/M.W.Gas)^{1/2}$ if all other conditions are held constant.

The standard high side test pressure is 29.7 P.S.I.A. and all flow rates where $P_1$ is twice as large as $P_2$ or greater, are directly proportional to $P_1/29.7$ with all other conditions being constant.

It is important to remember that pressures and temperatures expressed in the preceding formulae are in absolute terms. Atmospheric pressure is 14.7 P.S.I.A. only at sea level on a day when barometric pressure is normal. Adding 14.7 P.S.I. to gauge pressure will rarely give the correct absolute pressure. To establish standard flow orifices, or to use flow calibrated orifices, conditions must be very precise.

Orifices can be flow calibrated with precise accurancy by comparing them to a known standard orifice as long as all conditions remain the same. Basically a system has been devised to introduce a standard orifice to a computer system at a fixed set of conditions. The computer then compares the orifices being tested to the standard orifice at the same fixed conditions. The results are interpreted by the computer and communicated to a printer. Standard flow rate and the flow diameter printed are accurate to plus or minus a fraction of one percent.

Many different systems have been developed for flow calibrating orifices. Some of these are as follows:

1. The first system uses a water displacement method. Gas passing through the orifice goes into the top of a closed container partially filled with water. The gas pushes water out of a connection in the bottom of the container and up a connected vertical transparent tube. Two light sources with photocells are located on this tube and are electrically connected to the computer. The flow rate of a known orifice is typed into the computer and timed as the water rises from the lower photocell to the higher photocell. The known flow rate multiplied by time gives a volume. In subsequent flow calibration tests this volume is divided by computer measured time and converted into a rated flow and orifice diameter.

2. Another method used in flow calibration involves gas flowing into a closed container and measuring the time to build up a fixed pressure in this container. A pressure switch compares pressure build up time of a test orifice to a known orifice.

3. The third method of flow calibration compares the slope of the pressure build up curve with the pressure build up curve of a standard orifice. This is accomplished by monitoring the pressure building up in a closed container with a pressure transducer.

4. The suction pressure between an orifice and the suction of a vacuum pump will balance out at a fixed value. The value can be established with a standard orifice. Holes can then be drilled to flow with one side of the orifice connected to the vacuum pump suction and the other side exposed to atmosphere.

5. Liquids can also be used to flow calibrate orifices. A closed container of liquid with a fixed pressure of gas maintained on top of the liquid can force the liquid through the orifice and up a transparent vertical tube or tubes. The flow rates can then be determined the same way as described in the first method.

In all five methods of flow calibration, the orifice being calibrated is compared to a known standard orifice. This eliminates the need of watching barometric pressure, altitude, temperature, etc. Regardless of these factors the results are the same if conditions are held constant while orienting the system with a known orifice and calibrating an unknown orifice.

The standard orifices used in flow calibration have been compared to N.I.S.T. flow calibrated orifices and found to be accurate within plus or minus one half percent (± 0.5%).

On small orifices, surface tension can interfere with or stop the flow of liquids. Surface tension measurements for liquids are available in many books. However, no definitive information is available that determines at what pressures, hole diameters, and surface tensions flow stops.

The five methods of flow calibrating small holes described above are very accurate. These are primary type systems. Repeatability is excellent and usually identical to four significant figures. Reproducibility compares favorably with expensive and elaborate test facilities. Flow conduit valves, containers and other component parts are large compared to the orifices being tested. Pressure drops and dynamic pressures approach velocities are kept at very low levels and have little or no effect on test results.

Keep in mind that all pressures must be absolute and the flow conduit and orifice retaining device must have a diameter at least four times larger than the orifice, for the proceeding formula to be correct.

The following formula will approximately correct flow calculations when $d_1$ (orifice diameter)/ $d_c$ (conduit) diameter equals 0.20 to 0.70.

$$b=d_1/d_c$$

$$Flow = .01749 \times \frac{P_1}{29.7} \times \sqrt{\frac{29}{M.W.Gas}} \times Factor\#3 \times \sqrt{\frac{528}{Temp^{\circ}R}} \times d^2 \times \left(\frac{1}{1-b^4}\right)$$

Lenox Laser is not responsible for predicted flow rates if systems and conditions do not follow the proceeding information or if orifices have been physically deformed.

## $\Delta$ P/$P_1$ VS. Factor # 3

| $\Delta P/P_1$ | Factor #3 | $\Delta P/P_1$ | Factor # 3 | $\Delta P/P_1$ | Factor # 3 | $\Delta P/P_1$ | Factor # 3 | $\Delta P/P_1$ | Factor # 3 |
|---|---|---|---|---|---|---|---|---|---|
| 0.52 | 1 | 0.04 | 0.382 | 0.076 | 0.53 | 0.012 | 0.179 | 0.001 | 0.023 |
| 0.48 | 0.994 | 0.208 | 0.794 | 0.064 | 0.481 | 0.008 | 0.138 | 0.001 | 0.023 |
| 0.44 | 0.983 | 0.196 | 0.776 | 0.052 | 0.442 | 0.004 | 0.08 | 0.0009 | 0.0216 |
| 0.4 | 0.966 | 0.184 | 0.756 | 0.048 | 0.422 | 0.01 | 0.16 | 0.0008 | 0.002 |
| 0.36 | 0.944 | 0.172 | 0.736 | 0.044 | 0.402 | 0.009 | 0.15 | 0.0007 | 0.0183 |
| 0.32 | 0.918 | 0.16 | 0.715 | 0.04 | 0.382 | 0.008 | 0.139 | 0.0008 | 0.0162 |
| 0.28 | 0.884 | 0.148 | 0.693 | 0.036 | 0.361 | 0.007 | 0.127 | 0.0005 | 0.0139 |
| 0.24 | 0.845 | 0.136 | 0.672 | 0.032 | 0.334 | 0.006 | 0.113 | 0.0004 | 0.0115 |
| 0.2 | 0.782 | 0.124 | 0.647 | 0.028 | 0.309 | 0.005 | 0.097 | 0.0003 | 0.089 |
| 0.16 | 0.715 | 0.112 | 0.625 | 0.024 | 0.281 | 0.004 | 0.08 | 0.0002 | 0.0062 |
| 0.12 | 0.638 | 0.1 | 0.594 | 0.02 | 0.25 | 0.003 | 0.062 | 0.0001 | 0.0033 |
| 0.08 | 0.542 | 0.088 | 0.564 | 0.016 | 0.216 | 0.002 | 0.043 | 0 | 0 |