

# **Excel Worksheets for CONTROL VALVE SIZING**

## Instructions

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## INTRODUCTION

This paper provides instructions for Excel valve sizing worksheets prepared by the author for gas and for liquid. Even though there are a number of commercially available computerized control valve sizing programs, these worksheets will be of interest to a broad range of users for several reasons.

1. These worksheets can optionally calculate and graph a valve's installed flow characteristic and installed gain. If you are not familiar with the subjects of installed flow and installed gain, there are links in the **using the installed flow** and **installed gain** tabs to articles you might find helpful. The only other free control valve sizing program that is known to the author that has these capabilities is Metso's Nelsize ® program. The capabilities of these worksheets are easily applied to the control valves of any manufacturer that publishes tables of valve parameters vs. valve opening. ( $C_v$  or  $K_v$ ,  $F_L$  and  $x_T$ )
2. There is certainly something to be said for using a program that one has a thorough understanding of exactly how the program works and what equations are used.
3. Because the results of all the intermediate calculations can be viewed in real time, these worksheets can be used as an educational tool for those who would like to learn how changes in various valve sizing parameters propagate through the entire calculation procedure.
4. These worksheets might also serve as a starting point for anyone who wishes to develop their own valve sizing application.
5. These worksheets could be used to verify the calculations made by another control valve sizing program whose method and formulas are not well documented. Because the valve sizing formulas can be easily traced back to the ISA Standard, one could verify the worksheet's calculations with hand calculations. Once this has been done it would be reasonable to assume that the calculations done by the worksheet are in accordance with the ISA Standard.
6. Many of the free valve sizing programs furnished by valve manufacturers are specific to that manufacturer's valves and are difficult to apply to the valves of other manufacturers.

Every effort has been made to conform to the ISA calculation methods given in ANSI/ISA-75.01.01 (IEC 60534-2-1 Mod) 2012, "Flow Equations for Sizing Control Valves". The equation numbers from the Standard are entered on the worksheet next to their formulas. Instead of using a looping macro for the necessary iterative calculation, the formulas that need to be iterated are simply entered into the worksheet a number of times sufficient for convergence for nearly any valve style and any practical combination of pipe size and valve size. References to the ISA Standard, 75.01.01 – 2012 also apply to the equivalent IEC Standard, IEC 60534-2-1 – 2011.

## DISCLAIMER

**These worksheets are distributed at no charge on an as-is basis. The author does not assume any liability for their use.**

## WORKSHEET PROTECTION AND COPYRIGHT

I have protected the worksheets to prevent accidental changes to the formulas and calculation method. It is still possible to see the formulas that are used so that those who are interested can verify the calculation method, or use my calculation method and formulas in their own worksheet or other programming environments. If you want to make changes to the worksheet, there is no

password, simply select “Unprotect Sheet” from the Excel “Review” tab, but you do so at your own risk.

I have not claimed copyright to these worksheets because I want them to be used by anyone who wants to. If you design your own worksheets or other program using my formulas and calculation methods, leave my name off, as I don't want credit for any incorrect calculations.

## **GAS SIZING WORKSHEETS** (one for volumetric flow and one for mass flow)

### **How the Worksheets Work**

You only need to read this section if you want to understand how the worksheet is configured and how the calculations work. Otherwise you can skip to the “Using the Gas Worksheets” section.

Each variable, constant or formula cell, is assigned, as its name, the variable name to its immediate left, and it is this name that is used whenever that cell's contents are used in a subsequent formula. With this knowledge, the user can see the flow of the calculations by studying the worksheet. (This naming of the cells only applies to the first column the variable, constant or formula appears in. When a variable or formula is duplicated in a subsequent column, cells are simply referred to by their cell number, i.e. “E3.”)

Sizing calculations can be done for either volumetric flow (where flow is in standard volumetric units and molecular weight is known), or mass flow (where flow is in mass flow units and the density of the gas is known).

The worksheets use the ISA formulas given in the ISA Standard (ANSI/ISA-75.01.01 (IEC 60534-2-1 Mod) 2012, “Flow Equations for Sizing Control Valves) to calculate the reducer corrected required valve capacity,  $C_V$  (or  $K_V$ ), along with the correction to the valve's rated choked (or terminal) pressure drop ratio,  $x_T$ , due to the effects of pipe reducers. In the worksheets, to be consistent with the ISA Standard, we refer to the valve's required flow coefficient as “C” which can be either  $C_V$  or  $K_V$  depending on the “Numerical Constants” that are used. The worksheets, as distributed, are configured to use US Customary units. The user can easily reconfigure the worksheet to use any of the sets of units that are supported by the ISA Standard. By entering a code (1 through 5) in Cell B1 immediately above the user interface, formulas in Column B in the user interface that indicate the units for each variable will enter the appropriate engineering unit for the selected set of units. Further down, in the Numerical Constants area, formulas will insert the proper Numerical Constant entries that will configure the worksheet calculations for the set of units selected by the user. Cell B2 contains a list of the codes (1 through 5) along with the unit set that they represent.

For the “volumetric” worksheet which is based on the ISA equation for gas flow in Standard volumetric units, the ISA Standard offers two sets of Numerical Constants, one for a standard reference temperature of 15 degrees C (60 degrees F) and one for a standard reference temperature of 0 degrees C (32 degrees F). A formula selects numerical constants based on the user's input in Cell C2.

When reducers are included in a calculation, the reducer corrections for  $C_V$  (or  $K_V$ ) and  $x_T$  are both a function of  $C_V$  (or  $K_V$ ). Since  $C_V$  (or  $K_V$ ) is the parameter we are trying to calculate, it is necessary to use an iterative approach. Initially the effect of reducers is ignored, and checking for choked flow, a first guess at the required  $C_V$  (or  $K_V$ ) is calculated. This first estimate of  $C_V$  (or

$K_v$ ) is then used to come up with reducer corrections to both  $C_v$  (or  $K_v$ ) and  $x_T$ , and checking for choked flow, a new  $C_v$  (or  $K_v$ ) is calculated. This process is repeated 60 times using the calculated  $C_v$  (or  $K_v$ ) from the previous iteration. The author has observed in all of his tests with realistic data that sixty iterations are always sufficient. (Don't try to calculate for a three inch valve in a ten inch pipe, but most people would not consider a three inch valve in a ten inch pipe.)

Aerodynamic noise is calculated by a method that is presented in the Metso Automation *Flow Control Manual*, and is based mainly on VDMA 24422 (1979). The method includes corrections that have been empirically determined for several common styles of control valves.

This noise calculation method was chosen for two reasons: 1) Metso Automation has used it for many years with satisfactory results. 2) The Author has extensive experience using this method and has found to be reliable. If desired users can implement any noise calculation they wish. In any case, before purchasing a control valve, it would be wise to ask your valve supplier to verify your selection based on their calculations.

On a second tab "**Installed Flow**" is an optional calculation that graphs the installed flow of the valve under analysis in the particular system that is under analysis as a function of valve relative travel. The flow axis is on a scale of 0 to 1.0 of the valve's fully open flow in this system. The relative travel axis is on a scale of 0 to 1.0 of the valve's full range of travel from closed to fully open.

This calculation of **installed flow** is based on a simple mathematical process model using the principle that pressure losses in a piping system are approximately equal to flow squared. There are ten sets of calculations, one for each 10 percentage point valve travel increment between 10 percent open (relative travel of 0.1) and 100 percent open (relative travel of 1.0). The calculation makes an initial guess for each of the ten calculations. The guess is always less than what the anticipated actual flow will be for that particular increment of relative travel. For the first travel increment (relative travel of 0.1) the initial guess is arbitrarily set at 0.01 (one one hundredth) of the minimum specified design flow. (It is reasonable to assume that the flow through any practical control valve at 10% travel will be greater than 1/100<sup>th</sup> of the minimum design flow.) For the subsequent calculations (relative travel increments between 0.2 and 1.0) the initial flow guess is the actual flow calculated from the previous travel increment's calculation.

The calculation at each increment of relative travel starts with its initial guess and the corresponding  $C_v$  (or  $K_v$ ) is calculated. The absolute value of the difference between this  $C_v$  (or  $K_v$ ) and the user's input of the valve's rated  $C_v$  (or  $K_v$ ) in the table above the graph is reported on the "Absolute value  $C_h$  - Selected C" line for that iteration. For the next iteration, the guess at flow is increased by 1% (for travel increments 0.2 through 1.0 and by 2% for travel increment 0.1) above the flow used in the previous iteration and the above process is repeated. In each iteration, the flow is increased by the same percentage from that of the previous iteration, and the process model is used to determine valve P1 and pressure drop at that flow. After 362 iterations for relative travel of 0.1 and 331 iterations for relative travels of 0.2 through 1.0 for the Gas worksheet, and 400 iteration for all relative travels for the Steam or Vapor worksheet the list of calculated "Absolute value  $C_h$  - Selected C" is searched for a minimum value. This minimum is the point where the calculated  $C_v$  (or  $K_v$ ) comes the closest to the valve's  $C_v$  (or  $K_v$ ) in the table above the graph for that increment of relative travel. The flow from this iteration then becomes, within 1% (2% for 0.1 relative travel), of the flow at this increment of relative travel for this valve in this system.

The value of the valve's Choked pressure drop ratio factor,  $x_T$ , tabulated by the user in the table above the graph is used in the calculation for each increment of valve relative travel to calculate the "Choked pressure drop ratio ( $X_{choked}$ )."

In the Volumetric flow worksheet, because finding a mathematical model for upstream temperature and compressibility factor that would be useful in each of the ten increments of relative travel would be impractical, the worksheet uses the convention used by Metso's Nelprof<sup>®</sup> of using the user's specified temperature and compressibility factor in the maximum flow case in the calculations for each increment of relative travel. In the Mass flow worksheet, the worksheet uses the convention used by Metso's Nelprof of using the user's specified density in the maximum flow case and adjusting it for the pressure determined by the system model for each increment of relative travel. No attempt is made to correct the density for temperature in each increment of relative travel.

On a third tab "**Installed Gain**" is an optional calculation that graphs the installed gain of the valve under analysis in the particular system that is under analysis as a function of flow divided by the maximum specified design flow.

The gain of a device is defined as "the change in output divided by the corresponding change in input." For a control valve, the output is the flow in the system and the input is the valve's relative travel. As explained below, we use the relative flow, based on the system's specified maximum design flow as the output.

In the table on Line 40 of the Installed Gain tab the relative flow is tabulated for each of the 10 flow increments determined on the Installed Flow tab plus another 10 intermediate flow increments that are each halfway between the increments calculated on the installed flow tab. The relative flow is calculated by dividing the flow for each of the twenty flow increments by the specified maximum design flow ( $Q_{max}$ ) for the system. The maximum system design flow is used as the reference point so that installed gain graphs for different sizes or styles of valves will have the same system requirements as a reference and the resulting gain graphs can be used to compare the control behavior of these different valves in the same system. If the fully open flow for each valve had been used as the reference for relative flow, comparing gain graphs for different sizes or styles of valves would each have a different reference point and comparison would be meaningless.

The **Gain** at each relative travel point tabulated on Line 41 is the change between the flow at the next relative travel point and the flow at the previous relative travel point (on Line 44) ( $\Delta Q$ ) divided by the change in relative valve travel (on Line 45) ( $\Delta h$ ). The change in relative valve travel between every two relative valve travel points is 0.1 in every case.

The vertical lines that represent the values of  $Q_{min}$  and  $Q_{max}$  are graphed as additional data series (data on Lines 43 and 44). Because the Gain graph's independent variable scale is  $Q/Q_{max}$  the  $Q_{min}$  vertical line is located on the scale at  $Q_{min}$  divided by  $Q_{max}$ . The vertical line that represents the value of  $Q_{max}$  will always be at 1.0 ( $Q_{max}$  divided by  $Q_{max}$ ). (On the Mass flow worksheet, the maximum and minimum flows are  $W_{min}$  and  $W_{max}$ .)

A fourth tab "**Typical  $x_T$** ," has typical values of  $x_T$  that you can optionally use in the absence of manufacturer's data. These values of  $x_T$  are based on data published by a source I know to be reliable. The data used on the tab is based on tables of valve  $C_v$  divided by valve size squared and is in the form of curve fit equations. Each  $x_T$  value reported on the Typical  $x_T$  tab is calculated using the appropriate curve fit equation, the

calculated Cv on the Valve Sizing tab and the valve size entered on the Valve Sizing tab.

### Using the Gas Worksheets

The main user interface of the Volumetric flow and Mass flow worksheets is in the upper left corner of the Valve Sizing tab in Columns A through G and Rows 3 through 23 for the Volumetric flow worksheet and Rows 2 through 23 for the Mass flow worksheet.

The user can easily configure the worksheets for any of the sets of engineering units that are supported by the ISA Standard. Cell C1 just above the user interface lists codes (1 through 5) for the unit sets that are supported by the Standard. Enter the code for the unit set that you want to use in Cell B1 and the worksheet will be configured for your chosen set of units.

The Volumetric flow worksheet, which is based on the ISA equation for flow in Standard volumetric units, has the option of using two choices for the standard reference temperature offered by the Standard. Select a reference temperature of 15C or 0C by entering the code in Cell B2 selected from the choices in Cell C2.

The current version of the ISA control valve Standard does not include a gas equation that uses the specific gravity of the gas, but only an equation that uses the molecular mass of the gas, and for that reason, the Volumetric flow worksheet follows that convention. If you do not know the molecular mass, but instead know either the density at the pressure and temperature you have entered in Column D of the Valve Sizing tab or the specific gravity of the gas, the "Mol Mass" tab has conversions that will give you the molecular mass.

On the Volumetric flow worksheet, the Compressibility Factor, Z, corrects for the degree to which the density of a particular gas deviates from the density of an "ideal," or "perfect" gas. Generally, most of the gasses that are used in industrial processes, at the temperatures and pressures at which they are normally used, usually (but not always) using a compressibility factor of 1.0 is sufficient for valve sizing purposes.

The Compressibility Factor is not included in the Mass flow worksheet because the ISA vapor equation assumes that the value of density used in the calculation is a true density based on accurate density tables or calculations. The "Density" tab on the Mass flow worksheet can calculate molecular mass from a known specific gravity, and if the actual density has not been given, it can calculate density from the pressures and temperatures and molecular mass you have entered on the Valve Sizing tab. If you know the compressibility factor, the density calculation will reflect "real gas" behavior.

The factor  $x_T$  is valve specific, and varies with valve opening. Ideally it should be obtained from manufacturer's literature. In the absence of valve manufacturer's data, the "Typical  $x_T$ " tab gives typical  $x_T$  values based on the calculated Cv (or Kv) and the valve size entered on the "Valve Sizing" tab. Whether you use manufacturer's  $x_T$  tables or those on the "Typical  $x_T$ " tab you will need to make an initial guess at the  $x_T$  values to use before you know the Cv. I usually make an initial guess that the valve will be 20% open at the minimum specified flow and 80% open at the maximum specified flow and choose my initial  $x_T$  values accordingly. The "Typical  $x_T$ " tab has suggestions for initial  $x_T$  values. Once I have initial Cv calculations I adjust the  $x_T$  values. Usually one or two adjustments will result in calculated Cv values that are close enough for all practical purposes.

The "Valve style SPL code" can be selected from Table 6 to correct the noise calculation for the specific type of valve being considered. A table of SPL codes is also located on the worksheet

just to the right of the data input and final results area. Codes 0 through 4 are based on tests performed by one manufacturer known to the author of these worksheets. Code 5 for “Multi-stage globe” is for a representative multi-stage valve. Multi-stage valves vary widely in design and performance. This calculation is intended to give the user a general idea of the sort of noise reduction that is possible with multi-stage globe valves, but does not represent any particular manufacturer’s design or model.

The “Pipe wall correction,” identified in the user interface area of the worksheet as “DeltaLp,” for various downstream pipe sizes and schedules can be found in Figure 1. Figure 1 is also located on the worksheet just to the right of the data input and final results area.

Many users limit the allowable noise level to 90 dB(A) because this is the OSHA limit for eight hours of exposure. Depending on the valve's location it may be necessary to set a lower limit, or a higher limit may be reasonable.

*Under no circumstances should a noise level exceeding 110 dB(A) (based on uninsulated schedule 40 pipe) be allowed, because the resulting high level of vibration is almost sure to damage the valve or pipe. Keep in mind that most noise calculation methods are only accurate to within plus or minus 5 dB(A).*

High outlet velocities can generate noise levels which exceed the noise predicted by the noise calculation (the noise calculation is applicable to valve trim noise only and does not include noise generated by high velocities in the valve body). Valve outlet velocity should certainly be limited to less than Mach 1.0, and some valve manufacturers recommend that it should be limited to 0.5 for standard trim valves and 0.3 for low noise valves. Other authorities call for a maximum value of 0.3 for standard trim valves and 0.2 for low noise valves. Also be aware that the VDMA noise standard states that the noise predictions are only valid for outlet Mach numbers below 0.3. The VDMA standard also states that “As a result of the differences of the various test set-ups and test chambers, inevitable errors in the determination of the sound pressure level, and in the extrapolation of the test stand results to actual conditions, a tolerance band up to 10 dB(A) wide must be made allowance for.”

The result shown on Line 18, “Flow calculated from C\_ above,” is obtained by solving the appropriate ISA equation for flow given the value of C (Cv or Kv) calculated by the iterative method described above and displayed on Line 17, “Required flow coef. (Cv or Kv).” If you study the ISA equations for reducer corrections you will see that because they contain C they cannot be explicitly solved for C (thus the necessity for the iterative calculation) but can be explicitly solved for flow in a single step. If this calculation of flow on Line 18 equals (or at least very nearly equals) the given flow on Line 4, you are assured that the value of C produced by the iterative calculation is indeed correct. If the calculated flow confirmation is more than 2% less than the given flow on Line 4, the field will be highlighted in light red.

If the calculation does not converge to within a few percent it is possible that you are using too great a ratio of pipe size to valve size. Most people consider it poor piping practice to use a valve that is less than one half the pipe size. Also be aware that the ISA/IEC Standard states that reasonable accuracy can only be expected if  $Cv/d^2 \leq 30$ . Many fully open (or nearly fully open) rotary valves exceed this limit.

Calculated results only appear after all required input data has been entered into the worksheet.

## Using the Installed Flow tab:

This is an option that allows you to see a graph of the relationship between valve travel and flow. The calculation combines the valve's published inherent characteristic ( $C_v$  or  $K_v$ ) vs. relative valve travel, and the system's pressure loss vs. flow characteristic. The process pressure model is a curve fit based on the Flow, P1 and Delta P in Columns D and G on the Valve Sizing tab. The curve fit is based on the principle that piping pressure losses are approximately proportional to flow squared. This model should be treated as an **approximation**.

In most cases, an installed flow characteristic that is fairly linear between the specified minimum and maximum design flow rates is desirable. If you are not familiar with the subject of installed flow, you might find the first two pages of this article I wrote for *Flow Control Magazine* helpful:

<http://www.control-valve-application-tools.com/app/download/10903119457/FC%20Mag%20-%20Characteristics%20and%20Sizing.pdf?t=1433879602>

To begin using this option, you will need to fill in the table that is above the graph area on the Installed Flow tab with manufacturer's data for the valve you want to analyze ( $C_v$  and  $x_T$ ) vs. relative valve travel. Note that some manufacturers of rotary control valves publish tables of valve capacity ( $C_v$  or  $K_v$ ), and Pressure differential ratio factor ( $x_T$ ) as a function of valve travel in degrees on a scale of 10 to 90 degrees rather than on a scale of relative travel of 0.1 to 1.0 (which is equivalent to 10% to 100%) as required by the valve sizing worksheet. The valve sizing Zip file includes a worksheet, "90 Deg to relative travel Table.xlsx" that will convert 10 to 90-degree data to 0.1 to 1.0 relative travel data as required by the valve sizing worksheet.

When this option is not going to be used, the four columns of process conditions on the **Valve Sizing** tab are independent of each other. If you plan to use the **Installed Flow** tab option, you **must** observe the following: On the Valve Sizing tab, enter the minimum design flow along with its associated values of P1, Delta P and other parameters in Column D and the maximum design flow along with its associated values of P1, Delta P and other parameters in Column G. Any process conditions entered in Columns E and F are not used in the calculation of the installed flow.

The system pressure model will not be valid, and the installed flow and installed gain graphs will not be drawn if the following requirements have not been met:

1. The maximum design flow is to be entered in Column G. Therefore the flow in Column G must be greater than the flow entered in Column D. (The pressure model is also invalid if the maximum and minimum flows are equal.)
2. P1 must be constant or decreasing with increasing flow. Therefore P1 in Column G must be equal to or less than P1 entered in Column D.
3. P2 must be constant or increasing with increasing flow. Note that P2 is calculated from P1 and delta P. The calculated values of P2 at the minimum and maximum specified flows can be found on the **Installed Flow** tab in Cells R12 and R13.

Error messages indicating any of these reasons for the graphs not being drawn will appear on the Installed Flow tab to the right of the graph area.

To the right of the graph is a calculation of the flow in the system when the valve is fully open, and therefore corresponds to the relative flow of 1.0 on the Relative Flow axis. There are two dotted lines that show where the specified maximum and minimum design flow rates intersect the relative flow axis and the installed flow curve. By following the vertical grid lines on the graph from where they intersect the flow curve at the points where above mentioned dotted lines intersect the flow curve you can read the approximate valve relative travel at the maximum and

minimum specified design flow rates. Also to the right of the graph the TAG you entered on the Valve Sizing tab, the Valve style / model # and size you entered in the table of valve data, the maximum and minimum flows you entered on the Valve Sizing tab and the flow units specified on the Valve Sizing tab are all automatically entered for reference. The print range on the Installed Flow tab has been set to print the graph along with the data displayed to its right.

### Using the Installed Gain tab:

This option relies on the calculation performed on the Installed Flow tab. It is often difficult to compare the control capability of two valves with less than perfectly linear installed characteristics by simply studying their installed characteristic graphs, and one can learn more about how well they will control a particular system by examining their installed gain. Some general guidelines are that, within the specified flow range, the gain should be greater than 0.5, less than 3 and not change by much more than a 2 to 1 ratio. It is also desirable for the installed gain to be as constant as possible and as close to 1 as possible. If you are not familiar with the subject of installed gain, you might find this article that I wrote for *Flow Control Magazine* helpful:

<http://www.control-valve-application-tools.com/app/download/10900062557/FC%20Mag%20-%20Installed%20Gain.pdf?t=1437752660>

There are two dotted lines that show where the specified maximum and minimum design flow rates intersect the relative flow axis and the installed gain curve, so the specified flow range is the area between these two lines. It is important to notice that on this tab, the relative flow is  $Q/Q_{max}$ , (actual flow divided by the maximum specified design flow) where on the installed flow graph the relative flow is  $Q/Q_f$ , (actual flow divided by the fully open flow). This is an important difference as it makes it possible to compare the installed gain of valves of different sizes and types, as explained in the “How the Worksheet Works” section above. The dotted line that represents the maximum design flow will always be at 1.0 because at the maximum design flow, by definition, the flow,  $Q$ , will be  $Q_{max}$ . To the right of the graph the TAG you entered on the Valve Sizing tab, the Valve style / model # and size you entered in the table of valve data on the Installed Flow tab, the maximum and minimum flows you entered on the Valve Sizing tab and the flow units specified on the Valve Sizing tab are all automatically entered for reference. The print range on the Installed Gain tab has been set to print the graph along with the data displayed to its right.

## LIQUID SIZING WORKSHEET

### How the Worksheet Works

You only need to read this section if you want to understand how the worksheet is configured and how the calculations work. Otherwise you can skip to the “Using the Liquid Worksheet” section.

Each variable, constant or formula cell is assigned, as its name, the variable name to its immediate left, and it is this name that is used whenever that cell's contents are used in a subsequent formula. With this knowledge, the user can see the flow of the calculations by studying the worksheet. (This naming of the cells only applies to the first column the variable, constant or formula appears in. When a variable or formula is duplicated in a subsequent column, cells are simply referred to by their cell number, i.e. “E3.”)

The worksheet uses the ISA formulas given in the ISA Standard to calculate required reducer corrected valve capacity,  $C_V$  (or  $K_V$ ), along with the correction to the valve's rated liquid pressure recovery factor,  $F_L$ , due to the effects of pipe reducers. In the worksheet, to be consistent with the ISA Standard, we refer to the valve's required flow coefficient as "C" which can be either  $C_V$  or  $K_V$  depending on the "Numerical Constants" that are used. The worksheet, as distributed, is configured to use US Customary units. The user can easily reconfigure the worksheet to use any of the sets of units that are supported by the ISA Standard. By entering a code (1 through 5) in Cell B1 immediately above the user interface, formulas in Column B in the user interface that indicate the units for each variable will enter the appropriate engineering unit for the selected set of units. Further down, in the Numerical Constants area, formulas will insert the proper Numerical Constant entries that will configure the worksheet calculations for the set of units selected by the user. Cell B2 contains a list of the codes (1 through 5) along with the unit set that they represent.

When reducers are included in a calculation, the reducer corrections for  $C_V$  (or  $K_V$ ) and  $F_L$  are both a function of  $C_V$  (or  $K_V$ ). Since  $C_V$  (or  $K_V$ ) is the parameter we are trying to calculate, it is necessary to use an iterative approach. Initially the effect of reducers is ignored, and checking for choked flow, a first guess at the required  $C_V$  (or  $K_V$ ) is calculated. This first estimate of  $C_V$  (or  $K_V$ ) is then used to come up with reducer corrections to both  $C_V$  (or  $K_V$ ) and  $F_L$ , and checking for choked flow, a new  $C_V$  (or  $K_V$ ) is calculated. This process is repeated using the calculated  $C_V$  (or  $K_V$ ) from the previous iteration for a total of 59 iterations. At that point, the  $C_V$  (or  $K_V$ ) of the most recent iteration is considered close enough for all practical purposes to the required value of  $C_V$  (or  $K_V$ ). In the worksheet, an iterative loop is simulated by a small block of formulas so that the calculation is repeated a total of fifty nine times, with each iteration's calculation using the  $C_V$  (or  $K_V$ ) from the previous iteration.

The author has observed in all of his tests with realistic data that fifty nine iterations are always sufficient. (Don't try to calculate for a three inch valve in a ten inch pipe, but most people would not consider a three inch valve in a ten inch pipe.)

**The optional calculation for "Non-turbulent flow"** is also based on the ISA Standard. The Standard states that the method is applicable when  $C/N_{18} d^2 \leq 0.047$  which for units of  $C_V$  would be  $C_V/d^2 \leq 30.3$ . Segment ball valves, standard (reduced) port ball valves and high performance butterfly valves reach this limit when they are around 90 to 95 percent open. Full port ball valves reach this limit around 75 percent open. **The ISA Standard for Non-turbulent flow** is only applicable to non-vaporizing flow and states that the effect of close coupled pipe reducers is unknown and therefore calculation methods for Choked  $\Delta p$  and for reducers are not included.

Because the equations for valve Reynolds number ( $Re_v$ ) and for the Reynolds number factor ( $F_R$ ) include  $C_V$  (or  $K_V$ ), which is the variable we are trying to solve for, an iterative solution is required. The method used is to start with the non reducer corrected, non-choked, turbulent  $C_V$  and then calculate the resulting flow using the ISA Non-turbulent method. This flow is compared to the given flow (Line 2) and then the  $C_V$  used in this iteration is adjusted upward by the same ratio as the difference the flow calculated and the given flow. The above calculation is repeated using this adjusted  $C_V$ . I have observed that if this method is going to converge to a  $C_V$  that yields a flow that agrees with the given flow, it will do so in twelve or fewer iterations, so the worksheet uses twelve iterations. If at any point in the iterative operation the iteration stops converging, indicated on the worksheet by the fact that the difference between the given flow (Line 2) and the calculated flow ("Non-turbulent flow this iteration" line on the worksheet) stops decreasing (a negative decrease in the "Change from previous iteration" line on the worksheet) the iteration is stopped at that point and the  $C_V$  and the calculated flow from the previous

iteration are reported on the user interface.

Hydrodynamic noise is calculated by a method that is presented in the Metso Automation *Flow Control Manual*, and is based mainly on VDMA 24422 (1979). The method includes corrections that have been empirically determined for several common styles of control valves.

This calculation method was chosen for three reasons: 1) Metso Automation has used it for many years with satisfactory results. 2) The Author has extensive experience using this method and has found it to be reliable. 3) For many years Metso Automation has successfully been able to predict unacceptable levels of cavitation damage based on noise calculation results from this noise calculation method. If desired users can implement any noise calculation they wish. In any case, before purchasing a control valve, it would be wise to ask your valve supplier to verify your selection based on their calculations and their recommendations regarding the potential for cavitation damage.

On a second tab "**Installed Flow**" is an optional calculation that graphs the installed flow of the valve under analysis in the particular system that is under analysis as a function of valve relative travel. The flow axis is on a scale of 0 to 1.0 of the valve's fully open flow in this system. The relative travel axis is on a scale of 0 to 1.0 of the valve's full range of travel from closed to fully open.

This calculation of **installed flow** is based on a simple mathematical process model using the principle that pressure losses in a piping system are approximately equal to flow squared. There are ten sets of calculations, one for each 10 percentage point valve travel increment between 10 percent open (relative travel of 0.1) and 100 percent open (relative travel of 1.0). The calculation makes an initial guess for each of the ten calculations. The guess is always less than what the anticipated actual flow will be for that particular increment of relative travel. For the first travel increment (relative travel of 0.1) the initial guess is arbitrarily set at 0.01 (one one hundredth) of the minimum specified design flow. (It is reasonable to assume that the flow through any practical control valve at 10% travel will be greater than 1/100<sup>th</sup> of the minimum design flow.) For the subsequent calculations (relative travel increments between 0.2 and 1.0) the initial flow guess is the actual flow calculated from the previous travel increment's calculation.

The calculation at each increment of relative travel starts with its initial guess and the corresponding Cv (or Kv) is calculated. The absolute value of the difference between this Cv (or Kv) and the user's input of the valve's rated Cv (or Kv) in the table above the graph is reported on the "Absolute value C<sub>h</sub> - Selected C" line for that iteration. For the next iteration, the guess at flow is increased by 1% (for travel increments 0.2 through 1.0 and by 2% for travel increment 0.1) above the flow used in the previous iteration and the above process is repeated. In each iteration, the flow is increased by the same percentage from that of the previous iteration, and the process model is used to determine valve P1 and pressure drop at that flow. After 421 iterations the list of calculated "Absolute value C<sub>h</sub> - Selected C" is searched for a minimum value. This minimum is the point where the calculated Cv (or Kv) comes the closest to the valve's Cv (or Kv) in the table above the graph for that increment of relative travel. The flow from this iteration then becomes, within 1% (2% for 0.1 relative travel), of the flow at this increment of relative travel for this valve in this system.

The value of the valve's Liquid Pressure Recovery factor,  $F_L$ , tabulated by the user in the table above the graph is used in each increment of relative travel to calculate the "choked pressure drop ( $\Delta P_{\text{Choked}}$ )."

Note that for the first time, in the 2012 version of the ISA/IEC control valve sizing Standards, the pressure drop at which liquid flow becomes fully choked is given a name ( $\Delta P_{\text{Choked}}$ ). In previous versions of the Standards it was not given a name. As a result, valve manufacturers made up their own names for the same thing. Examples are: Allowable pressure drop, Terminal pressure drop, Maximum pressure drop, and Critical pressure drop.

Because finding a mathematical model for specific gravity and vapor pressure that would be useful in each of the ten increments of relative travel would be impractical, the worksheet uses the convention used by Metso's Nelprof® of using the user's specified specific gravity and vapor pressure in the maximum flow case in the calculations for each increment of relative travel.

On a third tab "**Installed Gain**" is an optional calculation that graphs the installed gain of the valve under analysis in the particular system that is under analysis as a function of flow divided by the maximum specified design flow.

The gain of a device is defined as "the change in output divided by the corresponding change in input." For a control valve, the output is the flow in the system and the input is the valve's relative travel. As explained below, we use the relative flow, based on the system's specified maximum design flow as the output.

In the table on Line 40 of the Installed Gain tab the relative flow is tabulated for each of the 10 flow increments determined on the Installed Flow tab plus another 10 intermediate flow increments that are each halfway between the increments calculated on the installed flow tab. The relative flow is calculated by dividing the flow for each of the twenty flow increments by the specified maximum design flow ( $Q_{\text{max}}$ ) for the system. The maximum system design flow is used as the reference point so that installed gain graphs for different sizes or styles of valves will have the same system requirements as a reference and the resulting gain graphs can be used to compare the control behavior of these different valves in the same system. If the fully open flow for each valve had been used as the reference for relative flow, comparing gain graphs for different sizes or styles of valves would each have a different reference point and comparison would be meaningless.

The **Gain** at each relative travel point tabulated on Line 41 is the change between the flow at the next relative travel point and the flow at the previous relative travel point (on Line 44) ( $\Delta Q$ ) divided by the change in relative valve travel (on Line 45) ( $\Delta h$ ). The change in relative valve travel between every two relative valve travel points is 0.1 in every case.

The vertical lines that represent the values of  $Q_{\text{min}}$  and  $Q_{\text{max}}$  are graphed as additional data series (data on Lines 42 and 43). Because the Gain graph's independent variable scale is  $Q/Q_{\text{max}}$  the  $Q_{\text{min}}$  vertical line is located on the scale at  $Q_{\text{min}}$  divided by  $Q_{\text{max}}$ . The vertical line that represents the value of  $Q_{\text{max}}$  will always be at 1.0 ( $Q_{\text{max}}$  divided by  $Q_{\text{max}}$ ).

A fourth tab "**Typical FL**," has typical values of  $F_L$  that you can optionally use in the absence of manufacturer's data. These values of  $F_L$  are based on data published by a source I know to be reliable. The data used on the tab is based on tables of valve Cv divided by valve size squared and is in the form of curve fit equations. Each  $F_L$  value reported on the Typical FL tab is calculated using the appropriate curve fit equation, the calculated Cv on the Valve Sizing tab and the valve size entered on the Valve Sizing tab.

**Note that the installed flow and gain calculations are only valid for turbulent flow.**

### Using the Liquid Worksheet

The main user interface of the Liquid worksheet is in the upper left corner of the **Valve Sizing** tab in Columns A through G and Rows 2 through 29.

The user can easily configure the worksheet for any of the sets of engineering units that are supported by the ISA Standard. Cell C1 just above the user interface lists codes (1 through 5) for the unit sets that are supported by the Standard. Enter the code for the unit set that you want to use in Cell B1 and the worksheet will be configured for your chosen set of units.

The only equation for calculation of Cv (or Kv) is flow is given in volumetric units, (gpm or m<sup>3</sup>/h) and that is how the liquid worksheet is designed. If you are given flow in mass flow units (most commonly lbm/h or kg/h) the “Mass to Volumetric Flow” tab will convert lbm/h to gpm or kg/h to m<sup>3</sup>/h based on your input of mass flow and the value entered for liquid specific gravity you have entered on the Valve Sizing tab.

**It is quite common for the flow going through a control valve to be fully turbulent, and you will usually not need to use the bottom portion of the user interface that is designated for “Non-turbulent flow.”** High viscosity and/or very low velocity can result in valve Reynolds Numbers below 10,000, which the IEC/ISA valve sizing standards defines as “non-turbulent flow.” If you suspect that flow in the valve will be non-turbulent, enter the viscosity and Valve style modifier,  $F_d$ , into the worksheet. If the Valve Reynolds Number is greater than, or equal to 10,000, the “Non-turb flow coef.” field on Line 26 will return “Turbulent” instead of a valve flow coefficient value. If the “Valve Reynolds Number” is less than 10,000, flow in the valve will be non-turbulent and you should use the “Non-turbulent flow coefficient” on line 26.

The IEC and ISA Standards state that the effect of pipe reducers attached to a control valve when flow is non-turbulent is unknown. Therefore, the effect of reducers is not included in the IEC/ISA equations of the non-turbulent flow coefficient. The Standards make the following suggestion: “The user of such valves is advised to utilize the appropriate equations for line-sized valves in the calculation of the  $F_R$  factor. This should result in conservative flow coefficients, since additional turbulence created by reducers and expanders will further delay the onset of laminar flow.”

Based on the above paragraph, the effect of reducers is not included in the calculation of the non-turbulent flow coefficient in the worksheet. Entries of pipe diameters in the worksheet have no effect on the calculation of the Non-turbulent flow coefficient, but the entry of “Valve size” in the worksheet does have an effect on the Non-turbulent flow coefficient. The non-turbulent methods presented in the IEC/ISA Standards (and used in the worksheet) apply only to non-vaporizing fluids, so discussions of choked flow, cavitation and flashing in the following paragraphs do not apply when flow is non-turbulent. The noise calculation in the worksheet does not apply to non-turbulent flow nor does the “Choked delta p” calculation. The “Valve style modifier,”  $F_d$ , used in the low Reynolds number calculation is a parameter specific to the particular valve being considered, and is also a function of the valve's degree of opening. Ideally,  $F_d$  should be obtained from the valve manufacturer's literature. Table 4 gives some typical values of  $F_d$ .

The “Recovery factor,”  $F_L$ , is a parameter specific to the particular valve being considered, and is also a function of the valve's degree of opening. Ideally,  $F_L$  should be obtained from the valve manufacturer's literature. In the absence of valve manufacturer's data, the “Typical FL” tab gives

typical  $F_L$  values based on the calculated  $C_v$  (or  $K_v$ ) and the valve size entered on the "Valve Sizing" tab. Whether you use manufacturer's  $F_L$  tables or those on the "Typical  $F_L$ " tab you will need to make an initial guess at the  $F_L$  values to use before you know the  $C_v$ . I usually make an initial guess that the valve will be 20% open at the minimum specified flow and 80% open at the maximum specified flow and choose my initial  $F_L$  values accordingly. The "Typical  $F_L$ " tab has suggestions for initial  $F_L$  values. Once I have initial  $C_v$  calculations I adjust the  $F_L$  values. Usually one or two adjustments will result in calculated  $C_v$  values that are close enough for all practical purposes.

The "Valve style SPL code" can be selected from Table 6 to correct the noise calculation for the specific type of valve being considered. A table of SPL codes is also located on the worksheet just to the right of the data input and final results area. Codes 0 through 4 are based on tests performed by one manufacturer known to the author of these worksheets. Code 5 for "Multi-stage globe" is for a representative multi-stage valve. Multi-stage valves vary widely in design and performance. This calculation is intended to give the user a general idea of the sort of noise reduction that is possible with multi-stage globe valves, but does not represent any particular manufacturer's design or model.

The "Pipe wall correction," identified in the user interface area of the worksheet as "DeltaLp," for various downstream pipe sizes and schedules can be found in Figure 1. Figure 1 is also located on the worksheet just to the right of the data input and final results area.

The "Choked pressure drop" calculation (applicable only to turbulent flow) is the pressure drop which determines whether the choked or non-choked calculation of  $C_v$  (or  $K_v$ ) is selected. If the actual pressure drop is greater than or equal to the Choked delta p, the calculated value of the Choked delta p in the final results area of the worksheet will be followed by an asterisk.

If the given vapor pressure is greater than or equal to the downstream pressure ( $P_2$ ) no value for Sound pressure level will be given, but in its place the word "Flashing" will appear. (There is no method known to the author for calculating noise under flashing conditions.)

Many users limit the allowable noise level to 90 dB(A) because this is the OSHA limit for eight hours of exposure. Depending on the valve's location it may be necessary to set a lower limit.

In the past, the classical discussion of cavitation has assumed that at pressure drops below the "Choked pressure drop" that flow is not choked and at pressure drops greater than the "Choked pressure drop" flow will be fully choked. In reality, there is a transition between non-choked and choked flow which is not addressed in the ISA Standard. At pressure drops below the "choked delta p" there can be localized cavitation and noise and the possibility of cavitation damage.

Since the same thing that causes noise (implosion of vapor bubbles) also causes cavitation damage, it is possible to correlate noise level with the potential for damage. Experience of Metso Automation has shown that for valves in the 4 to 6 inch size range, service life will usually be satisfactory if the noise level is below 85 dB(A) (calculated with uninsulated Schedule 40 pipe using the noise calculation method of the liquid worksheet). Noise levels much above 85 dB(A) have resulted in shortened life due to cavitation damage. The noise limit for smaller valves should be set at 80 dB(A), while larger valves can usually tolerate 90 dB(A) and still have satisfactory life. Even if the calculated noise is below these limits, if the actual pressure drop is greater than the "Choked pressure drop" and  $P_2$  is greater than the vapor pressure there is the potential for cavitation damage.

The "Valve inlet velocity" calculation indicates the liquid velocity in a section of the valve body

where the body cross section equals the valve's nominal diameter. Check with the valve manufacturer for recommendations regarding maximum allowable body velocity. Metso Automation recommends a maximum velocity in ball and segment ball valves of 32.8 feet per second (10 meters per second). VDMA 24422 puts a maximum limit of 10 m/sec on the applicability of its hydrodynamic noise calculation. One well known authority on control valves has stated that liquid velocity should not be a concern, however, if you disregard a manufacturer's velocity recommendations you might have trouble making a warranty claim.

The result shown on Line 16 "Turbulent Flow Calc from Cv or Kv" is obtained by solving the appropriate ISA equation for flow given the value of Cv or Kv calculated by the iterative method described above and displayed on Line 15 "Turbulent flow coef. (Cv or Kv)." If you study the ISA equations for reducer corrections you will see that because they contain C they cannot be explicitly solved for Cv or Kv (thus the necessity for the iterative calculation) but can be explicitly solved for flow in a single step. If this calculation of flow on Line 16 equals (or at least very nearly equals) the given flow on Line 3, you are assured that the value of C produced by the iterative calculation has converged and is indeed correct. If the non-turbulent flow calculation is being used, the flow calculated by the final iteration is shown on Line 27 to confirm that the flow coefficient calculation has converged. If the calculated flow confirmation on either Line 16 or 27 is more than 2% less than the given flow on Line 3, the field will be highlighted in light red.

If the turbulent calculation does not converge to within a few percent it is possible that you are using too great a ratio of pipe size to valve size. Most people consider it poor piping practice to use a valve that is less than one half the pipe size. Also be aware that the ISA/IEC Standard states that reasonable accuracy can only be expected if  $Cv/d^2 \leq 30$ . Many fully open (or nearly fully open) rotary valves exceed this limit.

When using the non-turbulent option, I have encountered a few combinations of very high viscosity, small valve size or low pressure drop where the calculation does not converge. In these cases, adding additional iterations do not help. In this worksheet, when this occurs, the worksheet selects the lowest Cv (or Kv) that the iteration has selected before it starts to diverge. I have had no actual installations of valves in these cases, but it is my opinion that the failure to converge indicates either a failure of the ISA/IEC equations or that the selected valve would be incapable of passing the required flow under the given process conditions.

In October of 2016 when Metso released version 6.2.1 of Nelprof they revised their non-turbulent liquid flow calculation to be in accordance with the 2011 version of the IEC Standard, and the 2012 version of the ISA Standard. The calculations of the worksheet described in this instruction, in the few cases I have checked, come very close to those of the 6.2.1 version of Metso's Nelprof which is encouraging. In one case involving very high viscosity (3,500 cP) and a one inch segment valve, Metso's Cv calculation and the calculation of this worksheet also come very close. However, when my worksheet back calculates from the Cv calculated both by the worksheet and Nelprof, it does not back calculate to the given flow rate. This gives credence to my conclusion in the preceding paragraph.

Calculated results on the **Valve Sizing** tab only appear after all required input data has been entered into the worksheet.

The print range on the Valve Sizing tab has been set to print the entire user interface area.

### **Using the Installed Flow tab:**

#### **This option is only valid for fully turbulent flow.**

This is an option that allows you to see a graph of the relationship between valve travel and

flow. The calculation combines the valve's published inherent characteristic ( $C_v$  or  $K_v$ ) vs. relative valve travel, and the system's pressure loss vs. flow characteristic. The process pressure model is a curve fit based on the Flow, P1 and Delta P in Columns D and G on the Valve Sizing tab. The Vapor pressure and specific gravity used in the installed flow calculation are the values entered in Column G on the Valve Sizing tab. The curve fit is based on the principle that piping pressure losses are approximately proportional to flow squared. This model is only valid for fully turbulent flow and should be treated as an **approximation**.

In most cases, an installed flow characteristic that is fairly linear between the specified minimum and maximum design flow rates is desirable. If you are not familiar with the subject of installed flow, you might find the first two pages of this article I wrote for *Flow Control Magazine* helpful:

<http://www.control-valve-application-tools.com/app/download/10903119457/FC%20Mag%20-%20Characteristics%20and%20Sizing.pdf?t=1433879602>

To begin using this option, you will need to fill in the table that is above the graph area on the Installed Flow tab with manufacturer's data for the valve you want to analyze ( $C_v$  and  $F_L$ ) vs. relative valve travel. Note that some manufacturers of rotary control valves publish tables of valve capacity ( $C_v$  or  $K_v$ ) and liquid pressure recovery factor ( $F_L$ ) as a function of valve travel in degrees on a scale of 10 to 90 degrees rather than on a scale of relative travel of 0.1 to 1.0 (which is equivalent to 10% to 100%) as required by the valve sizing worksheet. The valve sizing Zip file includes a worksheet, "90 Deg to relative travel Table.xlsx" that will convert 10 to 90 degree data to 0.1 to 1.0 relative travel data as required by the valve sizing worksheet.

When this option is not going to be used, the four columns of process conditions on the **Valve Sizing** tab are independent of each other. If you plan to use the **Installed Flow** tab option, you **must** observe the following: On the Valve Sizing tab, enter the minimum design flow along with its associated values of P1, Delta P and other parameters in Column D and the maximum design flow along with its associated values of P1, Delta P and other parameters in Column G. Any process conditions entered in Columns E and F are not used in the calculation of the installed flow.

The system pressure model will not be valid, and the installed flow and installed gain graphs will not be drawn if the following requirements have not been met:

1. The maximum design flow is to be entered in Column G. Therefore the flow in Column G must be greater than the flow entered in Column D. (The pressure model is also invalid if the maximum and minimum flows are equal.)
2. P1 must be constant or decreasing with increasing flow. Therefore P1 in Column G must be equal to or less than P1 entered in Column D.
3. P2 must be constant or increasing with increasing flow. Note that P2 is calculated from P1 and delta P. The calculated values of P2 at the minimum and maximum specified flows can be found on the **Installed Flow** tab in Cells R12 and R13.
4. Flow is fully turbulent. (If a Valve Reynolds number of less than 10,000 appears on the **Valve Sizing** tab in Columns D or G flow is not fully turbulent. If flow is fully turbulent, instead of a value for "Non-turb flow coef" appearing on Line 25 of Columns D and G the word "Turbulent" appears.)

Error messages indicating any of these reasons for the graphs not being drawn will appear on the Installed Flow tab to the right of the graph area.

To the right of the graph is a calculation of the flow in the system when the valve is fully open, and therefore corresponds to the relative flow of 1.0 on the Relative Flow axis. There are two dotted lines that show where the specified maximum and minimum design flow rates intersect

the relative flow axis and the installed flow curve. By following the vertical grid lines on the graph from where they intersect the flow curve at the points where above mentioned dotted lines intersect the flow curve you can read the approximated valve relative travel at the maximum and minimum specified design flow rates. Also to the right of the graph the TAG you entered on the Valve Sizing tab, the Valve style / model # and size you entered in the table of valve data, the maximum and minimum flows you entered on the Valve Sizing tab and the flow units specified on the Valve Sizing tab are all automatically entered for reference. The print range on the Installed Flow tab has been set to print the graph along with the data displayed to its right.

### Using the Installed Gain tab:

#### This option is only valid for fully turbulent flow.

This option relies on the calculation performed on the Installed Flow tab. It is often difficult to compare the control capability of two valves with less than perfectly linear installed characteristics by simply studying their installed characteristic graphs, and one can learn more about how well they will control a particular system by examining their installed gain. Some general guidelines are that, within the specified flow range, the gain should be greater than 0.5, less than 3 and not change by much more than a 2 to 1 ratio. It is also desirable for the installed gain to be as constant as possible and as close to 1 as possible. If you are not familiar with the subject of installed gain, you might find this article that I wrote for *Flow Control Magazine* helpful:

<http://www.control-valve-application-tools.com/app/download/10900062557/FC%20Mag%20-%20Installed%20Gain.pdf?t=1437752660>

There are two dotted lines that show where the specified maximum and minimum design flow rates intersect the relative flow axis and the installed gain curve, so the specified flow range is the area between these two lines. It is important to notice that on this tab, the relative flow is  $Q/Q_{max}$ , (actual flow divided by the maximum specified design flow) where on the installed flow graph the relative flow is  $Q/Q_f$ , (actual flow divided by the fully open flow). This is an important difference as it makes it possible to compare the installed gain of valves of different sizes and types, as explained in the “How the Worksheet Works” section above. The dotted line that represents the maximum design flow will always be at 1.0 because at the maximum design flow, by definition, the flow,  $Q$ , will be  $Q_{max}$ . To the right of the graph the TAG you entered on the Valve Sizing tab, the Valve style / model # and size you entered in the table of valve data on the Installed Flow tab, the maximum and minimum flows you entered on the Valve Sizing tab and the flow units specified on the **Valve Sizing** tab are all automatically entered for reference. The print range on the Installed Gain tab has been set to print the graph along with the data displayed to its right.

### CONVERSION OF VALVE PARAMETERS FROM 10 – 90 DEGREE DATA TO RELATIVE TRAVEL WORKSHEET

Some manufacturers of rotary control valves publish tables of valve capacity ( $C_v$  or  $K_v$ ), liquid pressure recovery factor ( $F_L$ ) and Pressure differential ratio factor ( $x_T$ ) as a function of valve travel in degrees on a scale of 10 to 90 degrees rather than on a scale of relative travel of 0.1 to 1.0 (which is equivalent to 10% to 100%) as required by the valve sizing worksheets on the **Installed Flow** tab. The valve sizing Zip file includes a worksheet, “90 Deg to relative travel Table.xlsx” that will convert 10 to 90 degree data to 0.1 to 1.0 relative travel data as required on the **Installed Flow** tab on the valve sizing worksheets.

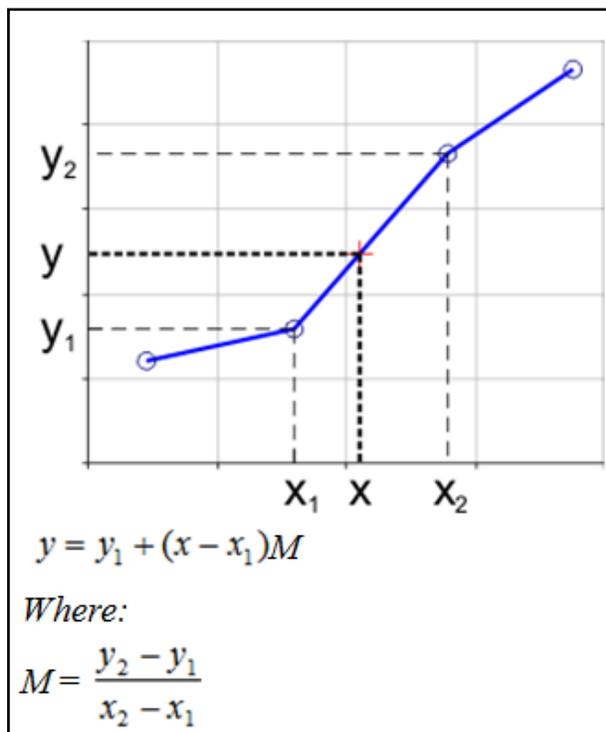
## How the Worksheet Works

You only need to read this section if you want to understand how the worksheet is configured and how the calculations work. Otherwise you can skip to the “Using the Parameter Conversion Worksheet” section.

Unlike the other worksheets, the layout of this one does not lend itself to giving cells names that describe their contents, so if you want to follow the step-by-step calculation you will need to pay closer attention to the formulas than with the valve sizing worksheets.

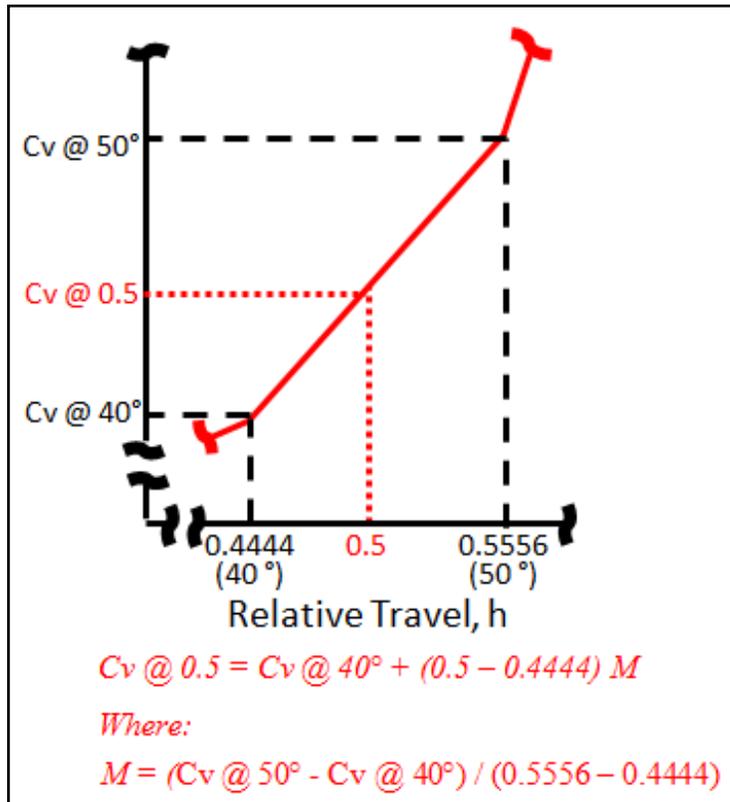
On Line 7 the relative travel (rotation in degrees divided by 90 degrees) is calculated for each increment of angular rotation (10 through 90 degrees). Therefore 90 degrees rotation represents a relative travel of 1.0. The relative travel on Line 7 is used in all three conversions (C (Cv or Kv), FL and  $x_T$ ). The conversions are performed using linear interpolation.

The classical method of linear interpolation to find an unknown value between two known points of a linear range is described in the figure below, where  $y$  is the intermediate value of the dependent variable being sought.  $y_1$  is the lower known value of the dependent variable and  $y_2$  is the upper known value of the dependent variable.  $x_1$  and  $x_2$  are the values of the independent variable corresponding to  $y_1$  and  $y_2$ .  $M$  can be interpreted as the slope of a straight line connecting points  $(x_1, y_1)$  and  $(x_2, y_2)$ .





The figure below shows how this method is implemented on the Conversion worksheet.



Here I have arbitrarily chosen to show how the worksheet finds the value of valve flow capacity,  $C_v$ , for a valve relative travel of 0.5 (which corresponds to a valve travel of 50%) given the  $C_v$  at 40 degrees (relative travel of 0.4444) and the  $C_v$  at 50 degrees (relative travel of 0.5556). Examining the graph in the figure it can be seen that the relative travel of 0.5 and the  $C_v$  at a relative travel of 0.5 fit between  $C_v$  and relative travel at 40 and 50 degrees, so using the linear interpolation formula will yield the  $C_v$  at a relative travel of 0.5 (50%). This process is performed on the worksheet to convert the table of  $C_v$  given for 10 through 90 degrees to a table of  $C_v$  for relative travel of 0.1 to 1.0. The same process is used to convert the tables of  $F_L$  and  $x_T$  from degrees to relative travel. For the  $C_v$  conversion at 10 degrees the worksheet needs to know the  $C_v$  at zero degrees. Although manufactures do not publish  $C_v$  values for fully closed valves it is a reasonable assumption that it is zero and the worksheet uses this assumption. For the  $F_L$  and  $x_T$  conversions it is not reasonable to assume values of zero when the valve is fully closed. Experience has shown that  $F_L$  and  $x_T$  do not change very much between around 10 and 20 degrees of rotation, so the worksheet makes the assumption that between zero and 10 degrees of rotation that  $M$  is zero.

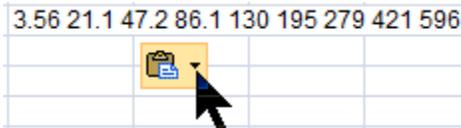
### Using the Parameter Conversion Worksheet

To convert manufacturer's valve parameters from 90 degree data of relative travel data, enter the 0 to 90 degree data into the worksheet. ( $C_v$  of  $K_v$  and either  $F_L$  or  $x_T$ .) The fields for data entry are highlighted in blue. The relative travel data required by the installed flow tab of the valve sizing worksheets will appear in the fields highlighted in orange.

To copy converted data to a valve sizing worksheet, select all of the cells that need to be copied, and copy (Ctrl + C). On the **Installed Flow** tab of the Valve Sizing worksheet, right click on the first cell that data is to be copied to. Select **Paste Special...** then select **Values** then click **OK**.

If you have a PDF file of the manufacturer's valve parameters, depending on how the PDF was created, it might be possible to simply copy and paste entire rows of data into the worksheet using the "Selection" tool  in Acrobat Reader or Acrobat. This worked for me using Fisher's Catalog 12 data available online.

With the Selection tool selected, highlight the line of data you want to transfer to the worksheet. Copy the data (Ctrl + C). In the worksheet, click on the first cell where the copied data is to start and paste (Ctrl + V). All the copied data will appear in that cell along with the "Paste options" menu:



From the Paste Options menu select: "Use Text import Wizard..."

Select "Delimited"

Click "Next"

Select "Space"

Click "Next"

Select "General"

Click "Finish" (When I do this, the selections of Delimited, Space and General are already selected, so all I have to do is quickly click Next, Next, Finish)

Click "OK" if this dialog appears "Do you want to replace the contents of the destination cells?"

The copied data will now be distributed into the correct cells:

3.56	21.1	47.2	86.1	130	195	279	421	596
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If the selection tool is not visible in the tool bar at the top of the Acrobat screen, you can add it by right clicking within the tool bar. Click on "Select & Zoom" in the sub menu. Then click on "Select Tool" to add it to the toolbar.

Below the tables on the worksheet are graphs that compare the given 90 degree data with the converted relative flow data. I put these there when I was developing the worksheet to satisfy myself that the conversions were working properly. You do not need to look at these graphs unless you want to satisfy yourself that the converted data does indeed fall on the graph of the given data. Each of these graphs consists of two graphs, one for the 0-90 degree data and one for the 0-1.0 data, one superimposed on top of the other with the top one configured with both the chart area and plot area configured with no fill, making it transparent so the bottom one shows through.

## VALVE SIZING PROCEDURE

First, gather all of the process data required by the sizing worksheet you intend to use. Sizing calculations should be performed at both the minimum and maximum design flow rates. Many people also perform a calculation at the anticipated normal flow rate. It has been the author's

experience that the most common error in collecting process data is in the selection of the sizing pressure drop. Usually the other process parameters such as flow rate, temperature, specific gravity, etc. are known, but all too often the pressure drop is selected at random without performing an analysis of the actual system, resulting in a meaningless calculation.

Assuming a system that has not yet been built, is not running, or does not have pressure gauges near the valve, the correct procedure for determining the sizing pressure drop is to perform a static analysis on the system. Starting upstream of the control valve at a point of known pressure (such as a pump discharge or pressurized vessel) work downstream toward the valve subtracting the pressure drop due to the pipe, fittings and equipment, such as heat exchangers, etc. until you reach the valve. At this point you will know the valve inlet pressure (which is also required for the sizing calculations). Next, go to a location downstream of the control valve where the pressure is known (such as a tank with known head) and work upstream toward the valve, adding the pressure drop due to the pipe, fittings, etc. until you reach the valve. At this point you will know the valve outlet pressure, which can be subtracted from the valve inlet pressure to arrive at the  $\Delta p$  or pressure drop. A separate analysis should be performed at each flow rate for which a sizing calculation will be performed, as pressure losses (and pump head) are a function of flow rate.

Note that pipe reducers at the control valve inlet and outlet are not included in the static analysis of the system. At the time you are doing the static analysis of the system, the size of the control valve is yet to be determined. The effect of pipe reducers at the valve inlet and outlet on control valve capacity is included in the ISA/IEC valve sizing equations by the Piping Geometry factor,  $F_P$ .

The ideal situation is where you have a say in determining what the control valve pressure drop at the maximum design flow will be, usually by specifying the pump that will be used. Some designers successfully use a rule of thumb that recommends calculating all of the dynamic losses in the system, excluding the control valve, and then adding a pressure drop of one half the other dynamic losses for the control valve and specifying the pump head at the maximum design flow appropriately. This is equivalent to saying that the control valve pressure drop at the maximum design flow should be 1/3 of the entire system pressure differential.

The next step is to select a valve style. Once a valve style is decided on, obtain valve manufacturer's data for the valve parameters such as  $x_T$ ,  $F_L$  and  $F_d$ . If actual data are not available, you can use the typical data given in Tables 2, 3 and 4. The control valve parameters  $x_T$ ,  $F_L$  and  $F_d$  are functions of valve opening, so it will be necessary to make an initial guess as to the valve's percent of opening. It is the author's preference to initially assume that the control valve will be 80% open at maximum flow and 20% open at the minimum flow and use valve parameters based on this assumption. After the actual valve size is determined, the valve parameters can be refined based on actual valve opening as determined by examining the manufacturer's tables of  $C_v$  (or  $K_v$ ) versus opening.

Because the purpose of a valve sizing calculation is normally to determine what size valve should be used for a particular application, it will be necessary to make an initial guess as to valve size. One can start by guessing that the valve will be line size. (It is quite common in actual practice to find that properly sized globe control valves are often one size smaller than the line, and properly sized ball, segment ball and butterfly valves are often two sizes smaller than the line, so these are also good initial guesses and may eliminate the need for a second

calculation.) Once an initial value of required valve capacity,  $C_v$  (or  $K_v$ ), has been calculated, consult valve manufacturer's tables of  $C_v$  (or  $K_v$ ) versus valve opening and select what would appear to be an appropriate size valve. Recalculate the worksheet to make sure that a calculation using the actual valve size and actual valve parameters confirms that the size selection is correct.

*Keep in mind that most designers consider it poor piping design practice to use a control valve that is less than one half the line size or larger than the line size.*

As you progress through the calculation procedure, you will want to keep an eye out for potential problem areas, such as noise, excessive velocity, and cavitation damage potential, as discussed in the "Using the Worksheet" sections.

As previously mentioned, it is recommended that you discuss your selection with your chosen valve manufacturer or his representative before actually purchasing a valve.

Table 1

## Numerical constants for the Gas and Vapor worksheets

Constant	Flow coefficient, C		Formulae unit					
	$K_V$	$C_V$	W	Q	P, $\Delta P$	$\rho$	T	d, D
N <sub>2</sub>	$1.60 \times 10^{-3}$	$2.14 \times 10^{-3}$ $8.90 \times 10^{-2}$						mm in
N <sub>5</sub>	$1.80 \times 10^{-3}$	$2.41 \times 10^{-3}$ $1.00 \times 10^{-3}$						mm in
N <sub>6</sub>	3.16 $3.16 \times 10^1$	2.73 $2.73 \times 10^1$ $6.33 \times 10^1$	kg/h kg/h lbm/h			kPa bar psia	$\text{kg/m}^3$ $\text{kg/m}^3$ lbm/ft <sup>3</sup>	
N <sub>9</sub> (ts = 0 °C)	$2.46 \times 10^1$ $2.46 \times 10^3$	$2.12 \times 10^1$ $2.12 \times 10^3$ $6.94 \times 10^3$		m <sup>3</sup> /h m <sup>3</sup> /h scfh		kPa bar psia		K K R
N <sub>9</sub> (ts = 15 °C)	$2.60 \times 10^1$ $2.60 \times 10^3$	$2.25 \times 10^1$ $2.25 \times 10^3$ $7.32 \times 10^3$		m <sup>3</sup> /h m <sup>3</sup> /h scfh		kPa bar psia		K K R
Flag 1	2	1						
Flag 2	3 2	3 2 1				kPa bar psia		

Ts = reference temperature for standard conditions

Table 2  
Typical Gas Terminal Pressure Drop Ratios ( $X_T$ ) $X_T$  at % of Rated Flow Capacity ( $C_V$  or  $K_V$ )

Valve type	10	20	40	60	80	100
Globe, parabolic plug Flow-to-open	0.77	0.77	0.77	0.75	0.70	0.66
Globe, 4 V-port cage Flow into center	0.79	0.79	0.79	0.75	0.70	0.70
Multi-stage globe	0.86	0.86	0.86	0.86	0.86	0.86
Eccentric rotary plug Flow-to-open	0.62	0.62	0.62	0.60	0.52	0.40
Segment ball Flow into ball face	0.64	0.64	0.63	0.59	0.49	0.32
Full ball Standard port	0.82	0.82	0.80	0.67	0.60	0.25
90 degree butterfly Shaft downstream	0.68	0.68	0.64	0.52	0.40	0.35

Table 3  
 Typical Liquid Pressure Recovery Factors ( $F_L$ )  
 $F_L$  at % of Rated Flow Capacity ( $C_v$  or  $K_v$ )

Valve type	10	20	40	60	80	100
Globe, parabolic plug Flow-to-open	0.96	0.96	0.96	0.95	0.91	0.89
Globe, 4 V-port cage Flow into center	0.97	0.97	0.97	0.95	0.90	0.90
Multi-stage globe	0.99	0.99	0.99	0.99	0.99	0.99
Eccentric rotary plug Flow-to-open	0.91	0.89	0.85	0.82	0.78	0.76
Segment ball Flow into ball face	0.94	0.93	0.89	0.80	0.75	0.42
Full Ball Standard port	0.91	0.91	0.90	0.85	0.77	0.67
90 degree butterfly Shaft downstream	0.87	0.85	0.80	0.75	0.66	0.58

Table 4  
 Typical Liquid Valve Style Modifier ( $F_d$ )  
 $F_d$  at % of Rated Flow Capacity ( $C_v$  or  $K_v$ )

Valve type	10	20	40	60	80	100
Globe, parabolic plug Flow-to-open	0.12	0.18	0.25	0.32	0.38	0.48
Globe, 4 V-port cage Flow into center	0.42	0.43	0.37	0.29	0.35	0.39
Eccentric rotary plug Flow-to-open	0.12	0.18	0.22	0.30	0.36	0.42
Segment ball Flow into ball face	0.71	0.79	0.86	0.93	0.97	0.99
Full ball Standard port	0.43	0.66	0.85	0.94	0.98	1.0
90 degree butterfly Shaft downstream	0.14	0.14	0.18	0.26	0.33	0.36

Table 5

Numerical constants for the Liquid worksheet

Constant	Flow coefficient, C		Q	Formulae unit				
	K <sub>v</sub>	C <sub>v</sub>		P, ΔP	ρ	d, D	Inlet velocity	v
N <sub>1</sub>	1.0 x 10 <sup>-1</sup> 1.0	8.65 x 10 <sup>-2</sup> 8.65 x 10 <sup>-1</sup> 1.0	m <sup>3</sup> /h m <sup>3</sup> /h gpm	kPa bar psia				
N <sub>2</sub>	1.60 x 10 <sup>-3</sup>	2.14 x 10 <sup>-3</sup> 8.90 x 10 <sup>2</sup>				mm in		
N <sub>4</sub>	7.07 x 10 <sup>-2</sup>	7.60 x 10 <sup>-2</sup> 1.73 x 10 <sup>4</sup>	m <sup>3</sup> /h gpm					m <sup>2</sup> /s cS
N <sub>18</sub>	8.65 x 10 <sup>-1</sup>	1.00 6.45 x 10 <sup>2</sup>				mm in		
N <sub>32</sub>	1.40 x 10 <sup>2</sup>	1.27 x 10 <sup>2</sup> 1.70 x 10 <sup>1</sup>				mm in		
N <sub>41</sub>	3.0 39.0 12.1	3.0 39.0 12.1		kPa bar psia	kg/m <sup>3</sup> kg/m <sup>3</sup> lbm/ft <sup>3</sup>			
Flag 1	2	1						
Flag 3	2	2 1	m <sup>3</sup> /h gpm			mm in	m/s ft/s	

Table 6

Valve Style SPL Codes for the Liquid and Gas Worksheets

Valve type	Valve style code (VSC)
Globe	0
Rotary eccentric plug	1
Segment ball	2
Butterfly	3
Full ball	4
Milti-stage globe	5

