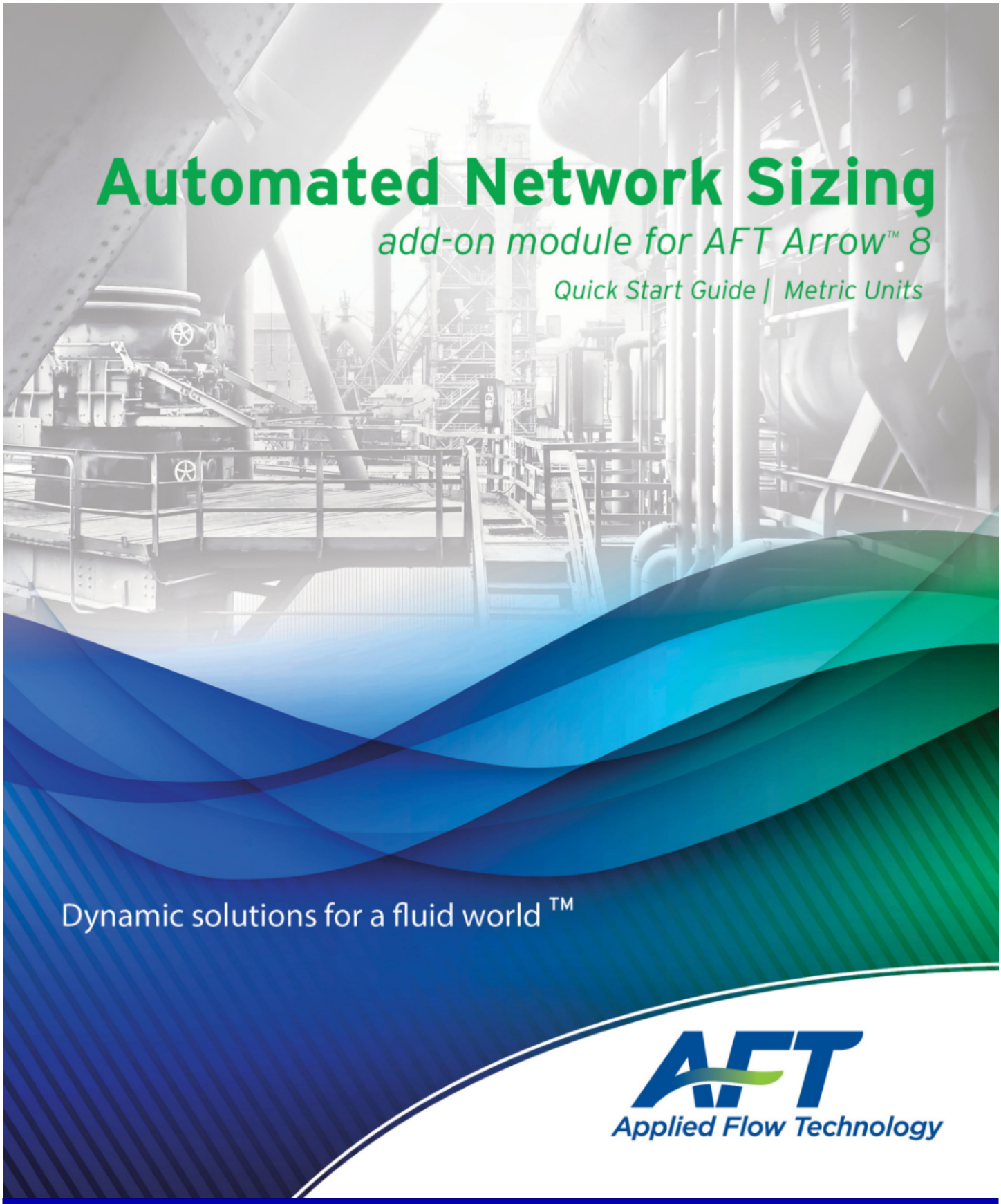

Automated Network Sizing

add-on module for AFT Arrow™ 8

Quick Start Guide | Metric Units

Dynamic solutions for a fluid world ™

AFT
Applied Flow Technology

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AFT Arrow™ ANS Module

Quick Start Guide

Metric Units

AFT Arrow Version 8

Automated Network Sizing Module

Dynamic solutions for a fluid world ™

CAUTION!

AFT Arrow is a sophisticated pipe flow analysis program designed for qualified engineers with experience in pipe flow analysis and should not be used by untrained individuals. AFT Arrow is intended solely as an aid for pipe flow analysis engineers and not as a replacement for other design and analysis methods, including hand calculations and sound engineering judgment. All data generated by AFT Arrow should be independently verified with other engineering methods.

AFT Arrow is designed to be used only by persons who possess a level of knowledge consistent with that obtained in an undergraduate engineering course in the analysis of pipe system fluid mechanics, have been trained in the specialized field of gas dynamics, and are familiar with standard industry practice in pipe flow analysis.

AFT Arrow is intended to be used only within the boundaries of its engineering assumptions. The user should consult the AFT Arrow internal help files for a discussion of all engineering assumptions made by AFT Arrow.

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CHAPTER 1

Introducing AFT Arrow ANS Module

Welcome to the AFT Arrow™ ANS module, Applied Flow Technology's powerful pipe and duct system automated sizing tool. With the ANS module you can automatically size all pipes or ducts in a system to minimize monetary cost, weight, volume, or surface area. In addition, you can concurrently size the compressors or fans and pipes to obtain the absolute lowest cost system that satisfies your design requirements. Finally, by including non-recurring and recurring costs, you can size pipe and duct systems to minimize life cycle costs over some specified duration.

How AFT Arrow ANS module works

The AFT Arrow ANS module consists of three basic elements: the Graphical Interface, the Compressible Flow Solver, and the Automated Sizing Engine. Figure 1.1 shows the relationship between the three.

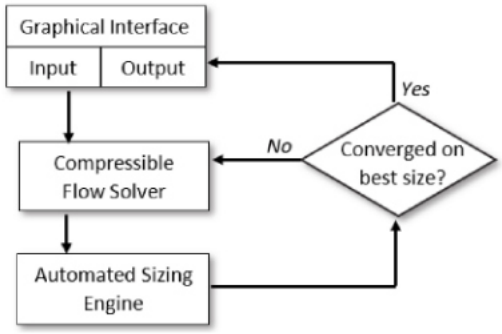


Figure 1.1 AFT Arrow ANS module main component flow chart

The Compressible Flow Solver obtains a balanced flow solution for a specific pipe or duct system. The Automated Sizing Engine then modifies the design, and the Compressible Flow Solver evaluates the modified design. The Automated Sizing Engine continues this process until it is satisfied that no further design improvements are possible. At this point, the Automated Sizing Engine has converged on a design, and the resulting sized design is then sent back to the Graphical Interface where it is displayed to the user.

The Compressible Flow Solver, which functions as the prime mover in performing an engineering analysis (e.g., AFT Arrow™), becomes a subroutine called by the Automated Sizing Engine. The Automated Sizing Engine is the prime mover in AFT Arrow ANS module.

The Automated Sizing Engine employed by AFT Arrow ANS module uses state-of-the-art numerical searching technology licensed from a leading developer in this field. This technology has been used for many years in engineering design, with extensive use in structural finite element analysis.

Analysis vs. design

Analysis

Traditional piping system engineering has employed pipe flow *analysis*. Engineering analysis is the process of using accepted calculation methods to predict the behavior of a given system. These calculation methods may be manual, or automated in a computer program.

The weakness of analytical methods for design is that they require the specification of the system before the methods are applied. Specifically, the pipe or duct sizes, compressors, valves and other equipment must be specified in order to perform the calculation.

However, when a new pipe system is being designed, these parameters are not known. To use the analytical methods, the engineer must guess at the pipe sizes and required equipment, perform the analysis, then modify his or her original selections as necessary.

The analytical methods are used iteratively to arrive at a final design.

Design

A design-oriented approach to piping system engineering would allow the selection parameters to be variables. Rather than specifying pipe diameters, the engineer solves for pipe diameters by specifying the flows and pressures (and other design requirements) and using these to select the appropriate pipes which minimize the overall system weight, volume or monetary cost.

Within certain limits engineers do this with traditional analytical methods, but the number of design tradeoffs that can be considered is limited and the tradeoffs considered are indirectly tied to weight, volume or monetary cost.

The ANS module offers a true design-oriented approach to piping system engineering by using advanced automated sizing methods to evaluate competing designs vs. weight, volume or cost, and select the best design. The analysis method (i.e., the Compressible Flow Solver) is called repeatedly by the ANS module in an effort to identify design improvements (i.e., improvements that reduce weight, volume or monetary cost).

Weight, volume and monetary cost are all costs

In the English language we usually associate the word “cost” with money. However, in engineering, that does not have to always be the case. If an engineer is designing an aircraft, for example, minimizing weight is essential. In that respect extra weight is a “cost”.

To simplify discussion in this guide, and to avoid needless repetition, the word “cost” will be used to represent any of the parameters an engineer may wish to minimize. In the ANS module this can be weight, volume, surface area or monetary cost. When discussing issues specifically related to monetary cost, the words “monetary cost” will be used unless the context is otherwise clear that the discussion refers to “monetary cost”.

Cost-based automated sizing vs. cost estimating

The ANS module is *not* a cost estimating tool. Rather, it offers a rational and automated approach for comparing potential pipe or duct system designs using the common denominator of cost. It is the pipe or duct

system design that the ANS module obtains that is of immense value, not the process of cost estimating.

AFT Arrow ANS module design capabilities

The AFT Arrow ANS module can be used to size a wide variety of engineering systems.

Types of systems that can be sized

- Piping, ducting and tubing systems
- Open and closed (recirculating) systems
- Network systems that branch or loop, with no limit on the number of loops
- Pressure-driven systems
- Compressor or fan-driven systems, including multiple compressor/fans in parallel or in series
- Compressors/fans with variable speed, controlled pressure, and controlled flow
- Systems with pressure and/or flow control valves
- Systems with valves closed and compressor/fans turned off
- Heat transfer analysis and system energy balance
- Systems with non-ideal gasses
- Systems that experience sonic choking, including multiple sonic choking points
- Systems with non-reacting flow streams mixing and user-defined mixtures
- Systems with elevation changes or rotation such as in turbomachinery

Types of automated sizing parameters available

- Pipe/duct size
- Pipe velocity, pressure gradient, pressure, and flow

- Compressor/fan pressure rise, proximity to BEP (Best Efficiency Point), power, and others
- Control valve pressure drop and open percentage

AFT Arrow ANS module primary window

When the ANS module is activated in AFT Arrow several changes are made to the interface, though the main impact is the addition of a sixth Primary Window, the Sizing window. The Sizing window allows for the sizing and (optionally) cost settings to be configured for the model. When the model is set to perform sizing, input information in the Workspace and Model Data windows for the components being sized are used as initial guesses. Components which are not being sized are treated as constants for the automated network sizing.

Automated sizing terminology

General automated sizing terminology applied to pipe systems is as follows:

Design requirements

There are numerous design requirements in the ANS module. Common requirements are pipe velocity, control valve pressure drop and proximity to compressor/fan BEP (Best Efficiency Point).

Active and inactive design requirements

An active Design Requirement is a requirement which has a direct impact on the solution, whereas an inactive Design Requirement is a passive requirement which does not impact the solution. If an active requirement is removed, the ANS module will find a different solution, whereas removing an inactive requirement will not affect the solution.

Consider a case where several Design Requirements are set for the velocity in a pipe. One may set the maximum to 30 m/sec, and the minimum to 3 m/sec. If the final pipe velocity were 29 m/sec, the maximum velocity Design Requirement would be active because the final value of the velocity is at or near the maximum velocity. On the other hand, the 29 m/sec pipe velocity is far away from the 3 m/sec

minimum. If we remove the minimum velocity Design Requirement, the result will still be an actual pipe velocity of 29 m/sec. Thus, the minimum velocity Design Requirement is inactive and does not influence the selected pipe size. On the other hand, if one removed the 30 m/sec maximum velocity Design Requirement, the actual velocity would probably increase above 30 m/sec, thus resulting in a different pipe size.

Objective

This is the goal of the analysis. Typically, the objective is to minimize monetary cost either directly using monetary cost data, or indirectly by minimizing parameters such as pipe weight. As the ANS module varies the pipe sizes, the objective parameter (cost, weight, etc.) varies. The Automated Sizing Engine searches for combinations of pipe sizes that achieve the objective by comparing these variations.

Continuous vs. discrete sizing

Discrete data is a set of data which lists explicit values which can be used, such as a set of pipe sizes within a given schedule. Continuous data is a set of data which can include any values within the given minimum and maximum, such as with percent open values for a valve.

Generally the desired sizing within the ANS module is discrete, since commercial pipe sizes must be chosen from a set of specific sizes. However, since it is much easier to minimize values using a continuous solution, many methods in the ANS module will first implement continuous sizing, then use this solution to find a nearby discrete solution for the system. Note that this is not as simple as just choosing the closest discrete value around the continuous minimum. Good searching algorithms like those used in the ANS module will consider values more than one discrete size from the continuous value.

Common size groups

The automated sizing process takes longer as the number of pipes being independently sized increases. Frequently there are groups of pipes in a system which would ideally be the same size for design purposes, or must be the same size by virtue of their location in the system. To link the sizes for pipes together one can create Common Size Groups. When one places pipes into a Common Size Group, one is saying that the group of pipes all must have the same pipe size, and be the same material and

schedule, class, or type. A Common Size Group thus consolidates the individual pipes that are part of that group to a single independently sized pipe for that group. There can be multiple Common Size Groups in a model, but each pipe can only belong to one Common Size Group.

Feasible and infeasible designs

A feasible design is one which satisfies all Design Requirements, while an infeasible design does not satisfy one or more Design Requirements. There are many ways you can create a model that has no feasible solution. For example, connect a pipe to an Assigned Pressure junction set to 14 bar. Then place a Design Requirement on the pipe that it cannot have a pressure greater than 7 bar. Since the pipe is connected to an Assigned Pressure junction at 14 bar, there is no way for it to satisfy the 7 bar Design Requirement. Thus, no feasible solution exists.

Candidate sets

A Candidate Set is a collection of potential sizes that will be considered for the sizing calculations. Each pipe being sized in the system must have one Candidate Set assigned to it. If continuous sizing is being performed, only the minimum and maximum pipe sizes in the Candidate Set will be used to bound the continuous sizing.

CHAPTER 2

Weight Sizing Example

This example shows how to use the ANS module to perform a non-monetary automated sizing on a system. Parameters such as pipe weight or flow volume frequently relate closely to the actual pipe cost, and are easier to set up than cost based automated sizing. This makes them useful for an initial estimation. Further, on some systems such as aircraft, marine vessels or automobiles, minimizing weight may be the primary goal.

This example demonstrates minimizing the *pipe weight* in a system.

Topics covered

- Non-monetary parameter automated sizing
- Creating Common Size Groups
- Defining Candidate Sets
- Control Valve Design Requirements

Required knowledge

No prior knowledge is required for this example. However, users who are completely new to AFT Arrow are advised to first complete the AFT Arrow Quick Start Guide examples. There one will see how to use basic features for conventional pipe flow modeling. This example focuses on the automatic sizing features in the ANS module.

Model file

This example uses the following file, which is installed in the Examples folder as part of the AFT Arrow installation:

- *Metric – Control Valve – ANS.aro* – AFT Arrow model file

This example is provided in English units under the *US – Control Valve - ANS.aro* .

This example will require you to build the model from scratch to help familiarize yourself with the steps required to build a complete model in AFT Arrow. Therefore, use this example model file as a reference only.

Problem statement

The example is for a steam transfer system that feeds steam from a pressurized tank to a lower pressure tank. A control valveis used to control the flow rate to 4540 kg/hr and must have a minimum pressure drop of 140 kPa. We will locate the flow control valve at the midpoint of the 80 meter pipeline.

The pipeline is limited to STD (schedule 40) Steel - ANSI pipe in the size range from 1-10 inches.

Step 1. Start AFT Arrow

From the Start Menu, choose AFT Products and AFT Arrow.

Activate the ANS module from the Startup Menu by checking the box next to the ANS module. Alternatively, the ANS module can be activated from the Module button at the bottom of the Quick Access Panel, or from the Activate Modules option in the Tools menu.

Once the ANS module has been activated check that it is enabled for use by going to Automated Sizing under the Analysis menu and selecting Network as shown in Figure 2.1. This should be done automatically by AFT Arrow when the module is activated.

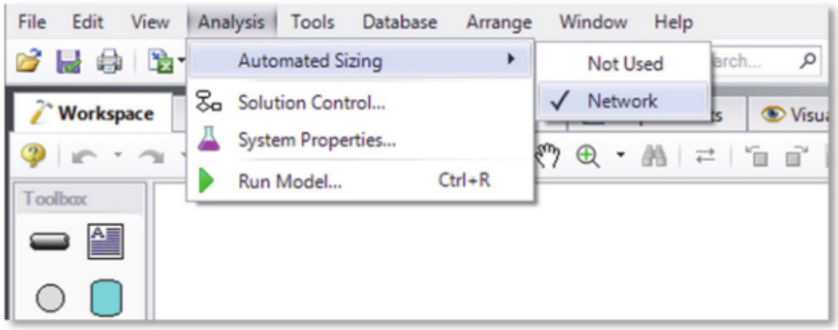


Figure 2.1 **Enabling the ANS module for use. The Automated Sizing option becomes available when the ANS module has been activated.**

Step 2. Specify system properties

1. Open the System Properties window by selecting System Properties in the Analysis menu.
2. On the Fluid Data tab, select the AFT Standard database and then select “Steam” in the Fluids Available in Database list.
3. Click “Add to Model” to select steam for use in this model.
4. Click OK.

Step 3. Build the model

A. Place the pipes and junctions

At this point open the Checklist. The Checklist can be accessed by clicking the checkmark icon on the toolbar, or from the Tools menu, and provides a summary of items that must be completed before the model is run. When the ANS module is activated the fourth checklist item changes from “Specify Cost Settings” to “Define All Sizing Input”.

For this model the first two items have been completed. The next Checklist item is to “Define All Pipes and Junctions”. In the Workspace window, assemble the model as shown in Figure 2.2.

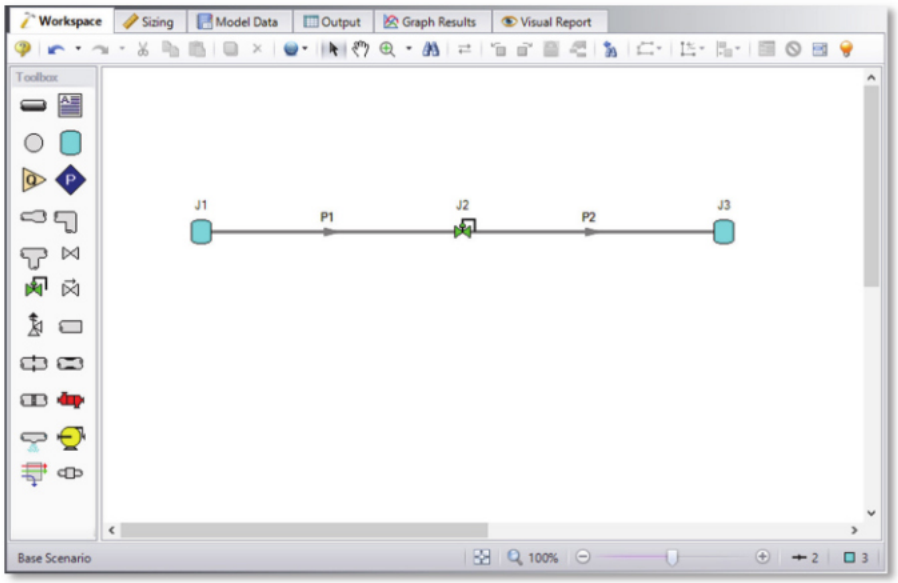


Figure 2.2 Control Valve system layout

B. Enter the junction data

J1 - Tank

1. Elevation = 0 m
2. Pressure = 1725 kPa
3. Temperature = 315 deg. C

J2 – Control Valve

1. Elevation = 0 m
2. Valve Type = Flow Control Valve (FCV)
3. Mass Flow Rate = 4540 kg/hr

J3 – Tank

1. Elevation = 0 m
2. Pressure = 1380 kPa
3. Temperature = 315 deg. C

C. Enter the pipe data

For this example, we need to find the best pipe size, but we are limited to STD (schedule 40) pipe sizes. Now we need to use engineering judgment to take an initial guess at the pipe size for a flow rate of 4540 kg/hr. Let's try 6 inch pipe. Specify both pipes as follows:

1. Pipe Material = Steel – ANSI
2. Size = 6 inches
3. Type = STD (schedule 40)
4. Length = 40 m
5. Friction Model = Standard

Step 4. Define sizing input

The first three items have now been completed on the Checklist, leaving one last item to "Define All Sizing Input".

In this model we are going to perform sizing to minimize the pipe weight, while maintaining a minimum pressure drop of 140 kPa across the control valve. To do this, first go to the Sizing window by clicking on the Sizing tab, or from the Window menu.

The Sizing window is comprised of multiple panels which can be accessed using the buttons on the Sizing Navigation Panel along the bottom of the window, as shown in Figure 2.3. The sizing panels can be accessed in any order, though it is easiest to enter the information by navigating the panels from left to right, since the input on panels such as the Sizing Objective and the Sizing Assignments panels will affect the options available on later panels. Depending on the type of sizing being done, some panels may be disabled or unused.

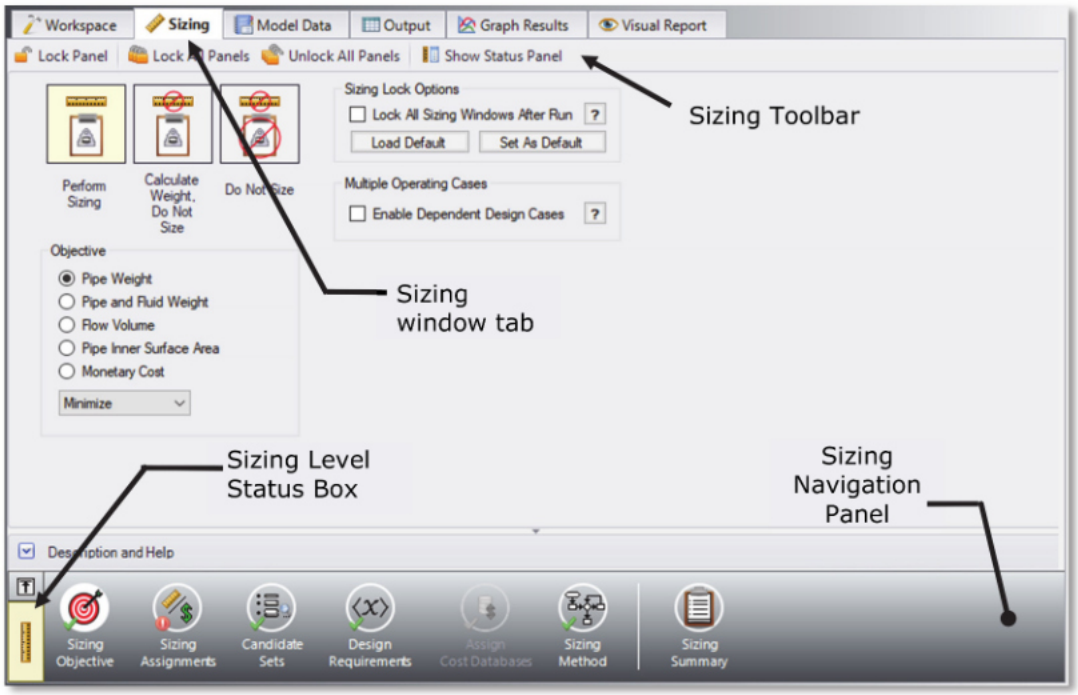


Figure 2.3 Sizing window layout identifying common features

Similar to the Checklist, each panel button contains either a green checkmark or red circle which denotes the completion status of that panel. If the minimum required information is present to run the model, the symbol will be green, whereas the red symbol represents incomplete input. The amount of information required will vary based on whether the sizing calculation is set to Perform Sizing, Calculate Weight/Do Not Size, or Do Not Size. A detailed summary of the items which have been completed and the items which are still incomplete can be seen in the Sizing Status window, accessed from the Checklist.

The type of sizing calculation being performed, also called the Sizing Level, can always be seen on the Sizing Level Status Box on the left of the Sizing Navigation Panel as shown in Figure 2.3. Clicking this box will bring you to the Sizing Objective panel, where the calculation type can be changed. The choice of continuous or discrete sizing is selected on the Sizing Method panel, which is discussed later.

Note that some panels, such as the Design Requirements panel, will always be shown as complete since the model can be run without any

additional information entered on them. However, in order to find the best system design it will often be necessary to enter more than the minimum information required by the Solver.

The Lock Panel toggle located on the Sizing Toolbar prevents changes to the current panel when it is enabled. This is primarily useful to prevent editing once a scenario has been run, since any changes that are made to a scenario which has output will cause all output to be erased. By default, all panels will lock after a sizing run is completed, requiring panels to be unlocked before any changes can be made. This setting can be changed on the Sizing Objective panel. All panels can be locked or unlocked simultaneously by using the Lock/Unlock All Panels buttons on the Sizing Toolbar.

A. Sizing objective

The Sizing Objective panel will be displayed by default when the Sizing window is first opened, as shown in Figure 2.3. This panel is used to select the option for calculation and to set the desired Objective.

The first option is "Perform Sizing", which sets up the model to perform the automated sizing calculation. While it is typically desired to run the sizing calculations, the other two selections can be useful in certain cases.

The second option is "Calculate Weight, Do Not Size". This option is similar to running AFT Arrow with the Cost Analysis option turned on and is useful to find the cost of the initial design, or for troubleshooting. By default, the cost for the model is calculated in terms of weight.

The last option is "Do Not Size". This is equivalent to performing a regular AFT Arrow analysis without needing to disable the ANS module and potentially lose the entered Sizing settings. This can also be useful to check the feasibility of the initial design before sizing.

- **Select “Perform Sizing”** to begin configuring the sizing run.

The next step is to set a Sizing Objective, which can be monetary cost, or a non-monetary cost such as pipe weight or flow volume. It is easier to perform a non-monetary sizing, since all of the geometry and material information necessary to calculate the pipe weight/volume is already contained in the pipe material databases. A monetary cost objective would require cost information to be obtained and entered into cost databases. For many systems, sizing the system using one of the simpler non-monetary objective options provides a sufficient approximation for

monetary cost. In this case, we will be performing a minimization for pipe weight.

- **For the Objective choose "Pipe Weight"** and select the Minimize option from the drop-down list.

B. Sizing assignments

On the Sizing Navigation Panel select the Sizing Assignments button. The Sizing Assignments panel allows the user to define what will be sized in the model, and what will be included in the cost calculation without being sized (in this case, what will be included in the weight, but will not have its weight minimized). Common Size Groups for pipes can be created on this panel as well when appropriate.

The Sizing Assignments panel can be used to select various options to either “Automatically Size”, or “Do Not Size” each pipe.

If an “Automatically Size” option is selected, the ANS module will treat the pipe diameter as a variable and vary it according to certain criteria that will be discussed shortly.

In a new system, typically all pipes will be desired to be sized and included in the cost calculation (in this case, the cost is being calculated in terms of weight). If you are instead analyzing the possible replacement of existing pipes, it may be better to choose “Include in Weight if Size Changes”. This will allow the weight to only be calculated for pipes if they change size, since using the existing pipes will incur no new costs.

If “Do Not Size” is selected, the pipe will retain the settings currently set in the Workspace. Why would one choose to not size a pipe? There could be a number of reasons, but one good reason is that the pipe represents a pipe in an existing system and the design does not allow the replacement of that pipe with a new one. Therefore, its diameter is fixed, and sizing the pipe would be incorrect.

Another reason may be if a certain size is necessary for the design due to specific requirements, in which case the pipe cost can be included without sizing the pipe by choosing “Include in Weight”.

This model is a new system, so all pipes will be sized and included in the cost (weight).

- **Select "Always Include in Weight"** next to each of the pipes.

For this system it is required that both pipes be the same size. We will need to add both pipes to a Common Size Group to specify this as follows:

1. Click the "New" button above Pipe Grouping, and specify a name (e.g. Main Pipes)
2. A new section will now appear with the Main Pipes group listed under Common Size Groups. Add both pipes to this group by clicking the corresponding radio buttons (Figure 2.4).

Now that the pipes are both in a Common Size Group, the ANS module will force them to have the same diameter, rather than allowing them to be varied separately.

For larger models, multiple Common Size Groups can be created as desired. Selection tools are available at the bottom of the window to help assign multiple pipes to a Common Size Group at once. Pipes can only be assigned to a group once they are set to use one of the “Automatically Size” options.

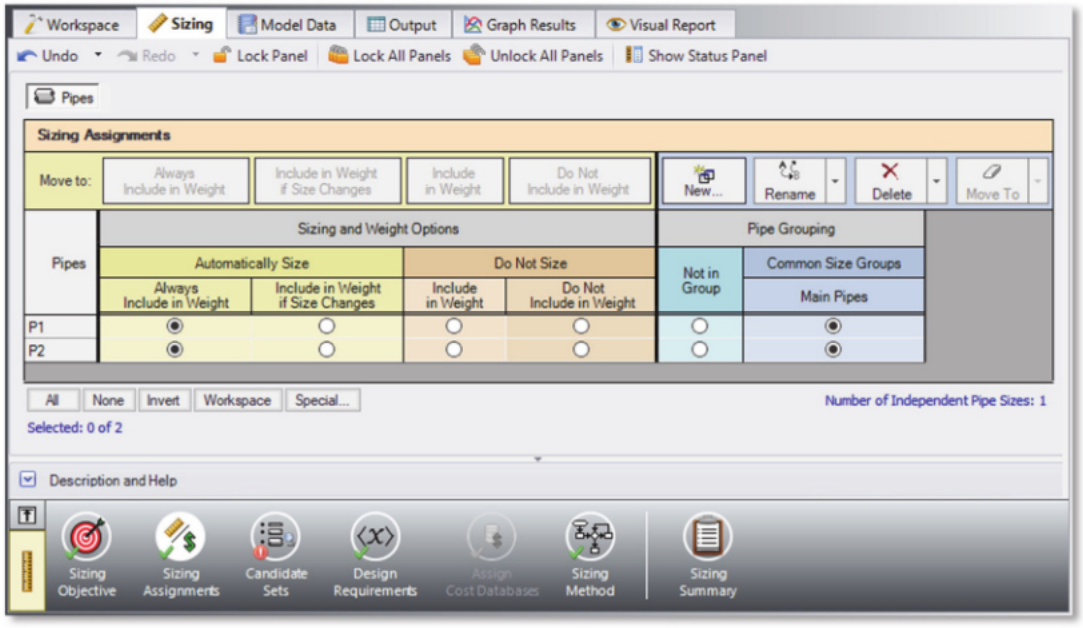


Figure 2.4 Pipes P1 and P2 settings in the Sizing Assignments panel

C. Candidate sets

Click on the Candidate Sets button to open the Candidate Sets panel.

To select a specific pipe size, the ANS module first needs a list of potential sizes from which to choose. This list is called a *Candidate Set*. A specific pipe can only access one Candidate Set, but a specific Candidate Set can be accessed by any number of pipes.

The Candidate Sets should include both smaller and larger pipes than your anticipated final size to avoid limiting the sizing unnecessarily. If you make the Candidate Set too small, you may limit the ability of the ANS module to find the best sizing. It is better to make the Candidate Set too large than too small. Experience applying the ANS module to actual systems will help you choose appropriate Candidate Sets. If after obtaining a solution you find that one or more of the sized pipes is at the extreme of the Candidate Set, a warning will appear and recommend that the defined Candidate Set be expanded.

To create a Candidate Set, do the following:

1. Under Define Candidate Sets, click the New button.
2. Give the set a name (e.g., "STD Pipes") and click OK.
3. From the drop-down list choose Steel - ANSI.
4. In the bottom of the Select Pipe Sizes window, check that the Sort option "Type, Schedule, Class" is selected.
5. In the Available Material Sizes and Types on the left, expand the STD pipe sizes list.
6. Double-click each of the sizes from 1 to 10 inches to add them to the list on the right or use the “add” button (Figure 2.5).
7. Click the OK button.

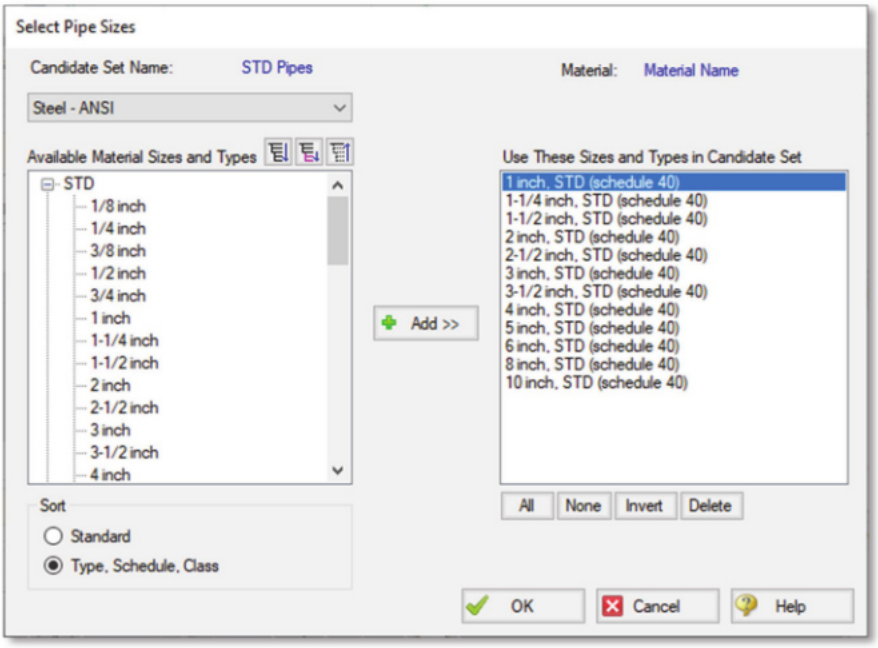


Figure 2.5 Select Pipe Sizes window with STD Steel-ANSI pipe sizes added for 1”-10” schedule 40

The "STD Pipes" candidate set will now appear. However, we still need to define which pipes will use this Candidate Set during the automated sizing. By necessity, a Common Size Group will use one Candidate Set for all pipes within the group, since all pipes in the group must be the same size. In this case there is only one item to assign the set to.

- **Under Assign Candidate Sets to Pipes, set the "Main Pipes" Common Size Group** to use the "STD Pipes" Candidate Set. The Candidate Sets are now fully defined and assigned to the appropriate pipes, as can be seen in Figure 2.6.

  Once a Candidate Set is selected, the list of available pipe sizes on the Pipe Properties window in the Workspace is restricted to pipes in that Candidate Set. In Figure 2.7 you can see the area normally described as "Size" is now described as "Size (From Common Size Group)". If the initially defined pipe sizes were not included in the assigned Candidate Set, the ANS module will provide the option to change the pipes in the Workspace to a pipe size from the defined Candidate Set when the model is run.

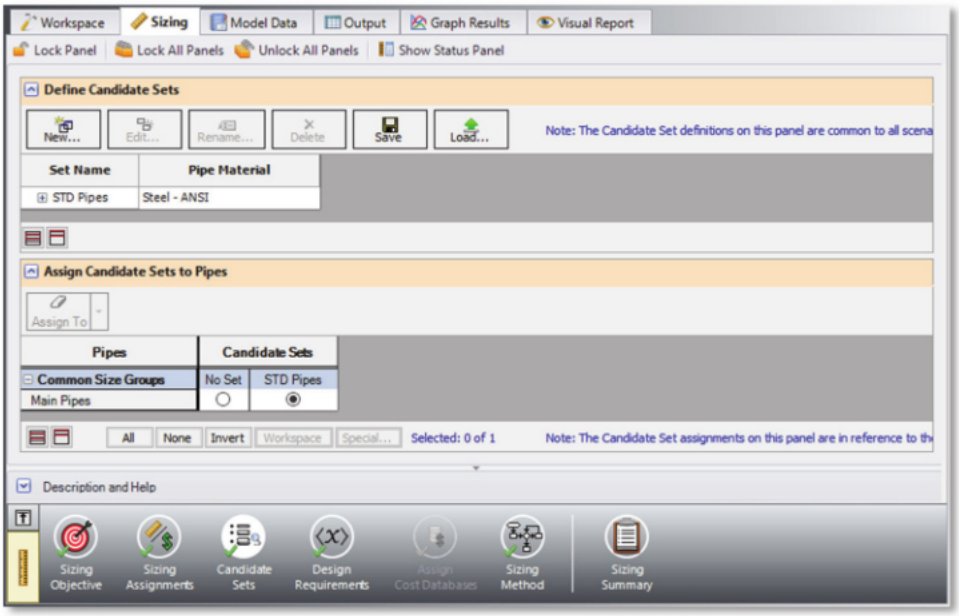


Figure 2.6 Candidate Sets panel fully defined for the model

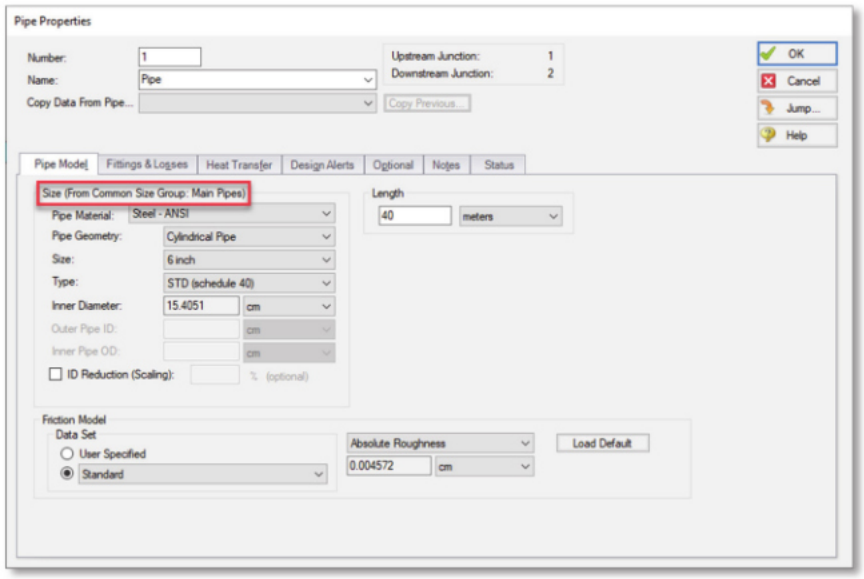


Figure 2.7 Pipe Properties Window after having a Candidate Set assigned to it – pipe size selections are limited to those in the Common Size Group

D. Design requirements

Select the Design Requirements button. This panel is used to define restrictions on the final solution by applying Design Requirements for the system.

For this model we only have one Design Requirement, which is for the minimum pressure drop across the Control Valve. To define this requirement:

1. Select the Control Valves button at the top of the window.
2. Click the New button under Define Control Valve Design Requirements.
3. Enter a name when prompted (e.g., "Min Pressure Drop").
4. Next to "Min Pressure Drop" in the table, select Pressure Drop Static as the Parameter.
5. Choose Minimum for Max/Min, and enter 140 kPa

Now that the Design Requirement is defined, it needs to be assigned to the appropriate junction.

➢ **Check the box next to the Control Valve Junction J2** in the "Assign Design Requirements to Control Valves" section. The Design Requirements panel should now appear as shown in Figure 2.8.

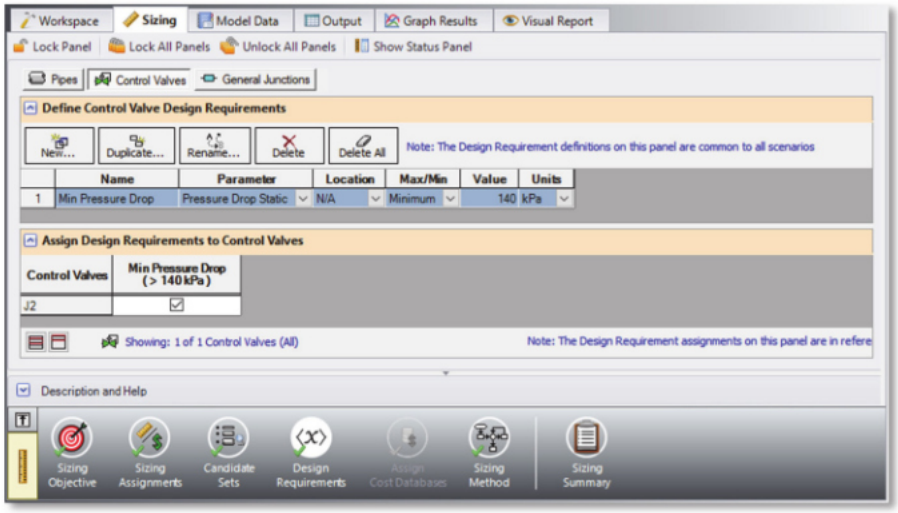


Figure 2.8 Minimum pressure drop requirement defined for the Control Valve

Note: It is strongly recommended that control valves have a Design Requirement specified for the minimum pressure drop or the maximum Cv/percent open at the valve. If no Design Requirements are applied, the ANS module will allow the control valve to control to any pressure required to meet the control setpoint, even if this requires the control valve to add pressure to the system for design purposes. To avoid this behavior in the final solution, a Design Requirement should be applied.

E. Assign cost databases

This panel is only used to assign the necessary monetary cost information when Monetary Cost is chosen as part of the Sizing Objective. In this case this button is greyed out since we are minimizing pipe weight.

F. Sizing method

Select the Sizing Method button from the Sizing Navigation Panel.

The Sizing Method panel is used to set up the calculation methods to be used for sizing the system. The user has the option to select whether discrete or continuous sizing will be used, and which search method will be applied.

If Continuous Sizing is selected, the ANS module will use the minimum and maximum Candidate Set sizes as boundaries. It will then calculate the ideal hydraulic diameter for the pipes being sized, which will likely not match any of the available commercial sizes. While this is not useful as a final solution, this may be helpful as a baseline to check the final solution using the provided discrete methods. For this model, make sure Discrete Sizing is selected.

For the Search Method, the ideal method will often change based on the number of independent pipe sizes (number of pipes not in group & Common Size Groups in sizing), number of Design Requirements, and feasibility of the initial system design. The Help file provides more information on the strengths and weaknesses of each method. It is generally recommended to run the sizing with more than one method, as it is often not obvious which method will be most effective for each system. The “Suggest Best Method” button is useful to determine a search method to use initially.

For a simple model such as this one, the Modified Method of Feasible Directions (MMFD) or Sequential Quadratic Programming (SQP) method should be appropriate since there is only one Design Requirement, and only one pipe size is being varied. Choose the default “Modified Method of Feasible Directions (MMFD)”.

Step 5. Run the automated sizing

We are now in a position to run the automated sizing. Before doing so, take a moment to consider what this model is trying to accomplish. The pipe P1 and P2 sizes will be selected together from the "STD Pipes" candidate set such that their weight is minimized while still obtaining a minimum 140 kPa pressure drop across the control valve.

To begin sizing the system select Run from the Analysis menu. While the model is running, the Solution Progress window shows the "Sizing Calls to Solver". This is how many times a complete compressible flow analysis was run.

The Solution Progress window also displays the Current Cost, which is the last calculated value for the cost, as well as the Best Feasible Cost which has been found so far (Figure 2.9). The Solver will continue to iterate using the defined method to find a global minimum. For most methods, the Solver will first perform a continuous sizing, then perform discrete sizing based on the continuous solution, though this is not always the case.

Note: For complex systems using the Genetic Algorithm Sizing Method, the solution can be paused and accepted at any time by using the Pause button, then selecting “Accept Sizing” under Other Actions. This allows the user to accept the best current solution, rather than continuing to search for the global minimum.

When the sizing has completed, click the Output button to display the results.

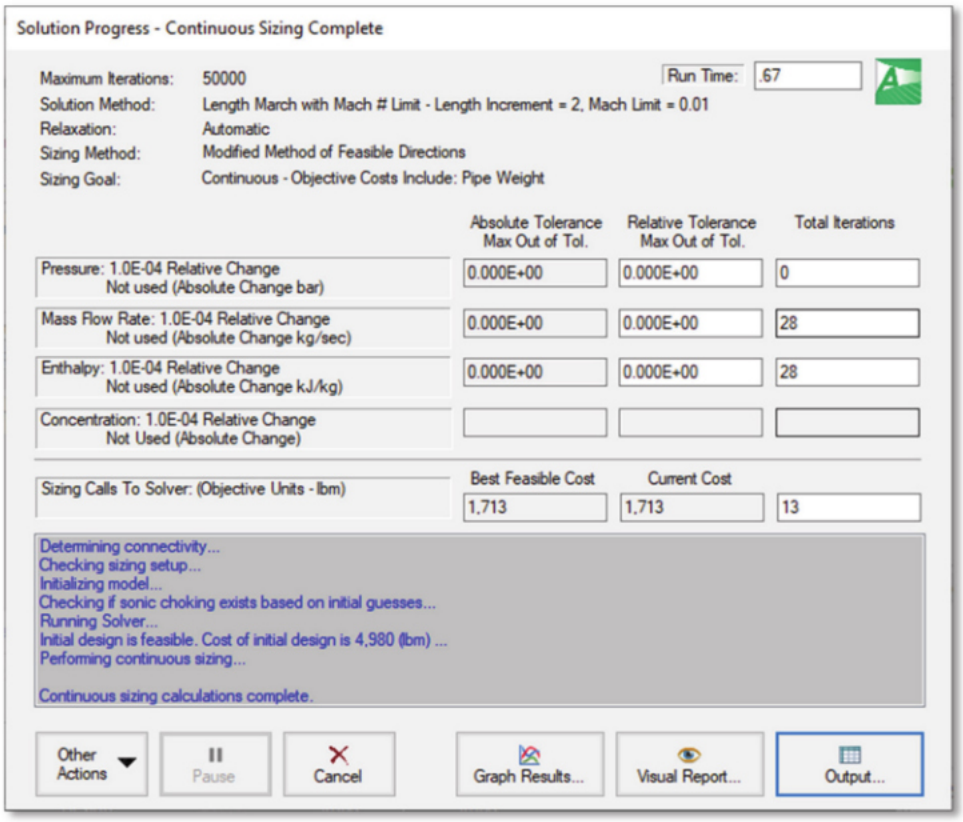


Figure 2.9 **The Solution Progress window shows the progress of the AFT Arrow Solver and the ANS module**

Step 6. Review automated sizing results

The Cost Report tab in the General Output section shows a total weight of 902 kg, while each pipe has a weight of 451 kg (Figure 2.10). This result makes sense since the pipes have the same length and a common diameter due to the fact that they are in a Common Size Group.

The Sizing tab in the Pipe Output section shows the ideal pipe size was found to be 3 inch for the pipes when sized together.

The CV Design Requirements tab shows that the 140 kPa minimum pressure drop is satisfied in that the pressure drop for 3 inch pipe was

236.8 kPa. Note that the Design Requirement result is highlighted in blue, indicating that the Design Requirement was active during the continuous solution, but the pipe sizes in the discrete solution were outside of a certain limit from the continuous solution pipe sizes. Yellow highlighting will be used if the Design Requirement is active in the final solution, and the difference between discrete and continuous solution pipe sizes is within the defined limit.

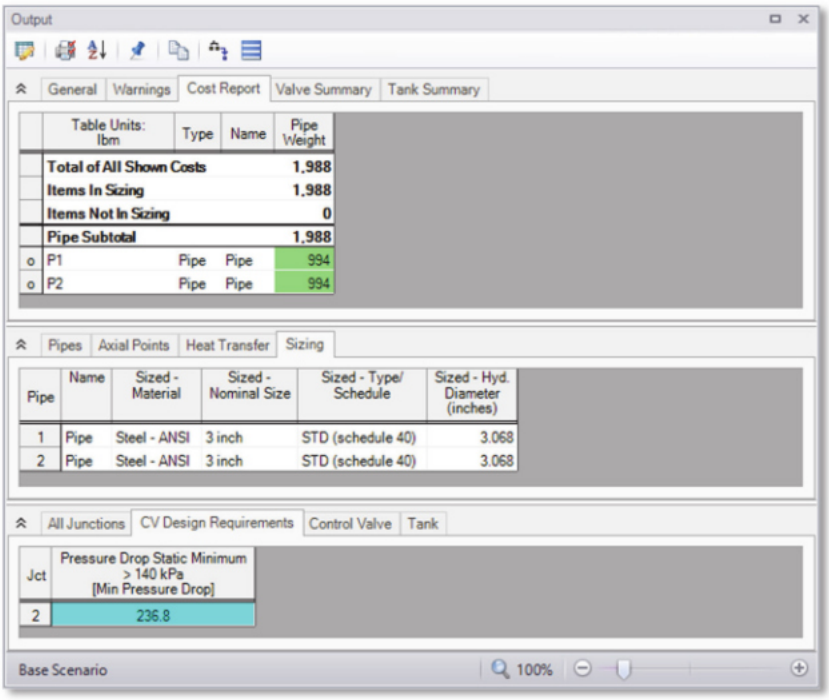


Figure 2.10 The Output window shows the results of the sized system, plus the sizing results. The blue color for the CV Design Requirement indicates this Design Requirement was "Active".

Conclusions

This example demonstrates the automated sizing capabilities of the ANS module for a simple system with a single Design Requirement. Sizing for non-monetary objectives such as pipe weight is fast and easy to implement.

CHAPTER 3

Initial and Life Cycle Cost Sizing

This example demonstrates some key features by using the ANS module to size an air distribution system for monetary cost.

Topics covered

- How to connect and use existing engineering and cost databases
- Sizing for Initial or Life Cycle Cost and using Initial Cost Limits
- The process to size a compressor, and size piping for the chosen compressor
- Interpreting Cost Reports

Required knowledge

This example assumes that the user has some familiarity with AFT Arrow and the ANS module such as placing junctions, connecting pipes, entering pipe and junction specifications, and creating and using Candidate Sets and Design Requirements. Refer to the Weight Sizing Example in Chapter 2 for more information on these topics.

Model files

This example uses the following files, which are installed in the Examples folder as part of the AFT Arrow installation:

- *Metric - Air Distribution - ANS.aro* - AFT Arrow model file
- *Metric - Air Distribution - ANS COMPLETE.aro* – completed AFT Arrow model file
- *Metric - Air Distribution Components.dat* - junction engineering database
- *Metric - Air Distribution Components Cost.cst* - cost database associated with Air Distribution Components.dat
- *Metric - Air Distribution Pipe Cost.cst* - cost database for steel piping

Problem statement

This example uses an existing model to investigate three automated sizing cases:

1. Size system for *initial cost* with a 5-year system life
2. Size system for *life cycle cost* with a 5-year system life
3. Size system for *life cycle cost* with an initial cost limit for a 5-year system life

Step 1. Start AFT Arrow

From the Start Menu, choose AFT Products and AFT Arrow.

Enable the ANS module from the Startup Menu by checking the box next to the ANS module. Alternatively, the ANS module can be activated from the Module button at the bottom of the Quick Access Panel, or from the Activate Modules option in the Tools menu.

Step 2. Open model file

For this example we will be starting from a pre-built model file that is fully defined for a normal AFT Arrow run. We will use automated sizing to find a more cost-effective design. From either the startup screen or the File menu, browse to the model file name shown above and copy it to a new location. The Workspace should appear as shown in Figure 3.1.

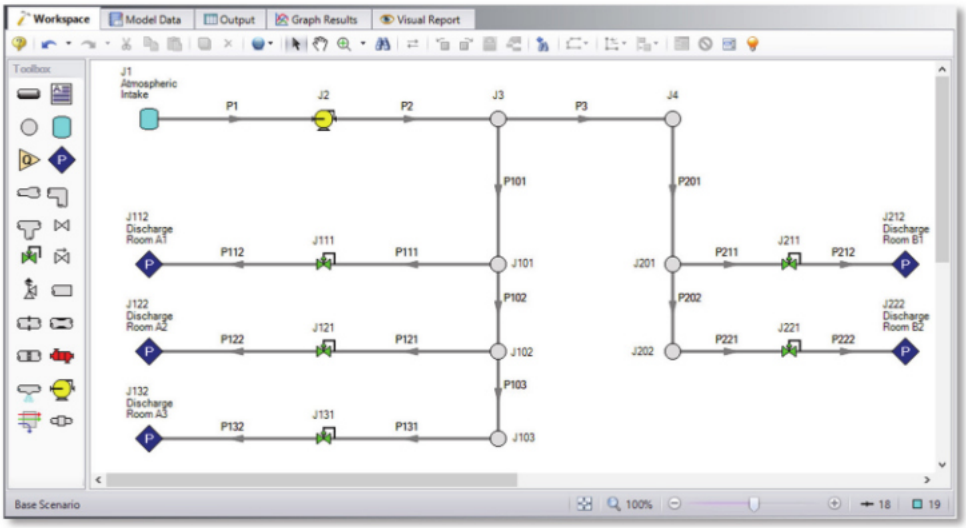


Figure 3.1 Air Distribution example model

Sizing systems with compressors

A centrifugal compressor can be modeled with a Compressor Curve or with a fixed flow rate or pressure as the Sizing option. Generally, if a specific compressor has been identified, the Compressor Curve type would be chosen, whereas the Sizing option is useful during the selection stage in order to identify the compressor requirements for the system. In some cases, even though the specific compressor has not been chosen, several candidate compressors are available. For this third case it would be best to model each candidate compressor with a compressor curve using separate scenarios for each compressor.

Compressor model in this system

The compressor in our air distribution case is set as Sizing with a fixed flow of 2125 sm3/h. In order to allow the compressor to be defined as a fixed flow, the flow control valve at J131 has been defined at a fixed pressure drop of 14 kPa. This model thus represents a first cut model where, based on the first cut results, the compressor will become an actual compressor with a compressor curve, and control valve J131 will become a flow control valve controlling to 425 sm3/h, similar to the other control valves.

As already stated, when a compressor is modeled as a fixed flow, it is not a specific compressor from a specific manufacturer. Thus, the costs for the compressor can only be approximated. For a first approximation it should be possible to estimate the non-recurring cost (i.e., material and installation cost) for the compressor as a function of power requirements. For instance, a typical ten kilowatt compressor (of specific configuration and materials of construction for a given flowrate) may cost $2700, and a forty kilowatt may cost $8250. Other typical costs for different power requirements can be approximated. The actual cost for the compressor will highly depend on the application. These costs are entered into a cost database and are accessed by the Solver. As AFT Arrow evaluates different combinations of pipe sizes, each combination will require a certain power from the compressor. With a cost assigned to this power, the ANS module can account for energy costs over the life of the system. Later in this chapter, we will look at the costs for the compressor in our example air distribution network.

In addition to non-recurring costs, recurring costs can also be estimated. Specifically, the cost of the power used by the compressor over a period of time (which the ANS module calls the "system life") can be determined. All AFT Arrow needs is an overall compressor efficiency to determine the actual power from the ideal power. Again, since we do not have a specific compressor selected yet, the efficiency can only be approximated. The ANS module calls this the "nominal efficiency".

A step-by-step method of compressor selection proceeds in two phases. The steps are outlined in the Help System.

Step 3. Review model settings

The model is already defined, but we need to review and complete the sizing settings before running the analysis. In the Analysis menu check that Automated Sizing is set to Network, then go to the Sizing window by clicking the tab.

A. Sizing objective

The Sizing Objective panel should be displayed by default.

To begin we will first need to choose the calculation option, so select “Perform Sizing”.

The Sizing Objective panel also provides features to characterize the automated sizing objective. As explained previously, a non-monetary parameter such as weight could be chosen to simplify the sizing. However, there are a few downsides to this method, as this does not allow one to include compressor costs, or other junction initial costs, in the sizing. Additionally, recurring costs cannot be calculated using non-monetary cost. To more thoroughly size the compressor in this system we will need to minimize monetary cost directly.

- **Select Monetary Cost as the Objective** and select Minimize.

  With the Monetary Cost selected, the options to minimize monetary cost will appear displayed in a table, along with several options to the side that will activate depending on the cost types being analyzed. Several common analysis types can be selected in the list box above the table to automatically configure the table.

- **From the list box choose "Size for Initial Cost, Show Energy Costs"**. This will set the table to include material and installation costs in the Sizing Objective and will calculate the energy costs without including them in the Objective, as can be seen in Figure 3.2. This will allow us to size for the initial costs and include the energy costs for comparison when we later size the system for life cycle cost (initial costs and recurring costs combined).

  Since the energy costs are included in the cost calculation, the user must provide a System Life and, optionally, interest and inflation rates to calculate the present value of the recurring costs.

- **Enter 5 years for the System Life**, with 0% for the interest and inflation rates.

  The source of the energy costs must also be defined. Simple energy costs can be entered here, or it can be specified that energy costs come from energy cost databases, which would need to be added on the Assign Cost Databases panel. An Energy Cost Database allows variable energy costs to be used to account for varying prices during different times of day, different seasons, etc. If using the more straightforward simple energy costs, and if the compressor does not run all day every day, the easiest approach is to reduce the Energy Cost by an appropriate ratio.

- **Choose "Use this Energy Cost Information"**, with a cost of 0.11 U.S. Dollars per kW-hr. Note this assumes the compressor will run all day, every day, for the entire 5 years.

  The Sizing Objective panel should now appear as shown in Figure 3.2.

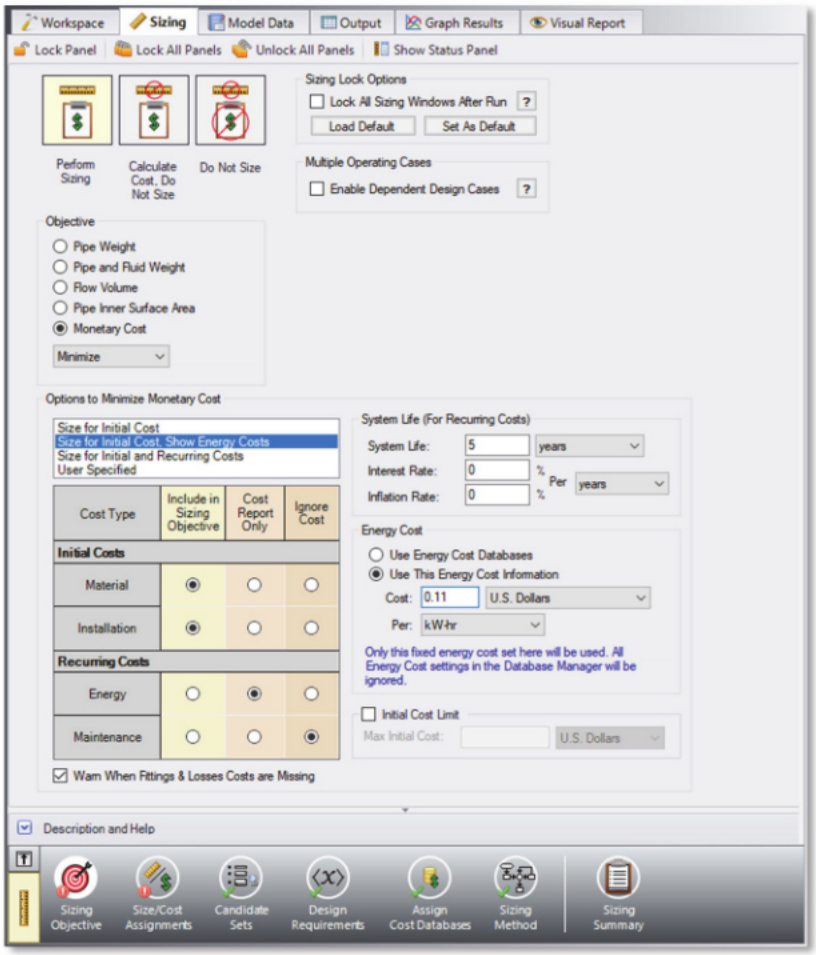


Figure 3.2 Sizing Objective panel setup for an Initial Cost analysis

B. Size/Cost assignments

On the Sizing Navigation Panel select the Size/Cost Assignments button. For this example we are sizing both the pipes and compressor for a new system, so we will need to calculate and minimize cost for all related components in the model.

➢ **Select the Pipes button** and set all pipes to "Always Include in Cost". See Figure 3.3.

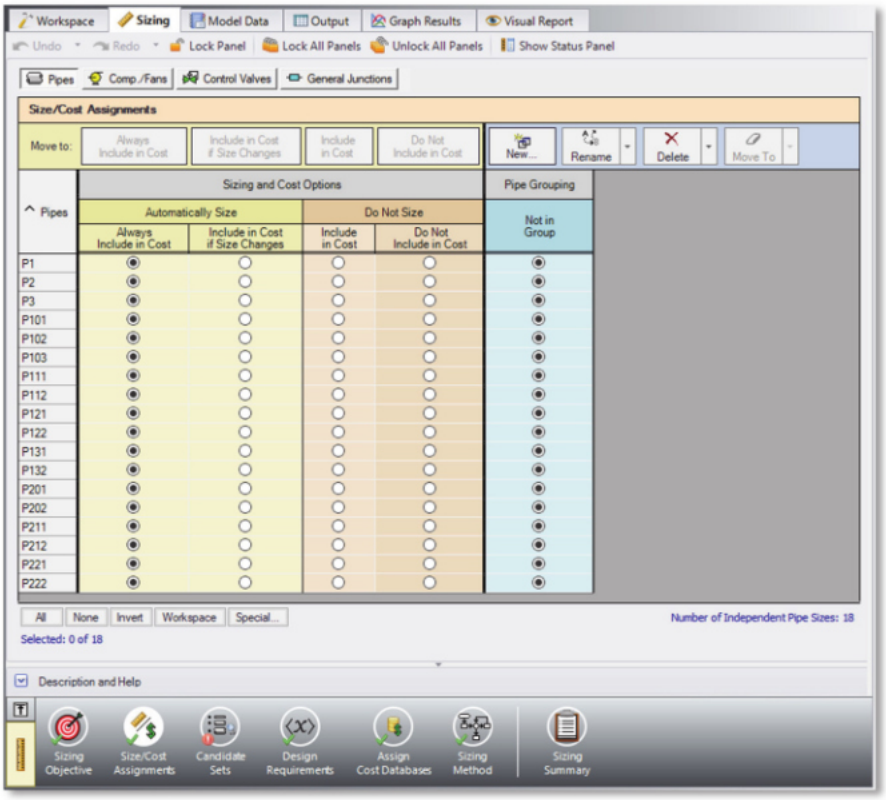


Figure 3.3 Size/Cost Assignments panel with all pipes included in sizing

To decrease the run time, reduce complexity and enforce some design uniformity, it is useful to create Common Size Groups to link the pipes in different sections of the model.

Note: The Number of Independent Pipe Sizes in the model can be seen in the bottom right of the Size/Cost Assignments panel, and denotes the number of pipe sizes being independently varied (i.e. the number of Common Size Groups, plus the sized pipes not in a group). This information is useful for choosing Sizing Methods.

For example, if all the 18 pipes are selected to be "Not In Group", then 18 pipe sizes will be independently selected by the automatic sizing engine. That could potentially mean, for example, different pipe diameters in pipes P111 and P112. If one wanted these pipes to be sized

to the same diameter, one would group them into a Common Size Group. To see how this works, in this model all discharge room piping will be put into a Common Size Group. This means that there will be one diameter chosen for this group of pipes, rather than potentially ten different diameters.

For this system we will define 4 groups. To set the groups, it is common to select pipes which must have the same size due to their placement relative to other pipes and junctions, such as pipes at the entrance and exit of valves. In Figure 3.4 we have identified these four groups.

First let's create a "Compressor Piping" size group for pipes P1 and P2.

➢ **Click the "New" button** above the Pipe Grouping section to create the group, and name it "Compressor Piping". Select the radio buttons under the "Compressor Piping" heading next to P1 and P2 to add them to the group. Alternatively, the pipes can be selected in the Workspace, then moved to a group by right-clicking the Workspace and selecting the corresponding option from the menu.

Now let's repeat this process for the discharge piping leading to each room. We will assume five identical control valves will be purchased, so therefore all these pipes will have a common size. Like before, create a new group called "Discharge Piping", and add the pipes outlined in Figure 3.4 to the new group.

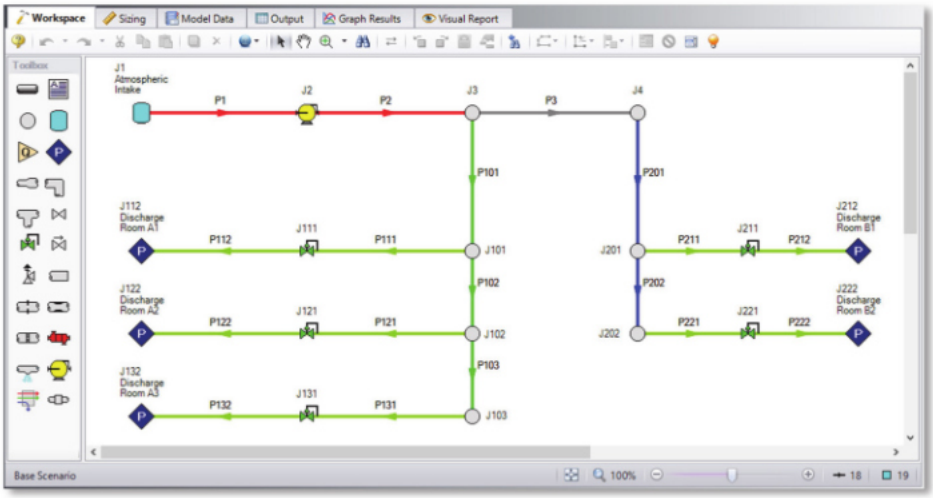


Figure 3.4 Air Distribution model with potential Common Size Groups identified by color

The headers supplying each room are one physical pipe in the field, represented as multiple pipes in AFT Arrow by necessity. Create two more groups; “Room A Header” and “Room B Header” and add the appropriate pipes to them. The Size/Cost Assignments should now appear as shown in Figure 3.5.

Note: Pipes in the Size/Cost Assignments table can be sorted by Common Size Group instead of sorting by number by clicking on the "Pipe Grouping" header. Clicking on the header for a particular group will sort the pipes in that specific group to the top of the window.

➢ **Click the Comp./Fans button** to switch to the Compressor Size/Cost Assignments. Select the option to “Include in Cost Report and Sizing” for the compressor so that the ANS module will size the compressor along with the pipes as shown in Figure 3.6.

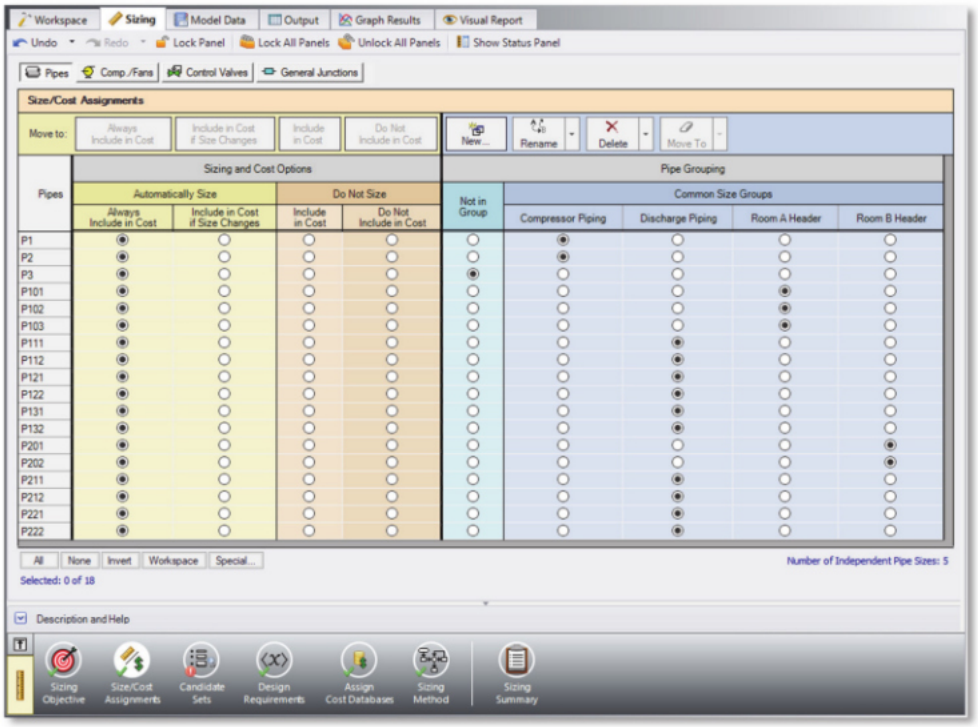


Figure 3.5 Pipe settings in the Size/Cost Assignments panel

Similar to the Common Size Groups for pipes, Compressors can be placed into Maximum Cost Groups based on monetary cost. If compressor costs are added to a Maximum Cost Group, the ANS module will determine the compressor in the group with the maximum costs and set all compressors in the group to the same costs as that compressor. In this case there is only one compressor so we cannot create a group.

Now go to the Workspace window. It is possible to inspect the Common Size Groups in the model by coloring the pipes. From the View menu, select All under Color Size Groups. The model should appear as shown in Figure 3.4, though the colors may be different.

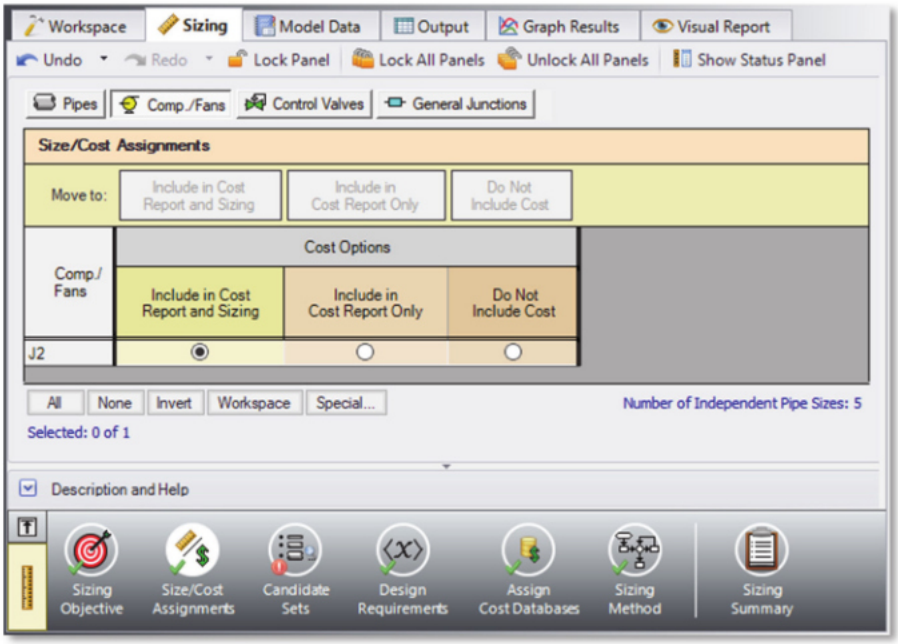


Figure 3.6 Compressor settings in the Size/Cost Assignments panel

C. Candidate sets

Click on the Candidate Sets button to open the Candidate Sets panel.

You should see that the STD Steel 2”-10” Candidate Set has already been created for the model. Expand the set by clicking the “+” sign next to its name to see that selected pipe sizes from 2" to 10" have been added for STD Steel - ANSI pipe.

In the bottom section of the window, check that each of the Common Size Groups and pipe P3 have been assigned to use the existing Candidate Set. The window should appear as shown in Figure 3.7.

D. Design requirements

Select the Design Requirements button.

Design Requirements can be applied to both sized and unsized pipes and junctions. Design Requirements are design limitations on certain parameters. For example, there may be a Design Requirement that the velocity cannot exceed 25 m/sec. As the ANS module evaluates different pipe sizes, if a particular size results in a velocity greater than 25 m/sec, that pipe size is rejected because it causes a Design Requirement violation.

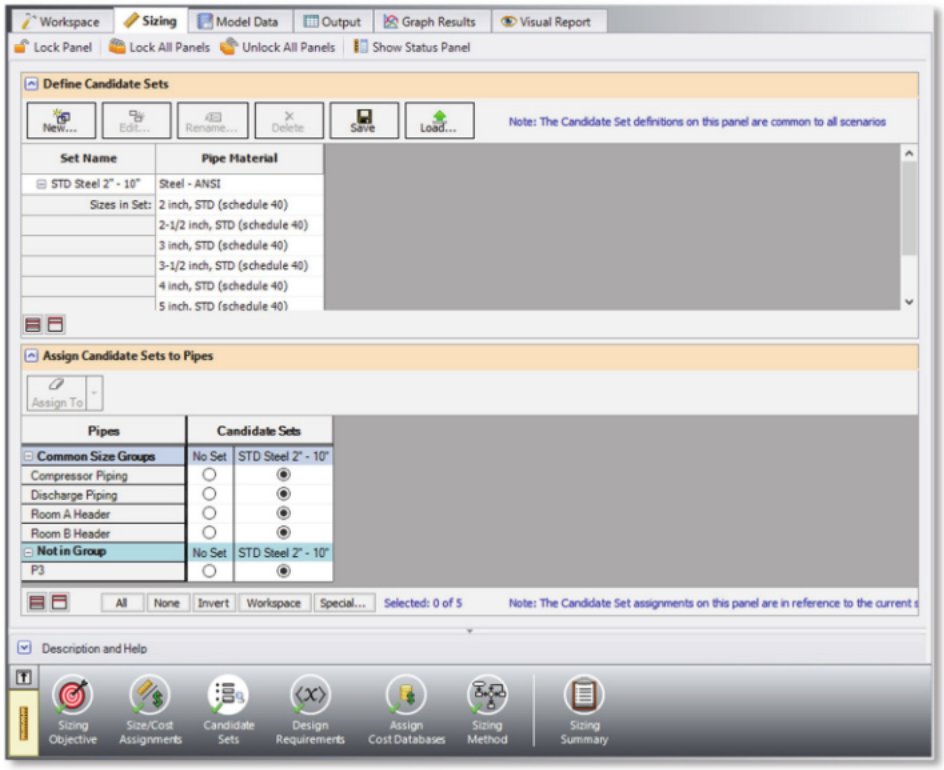


Figure 3.7 Candidate Sets panel fully defined for the model

When a pipe that is not sized has a Design Requirement, it means that the sized pipe sizes cannot be such that it violates the Design Requirement for the unsized pipe. There can be multiple Design Requirements defined and applied to a pipe, junction or group. For instance, in addition to a maximum velocity limit, a maximum pressure limit may exist. Individual pipes/junctions in a Common Size Group can have different Design Requirements applied.

For this model we have multiple requirements for the system:

1. All pipes have a maximum velocity of 45 m/sec
2. All control valves must have a minimum pressure drop of 14 kPa
3. All discharges must receive a minimum flow of 425 sm3/h

Define and assign the first requirement listed above as a Pipe Design Requirement for overall velocity and assign it to all of the pipes as shown in Figure 3.8.

For flow control valves J111, J121, J211, and J221, define and apply the minimum pressure drop requirement in the Control Valves section as shown in Figure 3.9. Note that for compressor sizing purposes as discussed earlier control valve J131 has been defined as a Constant Pressure Drop valve, so the pressure drop Design Requirement does not need to be applied to this valve.

Notice that we have accounted for the minimum flow requirement in this system by using flow control valves in each discharge line. By using an assigned flow compressor and flow control valves at each discharge, we have incorporated the necessary flow rate as a boundary condition, so we do not need to apply a Design Requirement to account for this item.

E. Assign cost databases

Select the Assign Cost Databases button. The material and installation costs for all pipes and junctions being sized must be entered into cost databases, which are then assigned to the appropriate components here. The cost databases needed for this example have been pre-built, and just need to be accessed.

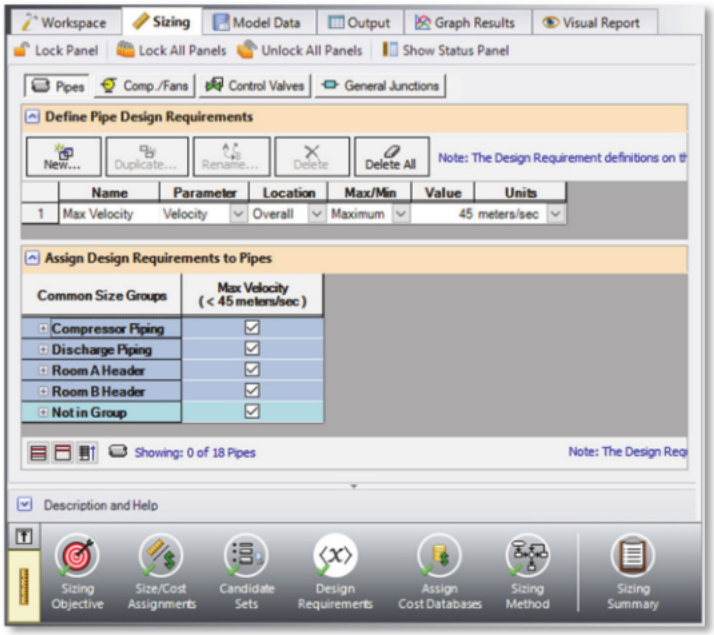


Figure 3.8 Design Requirements panel for pipes

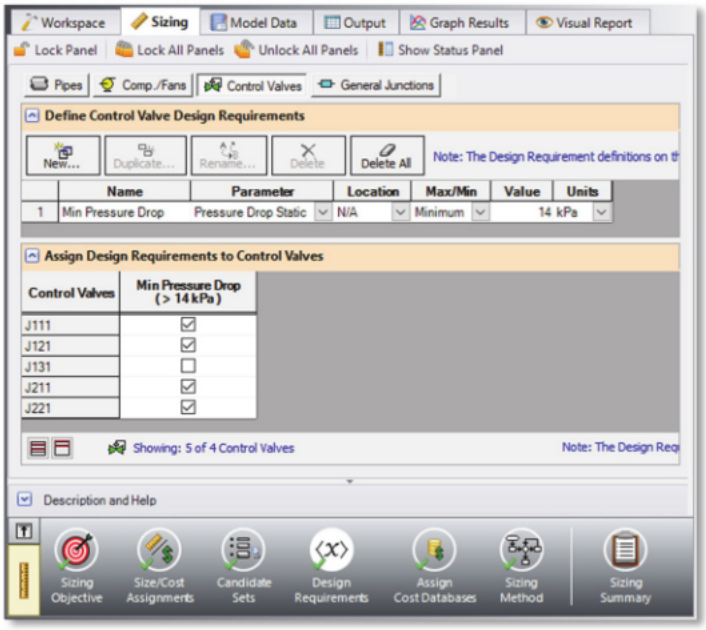


Figure 3.9 Design Requirements panel for control valves

The Database Manager (opened from the Database Manager button or Database menu) shows all of the available and connected databases. Databases can either be engineering databases or cost databases. Cost databases are always associated with an engineering database and are thus displayed subordinate to an engineering database in the database lists. Here we will summarize some key aspects of databases:

- Cost information for a pipe system component is accessed from a cost database. Cost database items are based on corresponding items in an engineering database. (The engineering databases also include engineering information such as pipe diameters, hydraulic loss factors, etc.)
- To access a cost for a particular pipe or junction in a model, that pipe or junction must be based on items in an engineering database. Moreover, that database must be *connected* to the model, and to the specific item in the model.
- There can be multiple cost databases associated with and connected to an engineering database. This makes it easier to manage costs of items. If multiple cost databases are assigned to a Candidate Set, then the costs will be stacked to find a cumulative cost.

➢ **Open the Database Manager** by clicking the Database Manager button. The AFT DEFAULT INTERNAL DATABASE, AFT ARROW LOCAL USER DATABASE, and PIPE MATERIAL DATABASES should be available and connected by default. In the top section of the window, Available Databases will be shown based on databases that AFT Arrow has identified on your machine. The default connected databases will be visible here, and additional databases may be visible from other example files, or from databases previously built and used on your machine.

This example uses one user-defined engineering database, “Air Distribution Components.dat”, which contains the data for the compressor. There are also two cost databases, “Air Distribution Components Cost.cst” and “Air Distribution Pipe Cost.cst”, which contain the cost data for the junctions and the pipe materials, respectively. “Air Distribution Components Cost.cst” was built off of the engineering database “Air Distribution Components.dat”, and “Air Distribution Pipe Cost.cst” was built off of the default PIPE MATERIAL DATABASE. To connect these databases, do the following:

1. Click the button to "Edit Available List" and select “Add Engineering Database”.

2. Browse to the AFT Arrow 8 Examples folder (located by default in C:\AFT Products\AFT Arrow 8\Examples\), and open the file titled "Metric - Air Distribution Components.dat".
3. Repeat the above steps, but choose “Add Cost Database” to browse for “Metric - Air Distribution Components Cost.cst”, then “Metric - Air Distribution Pipe Cost.cst”.

Once these steps have been completed, you should now see that the new databases have been added to the Available Databases list, and have been automatically connected to the model so that they can also be seen in the Connected Databases list, as shown in Figure 3.10 for the component databases. The component databases appear in the Connected Databases section under the names “Air Distribution Components” and “Air Distribution Components Cost”, with the cost database indented beneath the engineering database to denote that they are linked. The cost database for the pipes appears with the name "Air Distribution Pipe Costs” and is similarly indented under the Steel-ANSI database within the standard pipe material databases.

Once you have confirmed that the necessary databases are connected as shown, click Close to exit the Database Manager.

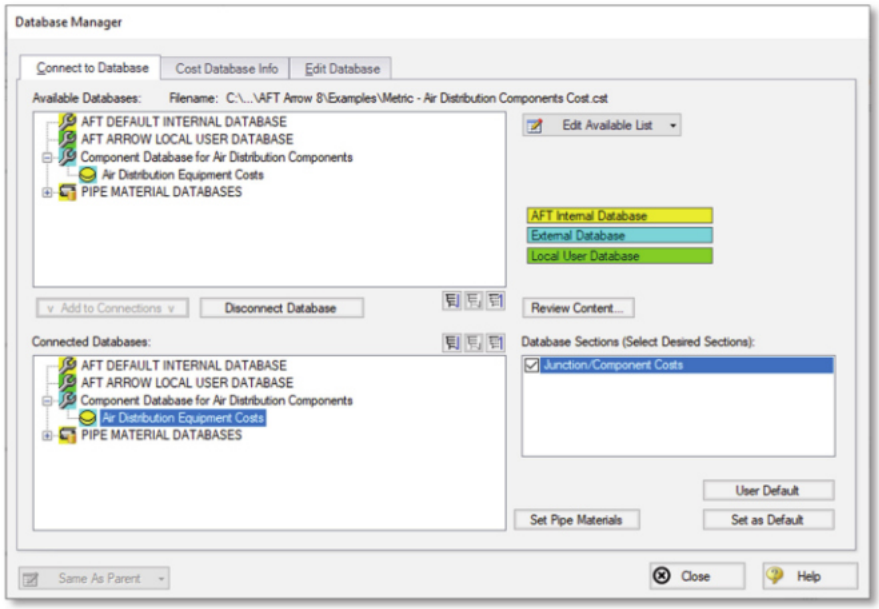


Figure 3.10 Database Manager showing the Air Distribution databases connected and available

Since we are connecting a pre-built database, we will need to take an additional step to make sure that the compressor in the Workspace is linked to the Air Distribution engineering database that we added.

1. Go to the Workspace, and open the compressor (junction J2)
2. From the Database List, select "Fixed Flow 2125 sm3/h". None of the input should change, as this database item is identical to the existing compressor. However, AFT Arrow will now recognize that this junction is connected to the engineering and cost database for this compressor.

We have now re-connected the junctions that will be considered for the Cost Report and sizing calculations to the engineering database. This is important, since a junction must be connected to an engineering database before cost information can be assigned to it. Let's now return to the Sizing window.

Back in the Assign Cost Databases panel for the Pipes, the "Air Distribution Pipe Cost" database should now be visible in the table. Make sure that the database is checked to be applied for the model as shown in Figure 3.11.

➢ **Click on the Comp./Fans button,** to view the cost database assignments for the Compressor. The "Air Distribution Components Cost" database should now be available. Make sure that the checkbox is selected under the database name so that the cost data will be applied for the compressor (Figure 3.12).

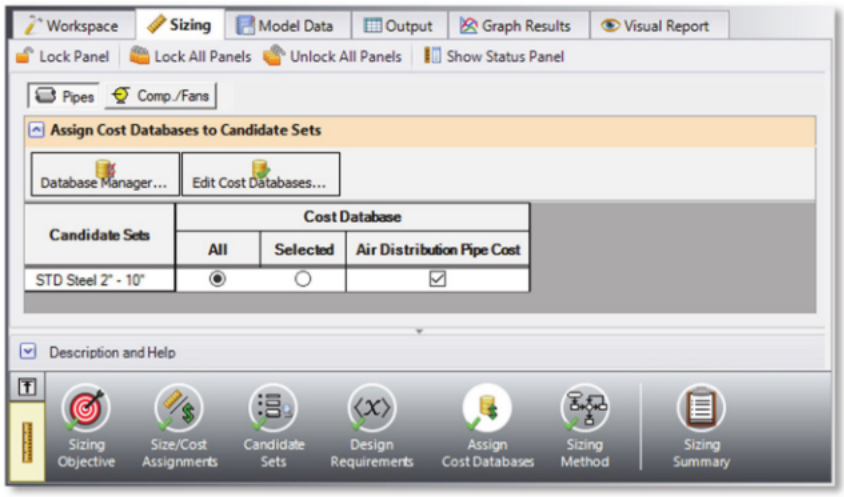


Figure 3.11 Assign Cost Databases panel for pipes

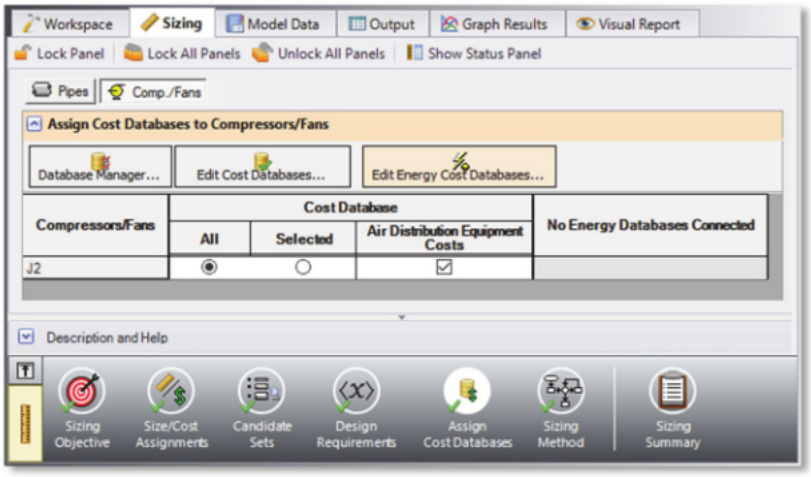


Figure 3.12 Assign Cost Databases panel for compressors

F. Sizing method

Select the Sizing Method button to go to the corresponding panel.

➢ **Select Discrete Sizing** to complete the sizing for a set of commercial pipe sizes.

For this model we have 5 independent pipe sizes as noted on the Size/Cost Assignments panel (4 groups and pipe P3), and 2 design requirements (1 pipe design requirement applied to all of the pipes, and a minimum pressure drop applied to 4 control valves). Due to the small number of independent sizes, it would be recommended to try the MMFD or SQP search method. Though it is not shown here, if both methods are run for this scenario the same solution will be obtained, though the Sequential Quadratic Programming (SQP) Method is slightly faster. Select this method from the list as shown in Figure 3.13.

Note: Different Search Methods will not always produce the same result, so it is always recommended to run the automated sizing with multiple search methods. The MMFD and SQP methods are recommended when there are less than 10 independent pipe sizes, while the GA and SU methods will work better for models with more than 10 independent pipe sizes. These are discussed further in the Help file.

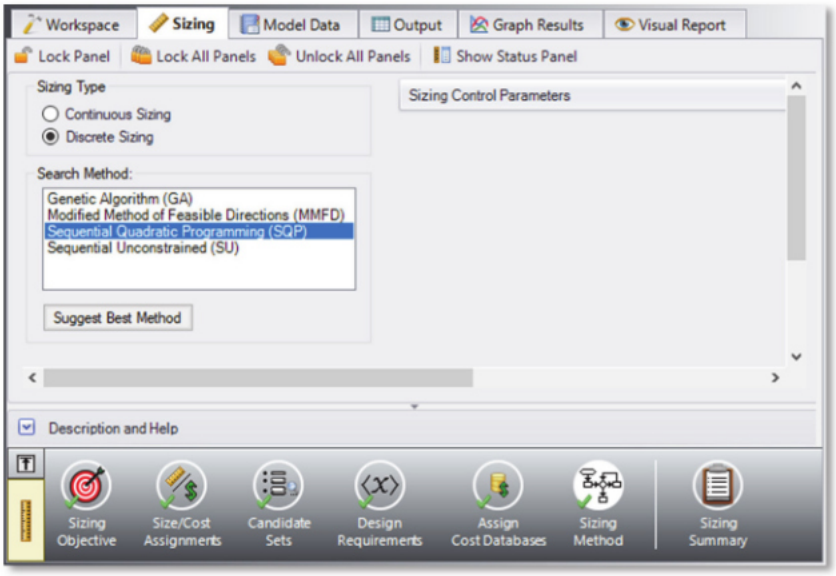


Figure 3.13 Sizing Method panel defined for Discrete sizing with the Sequential Quadratic Programming method

G. Sizing summary

From the Sizing Navigation Panel select the Sizing Summary button.

The Sizing Summary panel allows the user to view all of the sizing input for the model in a tree view layout, which is shown in Figure 3.14. Items can be organized by sizing parameters (Design Requirements, Candidate Sets, etc.), or information can be viewed for an individual pipe. For clarity these categories can be shown/hidden using the check boxes at the top of the panel.

Each tree node can be expanded/collapsed individually by using the '+' and '-' buttons on the node. Alternatively, the buttons on the bottom of the panel can be used to collapse/expand all items. Right-clicking on the nodes provides additional options to collapse/expand items, view related nodes, or to copy information to the clipboard. The Sizing Summary panel can be printed from the printer button at the bottom of the panel.

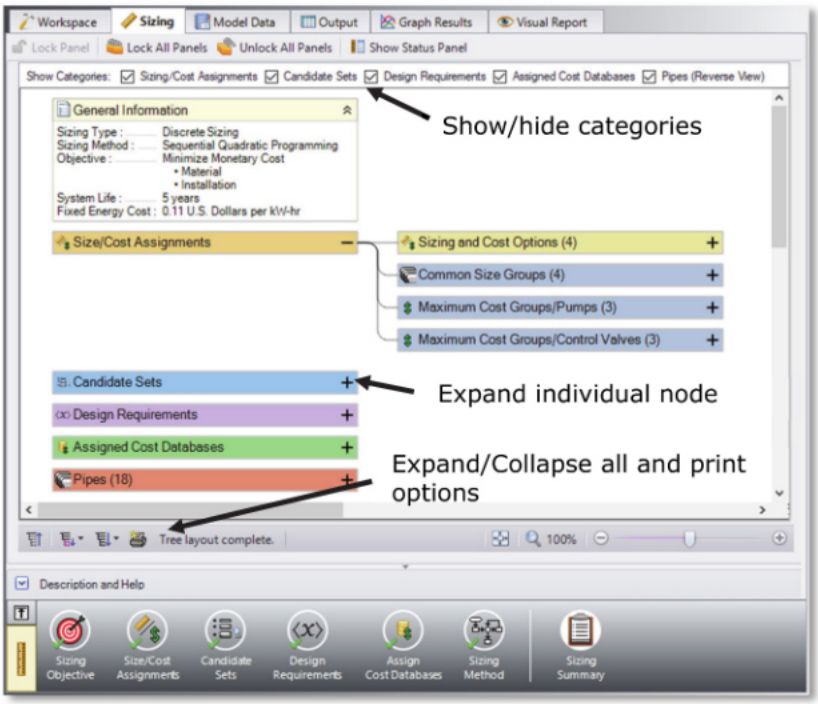


Figure 3.14 Sizing Summary panel layout with the Size/Cost Assignments expanded. The number of children nodes for each item can be seen in parentheses.

Step 4. Run the model

Select Run Model in the Analysis menu. This will open the Solution Progress window. This window allows you to watch as the AFT Arrow Solver and the ANS module converge on a solution.

After the run has been completed, the results can be reviewed by clicking the Output button at the bottom of the solution control window.

Step 5. Review the output

The Cost Report is shown in the General Section of the Output window (see Figure 3.15). The ANS module shows all costs in the Cost Report, including those that were calculated but not used in the automated sizing.

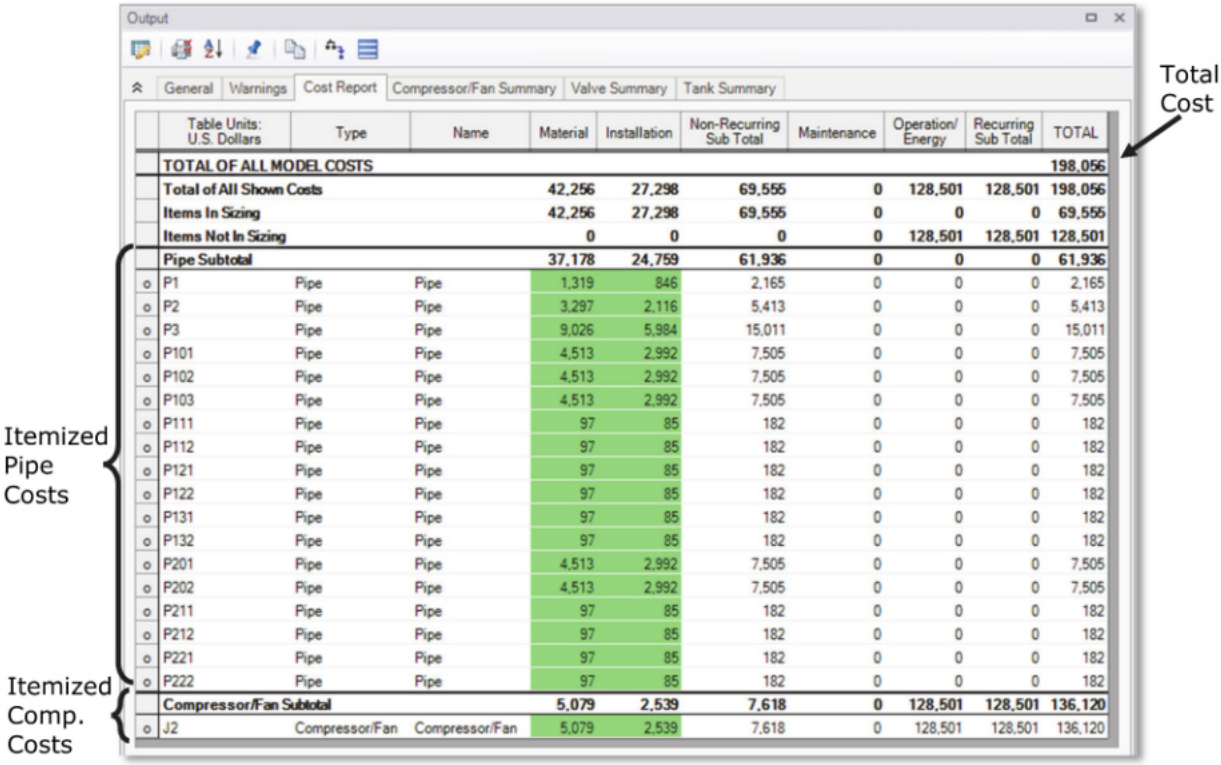


	Table Units: U.S. Dollars	Type	Name	Material	Installation	Non-Recurring Sub Total	Maintenance	Operation/ Energy	Recurring Sub Total	TOTAL
	TOTAL OF ALL MODEL COSTS									**198,056**
	Total of All Shown Costs			**42,256**	**27,298**	**69,555**	**0**	**128,501**	**128,501**	**198,056**
	Items In Sizing			**42,256**	**27,298**	**69,555**	**0**	**0**	**0**	**69,555**
	Items Not In Sizing			**0**	**0**	**0**	**0**	**128,501**	**128,501**	**128,501**
	Pipe Subtotal			**37,178**	**24,759**	**61,936**	**0**	**0**	**0**	**61,936**
o	P1	Pipe	Pipe	1,319	846	2,165	0	0	0	2,165
o	P2	Pipe	Pipe	3,297	2,116	5,413	0	0	0	5,413
o	P3	Pipe	Pipe	9,026	5,984	15,011	0	0	0	15,011
o	P101	Pipe	Pipe	4,513	2,992	7,505	0	0	0	7,505
o	P102	Pipe	Pipe	4,513	2,992	7,505	0	0	0	7,505
o	P103	Pipe	Pipe	4,513	2,992	7,505	0	0	0	7,505
o	P111	Pipe	Pipe	97	85	182	0	0	0	182
o	P112	Pipe	Pipe	97	85	182	0	0	0	182
o	P121	Pipe	Pipe	97	85	182	0	0	0	182
o	P122	Pipe	Pipe	97	85	182	0	0	0	182
o	P131	Pipe	Pipe	97	85	182	0	0	0	182
o	P132	Pipe	Pipe	97	85	182	0	0	0	182
o	P201	Pipe	Pipe	4,513	2,992	7,505	0	0	0	7,505
o	P202	Pipe	Pipe	4,513	2,992	7,505	0	0	0	7,505
o	P211	Pipe	Pipe	97	85	182	0	0	0	182
o	P212	Pipe	Pipe	97	85	182	0	0	0	182
o	P221	Pipe	Pipe	97	85	182	0	0	0	182
o	P222	Pipe	Pipe	97	85	182	0	0	0	182
	Compressor/Fan Subtotal			**5,079**	**2,539**	**7,618**	**0**	**128,501**	**128,501**	**136,120**
o	J2	Compressor/Fan	Compressor/Fan	5,079	2,539	7,618	0	128,501	128,501	136,120

Figure 3.15 The Cost Report in the Output window shows the total and individual costs for the sized system

The total cost for this system is $198,056. This includes all costs over 5 years. The initial cost, which was the basis for the automated sizing, was the total of the material and installation costs ($69,555). This total is listed as the total for the "Items in Sizing" line, since it was specified to only include the initial costs (material and installation) in the Sizing Objective section. Individual items that were included in the automated sizing have their costs highlighted in green.

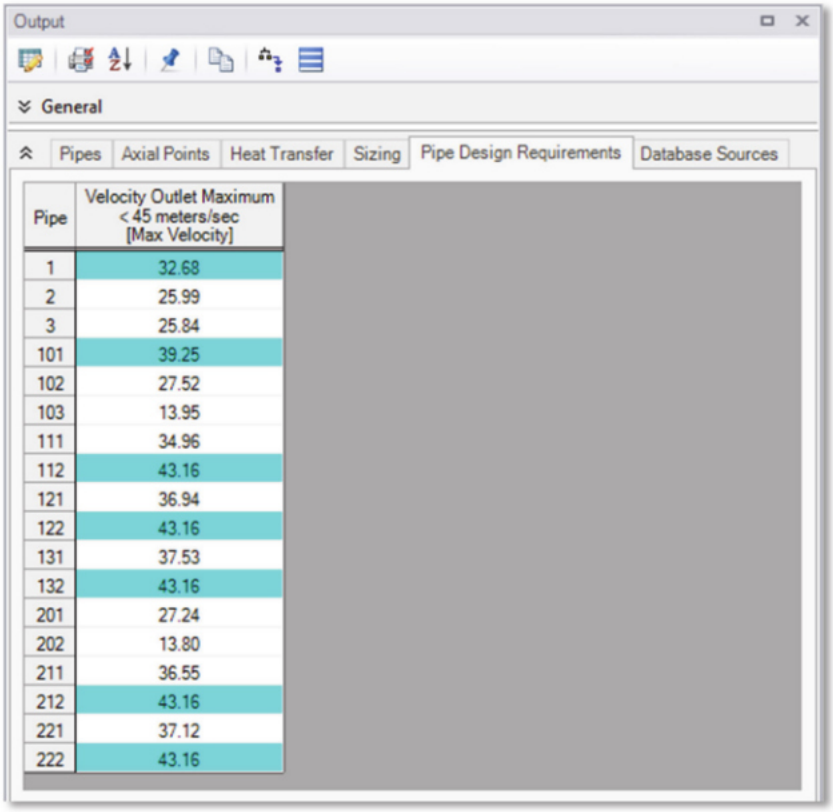
Other costs that are displayed in the Cost Report are "Items Not in Sizing". These are items that were set to have their costs calculated but

were not included in the automated sizing. Note that the Items Not in Sizing total to $128,501. Looking across at the subtotal one can see that all of this cost is in energy (i.e., compressor power costs). The total cost is the sum of the two. This cost will be included in the automated sizing later for comparison.

In the Pipes section of the Output window the final pipe sizes from the automated sizing can be seen, along with the Design Requirements status. For this sizing there were multiple pipe velocity requirements that were active, as is indicated by the highlighting (Figure 3.16). Though not shown here, one of the control valves also had an active design requirement in the model.

For this model, the final system used pipe sizes varying from 2-1/2 to 6 inches, as seen in Figure 3.17. Data on the Common Size Groups and pipe costs can also be viewed from here. The information for the compressor can be seen in the Compressor/Fan Summary tab in the General Section, which is also shown in Figure 3.17.

When a monetary cost objective is selected, additional tabs are available that display the Database Sources used for the Cost Report for each of

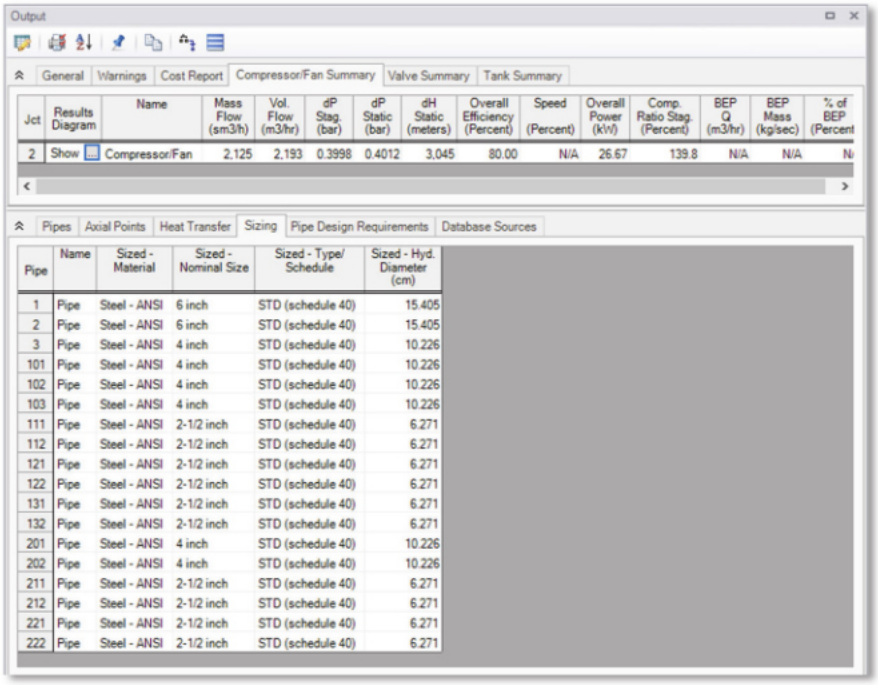


Pipe	Velocity Outlet Maximum < 45 meters/sec [Max Velocity]
1	32.68
2	25.99
3	25.84
101	39.25
102	27.52
103	13.95
111	34.96
112	43.16
121	36.94
122	43.16
131	37.53
132	43.16
201	27.24
202	13.80
211	36.55
212	43.16
221	37.12
222	43.16

Figure 3.16 Pipe Design Requirements section with the active design requirements highlighted

the pipes/junctions. In this case both the Pipe Material and Pipe Installation costs for all of the pipes came from the "Air Distribution Pipe Cost" database which was connected earlier. Information for the Compressor came for the "Air Distribution Components Cost" database. If multiple cost databases are used for the same cost type they will all be listed separated by commas. This is useful for model verification.

On the General tab of the Output window at the bottom of the report, the initial cost of the items included in the sizing can be seen, which was $110,156 for this design, showing the initial costs were reduced by about 37% from the initial design. We can also see that the initial design was feasible, meaning all of the design requirements were met (Figure 3.18).



Jct	Results Diagram	Name	Mass Flow (sm3/h)	Vol. Flow (m3/hr)	dP Stag. (bar)	dP Static (bar)	dH Static (meters)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (kW)	Comp. Ratio Stag. (Percent)	BEP Q (m3/hr)	BEP Mass (kg/sec)	% of BEP (Percent
2	Show	Compressor/Fan	2,125	2,193	0.3998	0.4012	3,045	80.00	N/A	26.67	139.8	N/A	N/A	N

Pipe	Name	Sized - Material	Sized - Nominal Size	Sized - Type/ Schedule	Sized - Hyd. Diameter (cm)
1	Pipe	Steel - ANSI	6 inch	STD (schedule 40)	15.405
2	Pipe	Steel - ANSI	6 inch	STD (schedule 40)	15.405
3	Pipe	Steel - ANSI	4 inch	STD (schedule 40)	10.226
101	Pipe	Steel - ANSI	4 inch	STD (schedule 40)	10.226
102	Pipe	Steel - ANSI	4 inch	STD (schedule 40)	10.226
103	Pipe	Steel - ANSI	4 inch	STD (schedule 40)	10.226
111	Pipe	Steel - ANSI	2-1/2 inch	STD (schedule 40)	6.271
112	Pipe	Steel - ANSI	2-1/2 inch	STD (schedule 40)	6.271
121	Pipe	Steel - ANSI	2-1/2 inch	STD (schedule 40)	6.271
122	Pipe	Steel - ANSI	2-1/2 inch	STD (schedule 40)	6.271
131	Pipe	Steel - ANSI	2-1/2 inch	STD (schedule 40)	6.271
132	Pipe	Steel - ANSI	2-1/2 inch	STD (schedule 40)	6.271
201	Pipe	Steel - ANSI	4 inch	STD (schedule 40)	10.226
202	Pipe	Steel - ANSI	4 inch	STD (schedule 40)	10.226
211	Pipe	Steel - ANSI	2-1/2 inch	STD (schedule 40)	6.271
212	Pipe	Steel - ANSI	2-1/2 inch	STD (schedule 40)	6.271
221	Pipe	Steel - ANSI	2-1/2 inch	STD (schedule 40)	6.271
222	Pipe	Steel - ANSI	2-1/2 inch	STD (schedule 40)	6.271

Figure 3.17 Compressor and pipe sizes after initial cost sizing is performed

Though not shown here, if the model is run using the objective to "Calculate Costs, Do Not Size", it can be seen that the total cost for the system before sizing was $178,719, which is actually less than the system that has been sized for initial costs. This is due to the fact that the larger pipe sizes in the original design allowed for lower energy costs over the 5 year system life, even though the material and installation costs were larger. This indicates that this system is weighted towards energy costs, since they have a large impact on the overall cost.

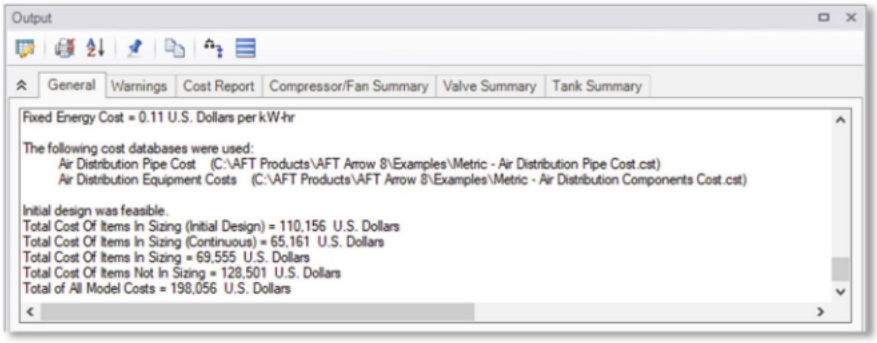


Figure 3.18 General section of Output window showing initial status of Items in Sizing

Step 6. Size system for life cycle cost

Now we want to size the system based on life cycle costs, rather than just minimizing the initial costs of the system. As previously discussed, the energy costs can often be weighted much more heavily than the initial cost of the system components. This means that sizing based on recurring costs will often result in larger pipes with higher material/installation costs being chosen so that smaller compressors with lower energy costs can be used.

From the Scenario Manager in the Quick Access Panel, we will create two child scenarios. With the “Metric Units” scenario selected, right click and choose “Create Child”. Name the new scenario “Initial Cost”. This scenario will store the initial cost sizing results we just obtained. Repeat this process to create a second child scenario under “Metric Units”, and name it "Life Cycle Cost". The “Life Cycle Cost” scenario should now be active, as indicated by the green check mark symbol. For this scenario the only change that will need to be made is to update the Sizing Objective.

➢ **Go to the Sizing window**, and make sure that the Sizing Objective panel is selected. Under “Options to Minimize Monetary Cost”, choose “Size for Initial and Recurring Costs”. This will move the Energy costs selection to “Include in Sizing Objective” as shown in Figure 3.19. The scenario is now complete.

➢ **Click Run from the Analysis menu** to run the automated sizing. When the calculations have finished, click Output to view the results. The new Cost Report can be seen in Figure 3.20.

After viewing the Cost Report, it can be seen that the overall cost is now $166,343. The "Items Not in Sizing" line now has a value of zero, and the Energy column is highlighted green, reflecting the changes made to include these costs in the Objective.

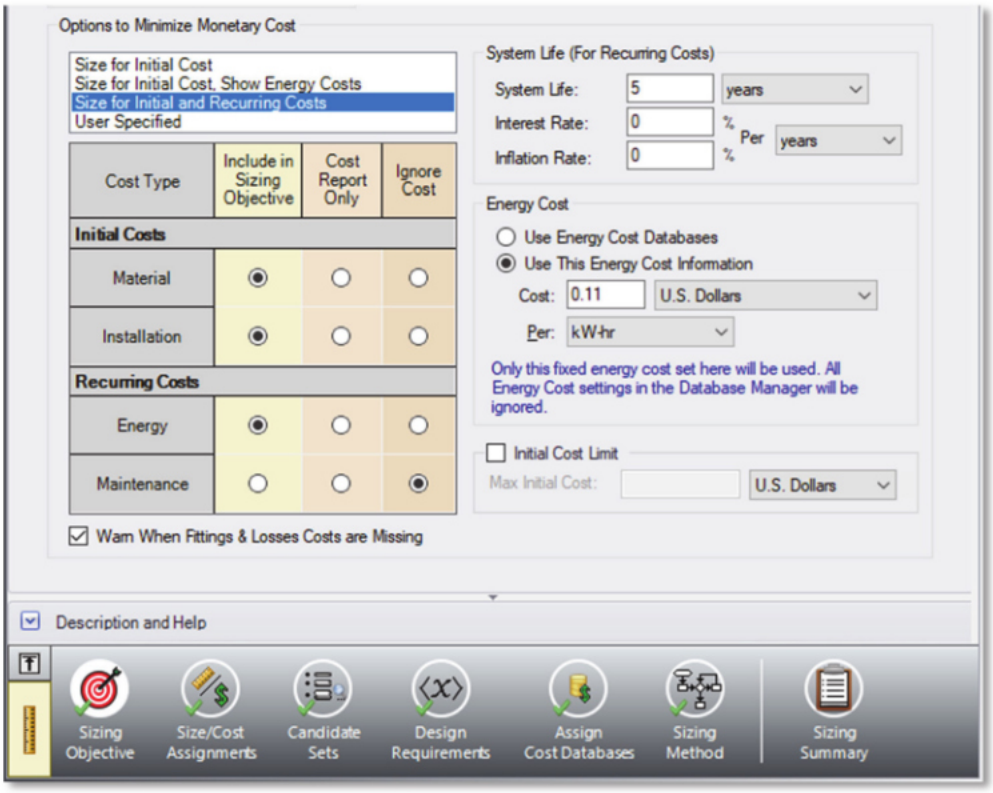
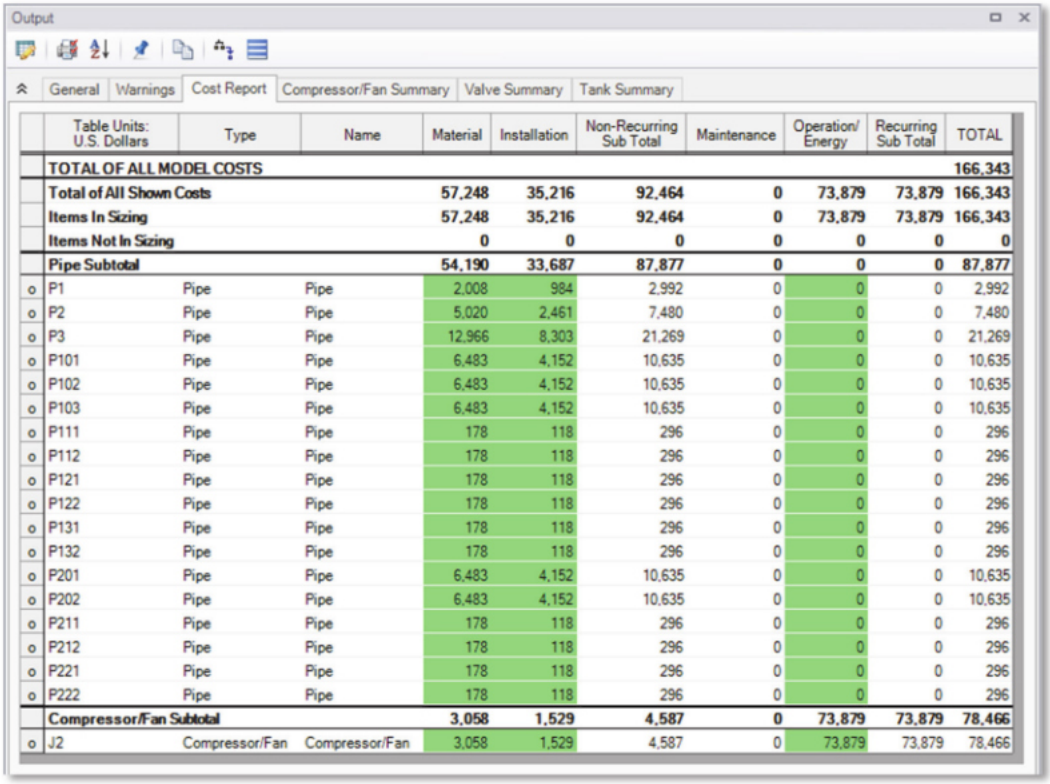


Figure 3.19 Options to Minimize Monetary Cost section of Sizing Objective panel defined for life cycle cost sizing



Output

General | Warnings | Cost Report | Compressor/Fan Summary | Valve Summary | Tank Summary

	Table Units: U.S. Dollars	Type	Name	Material	Installation	Non-Recurring Sub Total	Maintenance	Operation/ Energy	Recurring Sub Total	TOTAL
	TOTAL OF ALL MODEL COSTS									**166,343**
	Total of All Shown Costs			**57,248**	**35,216**	**92,464**	**0**	**73,879**	**73,879**	**166,343**
	Items In Sizing			**57,248**	**35,216**	**92,464**	**0**	**73,879**	**73,879**	**166,343**
	Items Not In Sizing			**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Pipe Subtotal			**54,190**	**33,687**	**87,877**	**0**	**0**	**0**	**87,877**
o	P1	Pipe	Pipe	2,008	984	2,992	0	0	0	2,992
o	P2	Pipe	Pipe	5,020	2,461	7,480	0	0	0	7,480
o	P3	Pipe	Pipe	12,966	8,303	21,269	0	0	0	21,269
o	P101	Pipe	Pipe	6,483	4,152	10,635	0	0	0	10,635
o	P102	Pipe	Pipe	6,483	4,152	10,635	0	0	0	10,635
o	P103	Pipe	Pipe	6,483	4,152	10,635	0	0	0	10,635
o	P111	Pipe	Pipe	178	118	296	0	0	0	296
o	P112	Pipe	Pipe	178	118	296	0	0	0	296
o	P121	Pipe	Pipe	178	118	296	0	0	0	296
o	P122	Pipe	Pipe	178	118	296	0	0	0	296
o	P131	Pipe	Pipe	178	118	296	0	0	0	296
o	P132	Pipe	Pipe	178	118	296	0	0	0	296
o	P201	Pipe	Pipe	6,483	4,152	10,635	0	0	0	10,635
o	P202	Pipe	Pipe	6,483	4,152	10,635	0	0	0	10,635
o	P211	Pipe	Pipe	178	118	296	0	0	0	296
o	P212	Pipe	Pipe	178	118	296	0	0	0	296
o	P221	Pipe	Pipe	178	118	296	0	0	0	296
o	P222	Pipe	Pipe	178	118	296	0	0	0	296
	Compressor/Fan Subtotal			**3,058**	**1,529**	**4,587**	**0**	**73,879**	**73,879**	**78,466**
o	J2	Compressor/Fan	Compressor/Fan	3,058	1,529	4,587	0	73,879	73,879	78,466

Figure 3.20 Cost Report for life cycle cost sizing scenario

Taken on its own, this new cost represents a savings of about $32,000 over the Initial cost scenario which was sized based on Initial Cost only. This represents a 14% cost reduction. In the initial cost scenario, the non-recurring cost was $69,555, while the overall cost was $198,056. Now the non-recurring cost is $92,464 while the overall cost is $166,343. The initial cost thus increased by about $23,000 in order to reduce the operating cost from $128,501 to $73,879 (a reduction of about $55,000). The source of the operating cost is the cost of power for the compressors. To reduce compressor power usage, it makes sense to increase the pipe size and thus reduce frictional losses. The larger pipe sizes can be reviewed by looking at the Sizing tab in the Pipe Output section.

Step 7. Apply initial cost limit

While the energy cost savings from life cycle cost sizing are desirable, the budget for the project may not support the higher initial cost that is required. In that case, we can apply an initial cost limit to the life cycle cost sizing.

- **Return to the Sizing Objective panel** and select the option for Initial Cost Limit. We will set the limit as $85,000, which is the given budget for this project. Run the model and go to the Output tab. The Cost Report can be seen in Figure 3.21.

Note: The initial cost in the final solution may be lower than the actual Initial Cost Limit that was defined, as is the case with this scenario. This occurs due to the Common Size Groups reducing the number of possible pipe size combinations. If the pipes in the Room A Header group are removed from the group, then the initial cost for the final solution is much closer to the $82,500 initial cost limit.

A summary of the difference between each of the initial and life cycle cost sizing scenarios for a 5 year life cycle can be seen in Table 3.1. Notice that while the material and installation costs were similar to the costs from the initial cost scenario, the energy costs were decreased by about $10,000. These energy costs were achieved by increasing the compressor pipe sizes, while decreasing the header pipe sizes to achieve a better efficiency in the compressor. Table 3.2 shows a comparison of the pipe sizes throughout the system for the original design and each of the sizing scenarios.

Table 3.1 Cost Summary of automated sizing runs for the Air Distribution System

Sized for:	Material	Installation	Total Non-recurring	Energy	Overall Total	Reduction
Not sized	67,223	42,933	110,156	68,563	178,719	
Sized for Initial cost	42,256	27,298	68,555	128,501	198,056	**-20,000**
Sized for Life cycle cost	57,248	35,216	92,464	73,879	166,343	**12,400**
Sized for Life cycle cost with initial cost limit	44,930	27,850	72,780	118,284	191,064	**-12,300**

Table 3.2 Summary of final pipe sizes from automated sizing runs for Common Size Groups in Air Distribution System

Sized for:	Compressor Pipes	Room A Headers	Room B Headers	Discharge Piping	Pipe P3
Not sized	6”	6”	6”	3”	6”
Sized for Initial cost	6”	4”	4”	2-1/2”	4”
Sized for Life cycle cost	8”	5”	5”	4”	5”
Sized for Life cycle cost with initial cost limit	8”	4”	4”	3-1/2”	4”

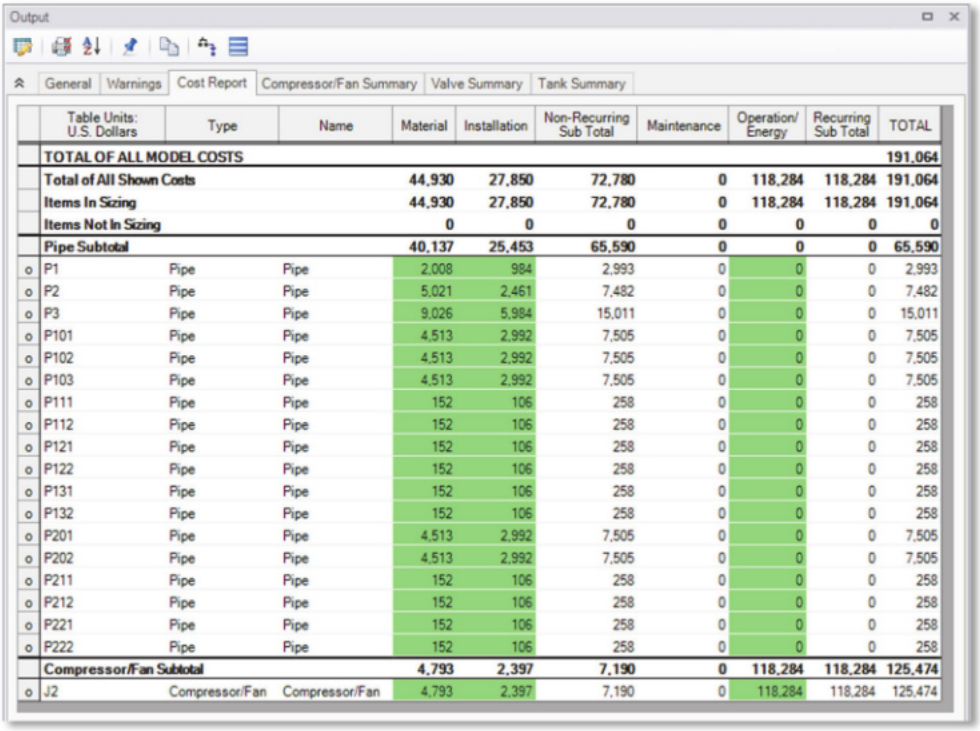


	Table Units: U.S. Dollars	Type	Name	Material	Installation	Non-Recurring Sub Total	Maintenance	Operation/ Energy	Recurring Sub Total	TOTAL
	TOTAL OF ALL MODEL COSTS									**191,064**
	Total of All Shown Costs			**44,930**	**27,850**	**72,780**	**0**	**118,284**	**118,284**	**191,064**
	Items In Sizing			**44,930**	**27,850**	**72,780**	**0**	**118,284**	**118,284**	**191,064**
	Items Not In Sizing			**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Pipe Subtotal			**40,137**	**25,453**	**65,590**	**0**	**0**	**0**	**65,590**
o	P1	Pipe	Pipe	2,008	984	2,993	0	0	0	2,993
o	P2	Pipe	Pipe	5,021	2,461	7,482	0	0	0	7,482
o	P3	Pipe	Pipe	9,026	5,984	15,011	0	0	0	15,011
o	P101	Pipe	Pipe	4,513	2,992	7,505	0	0	0	7,505
o	P102	Pipe	Pipe	4,513	2,992	7,505	0	0	0	7,505
o	P103	Pipe	Pipe	4,513	2,992	7,505	0	0	0	7,505
o	P111	Pipe	Pipe	152	106	258	0	0	0	258
o	P112	Pipe	Pipe	152	106	258	0	0	0	258
o	P121	Pipe	Pipe	152	106	258	0	0	0	258
o	P122	Pipe	Pipe	152	106	258	0	0	0	258
o	P131	Pipe	Pipe	152	106	258	0	0	0	258
o	P132	Pipe	Pipe	152	106	258	0	0	0	258
o	P201	Pipe	Pipe	4,513	2,992	7,505	0	0	0	7,505
o	P202	Pipe	Pipe	4,513	2,992	7,505	0	0	0	7,505
o	P211	Pipe	Pipe	152	106	258	0	0	0	258
o	P212	Pipe	Pipe	152	106	258	0	0	0	258
o	P221	Pipe	Pipe	152	106	258	0	0	0	258
o	P222	Pipe	Pipe	152	106	258	0	0	0	258
	Compressor/Fan Subtotal			**4,793**	**2,397**	**7,190**	**0**	**118,284**	**118,284**	**125,474**
o	J2	Compressor/Fan	Compressor/Fan	4,793	2,397	7,190	0	118,284	118,284	125,474

Figure 3.21 Cost Report for life cycle cost automated sizing scenario with initial cost limit

Discussion on sizing with compressor curve data

One can consider the previous discussion in this chapter as Phase 1 of the compressor and pipe sizing process. Phase 2 involves using the Phase 1 results in order to select actual compressors which have compressor curve data. The actual compressor should closely match the sizing results in the generated pressure at the design flow, efficiency at the design flow, and cost. If it does not, then it may be advisable to repeat the Phase 1 sizing with updated information from actual compressors (e.g., monetary costs, nominal efficiency, etc.). A complete Phase 2 analysis will run the automated sizing again for each actual compressor considered. The pipe sizing may change slightly for each compressor considered.

By reviewing the Compressor/Fan Summary for the life cycle cost sizing with an initial cost limit, one can see that the ideal system calls for a compressor of about 26 kW that generates about 38.6 kPa of pressure at 2125 sm3/h. The nominal efficiency used in the sizing part of the analysis was 80%. The material cost for such a compressor was about $5,800, and the installation cost was about $2,400. Note that if no actual compressors can be found that reflect these requirements, then the Phase 1 process should be repeated with better performance and/or cost data for the compressor.

Conclusions

Using cost databases in the automated sizing process involves increased complexity from simple non-monetary automated sizing as discussed in Chapter 2. However, it allows more powerful automated sizing options including the ability to size costs over a system life cycle.

CHAPTER 4

Multiple Design Case Example

This example will size the pipes for a natural gas supply system to five burners. It is desired to analyze two separate design cases using monetary cost automated sizing.

Topics covered

This example will cover the following topics:

- How dependent design cases are used to satisfy two different operating modes for a system
- Common Size Groups and their effect on how well the ANS module can size a system

Required knowledge

This example assumes that the user has some familiarity with AFT Arrow and the ANS module such as placing junctions, connecting pipes, entering pipe and junction specifications, and creating and using Candidate Sets and Design Requirements. Refer to the Weight Sizing Example in Chapter 2 for more information on these topics.

Model files

Metric - Natural Gas Burner.aro - AFT Arrow model file

STD Steel Pipe Costs.cst - Pipe cost database for steel pipe

Problem statement

This example uses an existing model to investigate a single system with two operating cases. The cases are as follows:

1. Normal flow to burners requires 2.4 kg/sec controlled by flow control valves. The pressure drop across the flow control valves must be at least 1.7 bar and velocity at the burners must be less than 60 m/sec.
2. The one burner off case has the center burner turned off. Total flow must be maintained, so each flow control valve must supply 3 kg/sec at a pressure drop of 1.7 bar, with the 60 m/sec maximum velocity requirement still applied.

We will design for both operating cases by first configuring the sizing settings for the normal flow case, then creating the one burner off case using the Dependent Design Cases feature.

Step 1. Start AFT Arrow

From the Start Menu, choose AFT Products and AFT Arrow.

Enable the ANS module from the Startup Menu by checking the box next to the ANS module. Alternatively, the ANS module can be activated from the Module button at the bottom of the Quick Access Panel, or from the Activate Modules option in the Tools menu.

Step 2. Open model file

For this example we will be starting from a pre-built model file that is fully defined for a normal AFT Arrow run. We will add automated sizing settings to find a more cost-effective design. From either the Startup Window or the File menu, browse to *Metric - Natural Gas Burner - ANS.aro* and copy it to a new location. Open the model to the base scenario.

This example consists of a natural gas supply (Tank J1) at 14 bar and 10 deg. C that supplies gas to five burners. All of the pipes in the system are

STD Steel-ANSI. The supply line to the heat exchanger is fixed at 6-inches. The model should appear as shown in Figure 4.1.

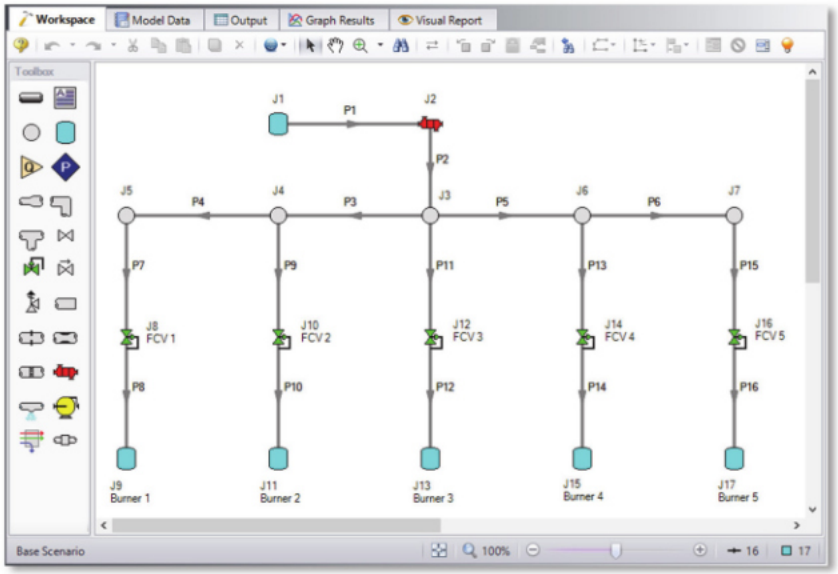


Figure 4.1 Natural Gas Burner model layout in Workspace

Step 3. Review model settings

A. Sizing objective

Go to the Sizing window by selecting the tab. The Sizing Objective panel should be selected by default from the buttons along the bottom.

For this analysis, we are interested in sizing the system considering the monetary cost for the initial costs only.

1. Set the calculation to Perform Sizing.
2. For the Objective, choose "Monetary Cost", and select the Minimize option from the drop-down list.
3. Under Options to Minimize Monetary Cost, choose "Size for Initial Cost", which will automatically configure the table to include all non-recurring costs in the sizing while ignoring the recurring costs.

B. Size/Cost assignments

On the Sizing Navigation Panel select the Size/Cost Assignments button. For the supply lines P1 and P2, the pipe size is fixed to 6 inches and will not be sized. However, we still want to consider their cost. The rest of the pipe sizes can be varied.

- **Move pipes P1 & P2** to "Do Not Size – Include in Cost", then select the remaining pipes (P11-P72) and move them to "Always Include in Cost".

  The four header pipes (P3, P4, P5, P6) represent a single header in the physical system, so it will be necessary to add them to a Common Size Group. A second Common Size Group should be created to contain all of the discharge piping (P7-P16), as each of the branches to the burners should be identical.

- **Select "New" above the Pipe Grouping table** to create two new groups with the names "Headers" and "Distribution Piping". Add pipes P3-P6 to the "Headers" group, then add pipes P7-P16 to the "Distribution Piping" group either from the table, or from the Workspace. The Size/Cost Assignments table should now appear as shown in Figure 4.2.

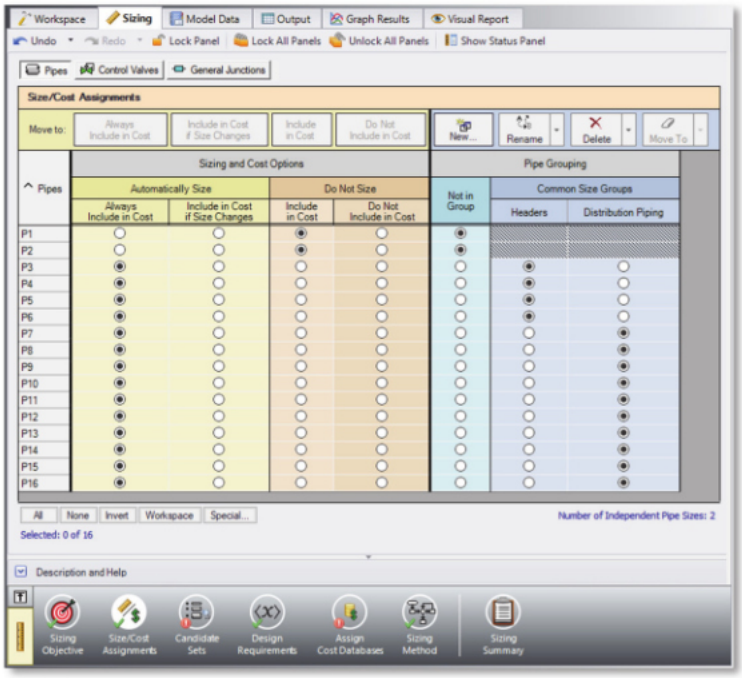


Figure 4.2 Size/Cost Assignments panel for the normal flow case

C. Candidate sets

Click on the Candidate Sets button to display the Candidate Sets panel.

In this case we will be considering schedule 40 Steel pipe within the range of 1" - 12".

1. Select New, and name the Candidate set "Steel Sch 40".
2. Choose Steel-ANSI from the material list.
3. Expand the “STD” type, then double click each of the sizes from 1 inch to 12 inch to add them to the Candidate Set.
4. Click OK to accept the defined set.

In the bottom section of the window make sure that the Common Size Groups are assigned to use the Candidate Set as shown in Figure 4.3.

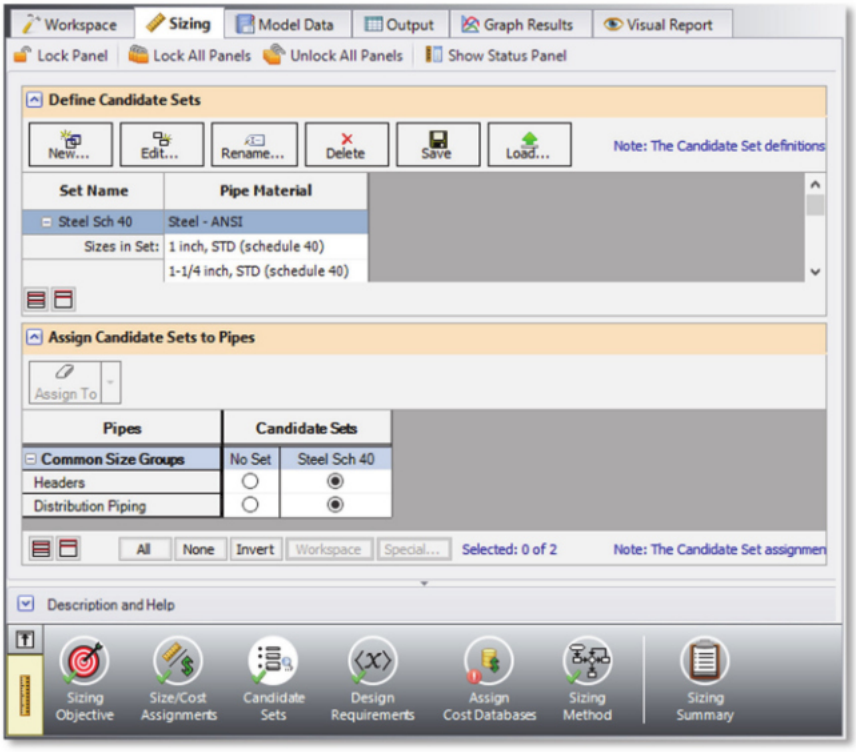


Figure 4.3 Candidate Sets panel for the normal flow case

D. Design requirements

Select the Design Requirements button.

In the normal flow case the following requirements need to be met:

1. The flow to the burners must remain below the maximum velocity requirement of 60 m/sec.
2. All control valves must have a minimum pressure drop of 1.7 bar

Make sure that the Pipes button is selected, then create a new Design Requirement named “Max Burner Velocity” specifying the maximum velocity at the outlet of the pipe as 60 m/sec (Figure 4.4). In the bottom section of the window, make sure that the velocity design requirement is applied to each of the discharge lines to the burners.

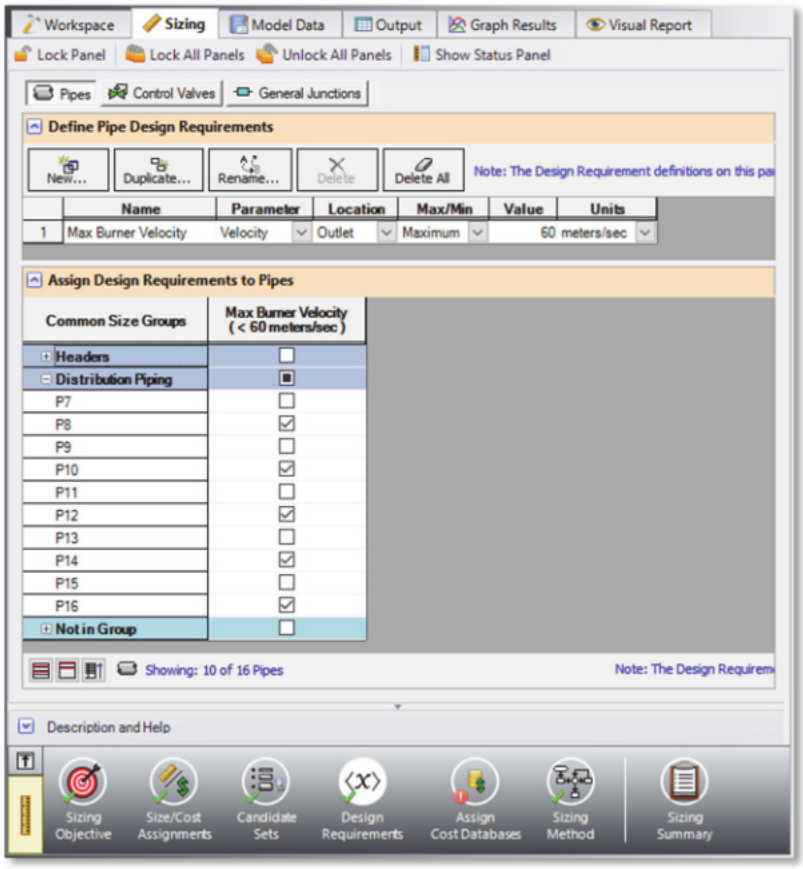


Figure 4.4 Pipe Design Requirements defined for the normal flow case

Next select the Control Valves button at the top of the window and create a new control valve Design Requirement. Name the Design Requirement “Min Pressure Drop”, and specify the Pressure drop static as a minimum of 1.7 bar. In the bottom section apply the Design Requirement to each of the control valves in the model (Figure 4.5).

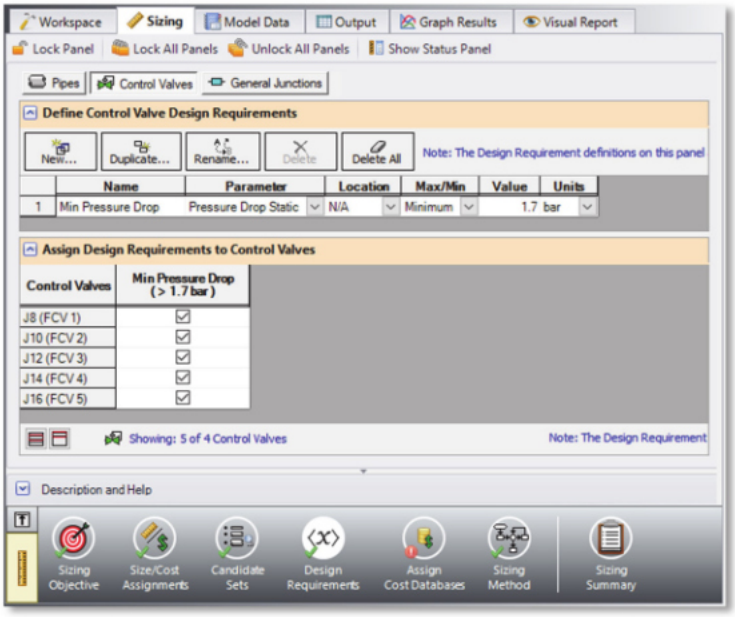


Figure 4.5 Control Valve Design Requirement defined for the primary case

E. Assign cost databases

Select the Assign Cost Databases button. The actual material and installation costs are contained in a pre-built cost database which we will need to connect.

➢ **Open the Database Manager** by clicking the Database Manager button to see which databases are connected.

This example uses a pre-built cost database for the pipes containing the Steel material costs. To connect the database do the following:

1. Click the button to "Edit Available List" and select Add Cost Database.

2. Browse to the Arrow 8 Examples folder (located by default in C:\AFT Products\AFT Arrow 8\Examples\), and open the file titled "STD Steel Pipe Costs.cst".

The new database should now be visible in the Available Databases list and be automatically connected to the model, as shown in Figure 4.6. Once you have confirmed that the database is connected, click Close to exit the Database Manager.

Back in the Assign Cost Databases panel for the Pipes the "STD Steel Pipe Costs" database should now be visible, and should be selected to show that it is being applied to the Candidate Set and each of the supply pipes.

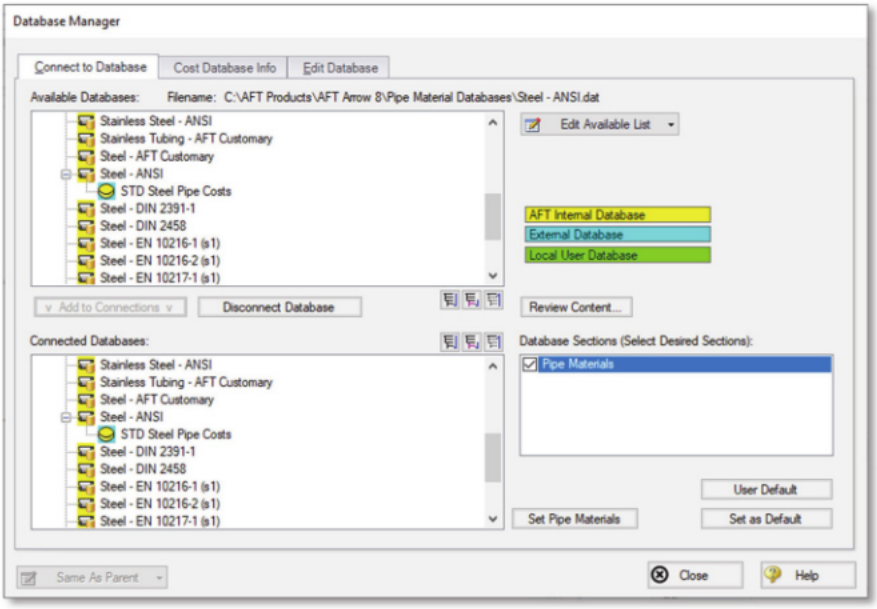


Figure 4.6 Database Manager showing the STD Steel cost database connected and available in the model

F. Sizing method

Select the Sizing Method button to go to the Sizing Method panel.

Ensure that Discrete Sizing is selected with the Modified Method of Feasible Directions (MMFD) chosen for the Search Method.

G. Dependent design cases

Now we have defined the sizing settings for the normal flow case. This is the *primary design case* from which we can create *dependent design cases*. A dependent design case (or DDC) in the ANS module is a system that represents the same physical pipes and junctions as the primary case, but with different operating requirements. The dependent design case for this model is when Burner #3 is closed. When the middle burner is closed, the flow to each of the other burners increases to 3 kg/sec.

Here are the steps to create this Dependent Design Case:

1. Go to the Sizing Objective panel and select the "Enable Dependent Design Cases" option. A new button will now be available for the Dependent Design Cases panel in the Sizing Navigation Panel as shown in Figure 4.7.

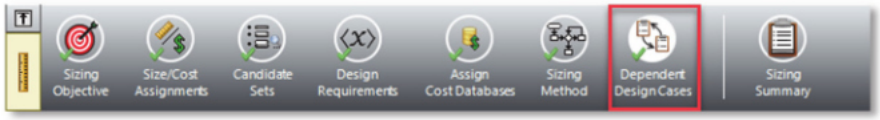


Figure 4.7 Sizing Navigation Panel with Dependent Design Cases enabled

2. Select the Dependent Design Cases button. You should now see instructions displayed to create the Dependent Design Case, along with a summary table of dependent design settings. We will need to use the Duplicate Special tool to create the dependent design case.
3. Go to the Workspace and choose Select All from the Edit menu.
4. Open Duplicate Special (from the Edit menu), enter an increment of 100 and select "Make Dependent Design Case" (Figure 4.8). Click OK.

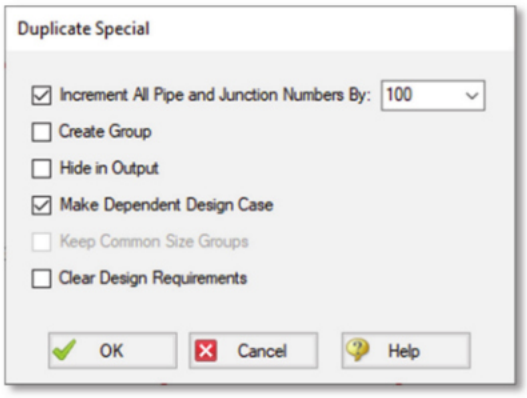


Figure 4.8 Duplicate Special for creating the DDC

5. Move the duplicated pipes and junctions to distinguish them from the original ones from the Primary Design Case (Figure 4.9).
6. Close control valve J112 in the DDC by setting the Special Condition on the Optional tab of the Pipe Properties window to closed.
7. Use Global Junction Edit (from the Edit menu) to change the flow setpoint for all open control valves in the DDC (J108, J110, J114, J116) to 3 kg/sec (Figure 4.10).
8. In the Sizing window navigate to the Design Requirements panel. On the Control Valves page remove the pressure drop requirement from J112, since this valve is closed for the DDC.

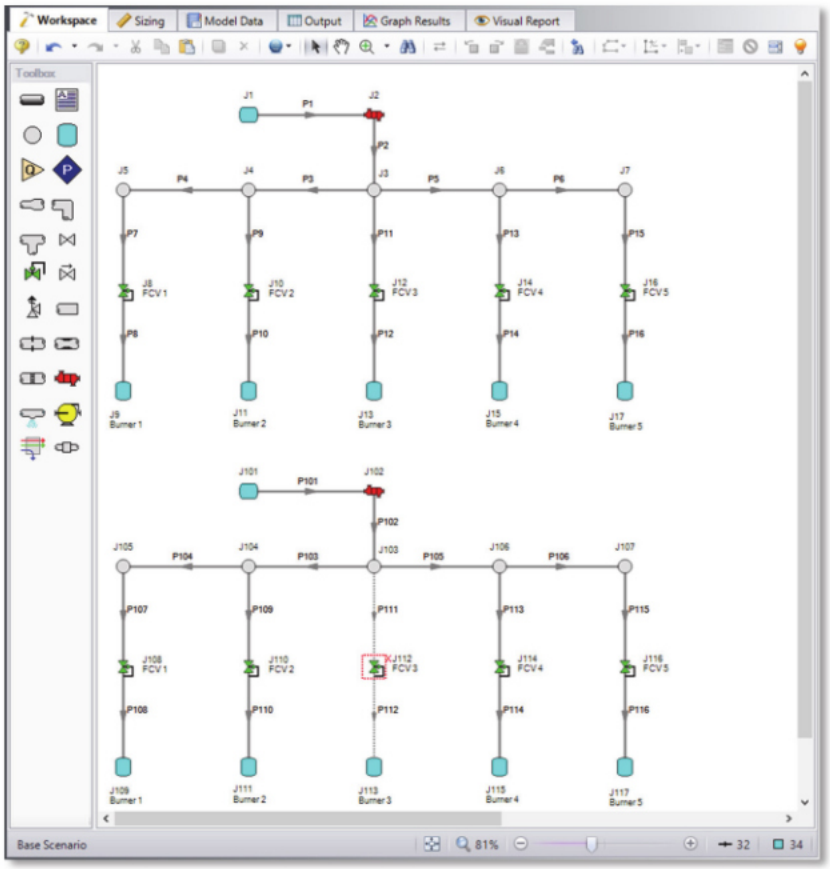


Figure 4.9 **Workspace with Primary Design Case (at top) and one Dependent Design Case (at bottom)**

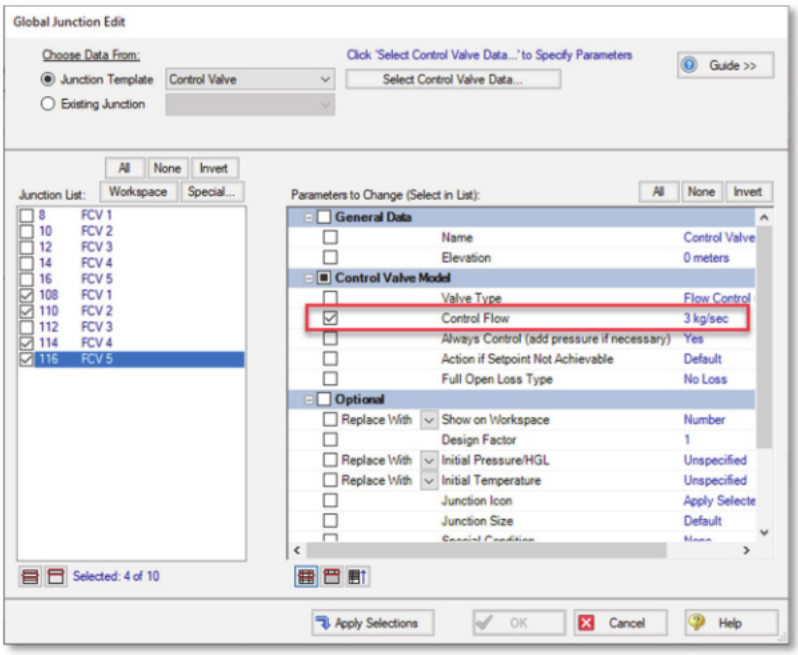


Figure 4.10 Global Junction Edit is used to change the control valve setpoints to 3 kg/sec in the DDC

Return to the Dependent Design Cases panel.

When Duplicate Special was performed with Dependent Design Case selected, each of the duplicated pipes was created with a special type of grouping. For example, pipe 101 is grouped with pipe 1 as a DDC pipe (see Figure 4.11). This type of assignment allows the dependent design pipes to be sized, but to not be counted in the cost so that the cost will not be duplicated.

It should also be noted that the dependent design grouping causes each of the dependent pipes to inherit their Common Size Groups, Candidate Sets, and Cost Database settings from the pipes in the primary case. The dependent design case pipes are therefore hidden on all sizing panels except for the Design Requirements and Dependent Design Cases panels.

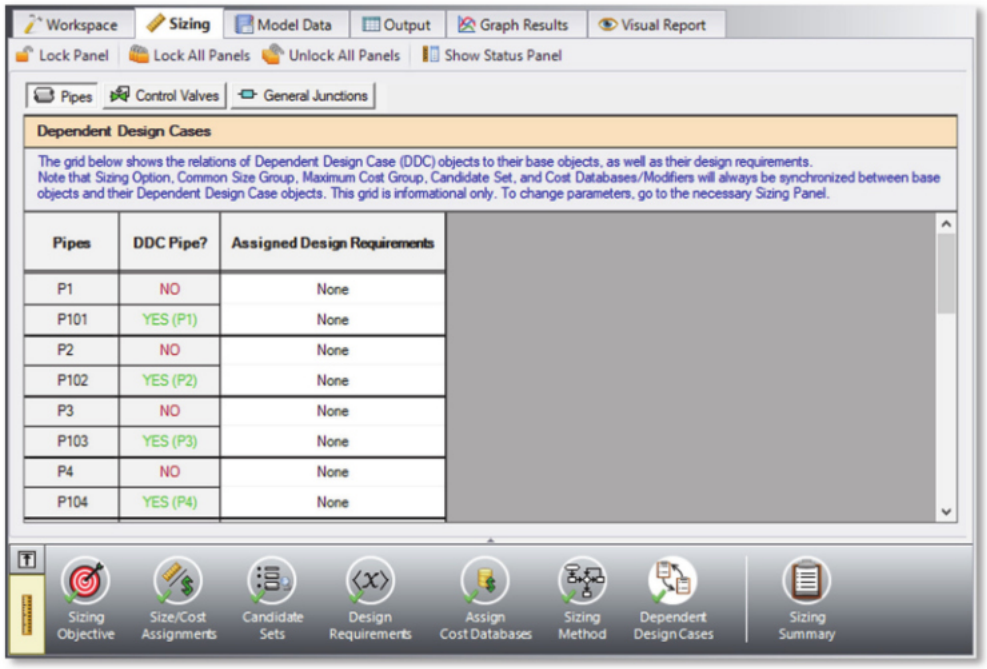


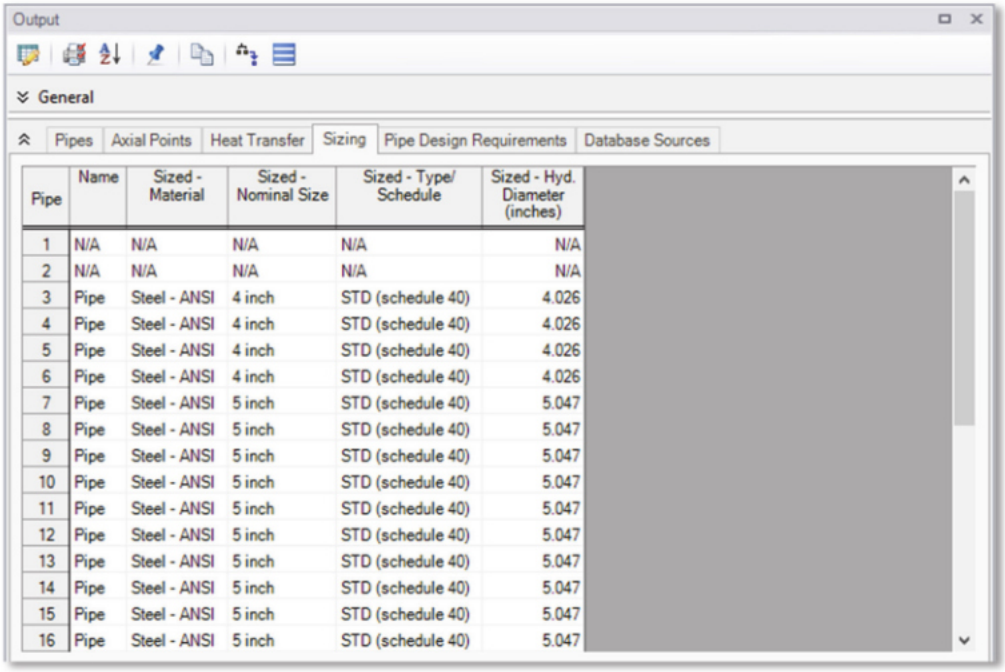
Figure 4.11 Pipes in Dependent Design Cases have a special grouping relationship with pipes in the primary case

Step 4. Run the automated sizing

Select Run from the Analysis menu to perform the automated sizing.

After the run finishes, examine the final pipe sizes calculated by the ANS module. One can see that the resultant size is 4-inch steel for the header, with larger 5-inch steel pipe for the distribution lines, as shown in Figure 4.12.

The total cost for the pipes is $46,557 (see Cost Report in Figure 4.13). This includes the $8,250 cost for the supply line pipes which were not sized, as well as the $38,437 cost for the pipes in the model which were sized, including the header and distribution piping.



Pipe	Name	Sized - Material	Sized - Nominal Size	Sized - Type/ Schedule	Sized - Hyd. Diameter (inches)
1	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A
3	Pipe	Steel - ANSI	4 inch	STD (schedule 40)	4.026
4	Pipe	Steel - ANSI	4 inch	STD (schedule 40)	4.026
5	Pipe	Steel - ANSI	4 inch	STD (schedule 40)	4.026
6	Pipe	Steel - ANSI	4 inch	STD (schedule 40)	4.026
7	Pipe	Steel - ANSI	5 inch	STD (schedule 40)	5.047
8	Pipe	Steel - ANSI	5 inch	STD (schedule 40)	5.047
9	Pipe	Steel - ANSI	5 inch	STD (schedule 40)	5.047
10	Pipe	Steel - ANSI	5 inch	STD (schedule 40)	5.047
11	Pipe	Steel - ANSI	5 inch	STD (schedule 40)	5.047
12	Pipe	Steel - ANSI	5 inch	STD (schedule 40)	5.047
13	Pipe	Steel - ANSI	5 inch	STD (schedule 40)	5.047
14	Pipe	Steel - ANSI	5 inch	STD (schedule 40)	5.047
15	Pipe	Steel - ANSI	5 inch	STD (schedule 40)	5.047
16	Pipe	Steel - ANSI	5 inch	STD (schedule 40)	5.047

Figure 4.12 Resulting header and distribution pipe sizes

Step 5. Review the results

The automated sizing we just ran had two operating cases. One was for operation when all burners are running, and the second was for the case where one burner is shut off. The all burners case is modeled by the network shown in the upper part of Figure 4.9. The second model shown at the bottom of Figure 4.9 represents the four burners case.

The pipes and junctions in the four burners case are separate entities for modeling purposes, but represent the same pipes and junctions as the all burners case. Thus, when performing automated sizing, we only count the cost of the pipes and junctions once. This occurs in the primary design case, which in this model is the all burners case. This is why pipes P101-P116 are not shown in the Cost Report.

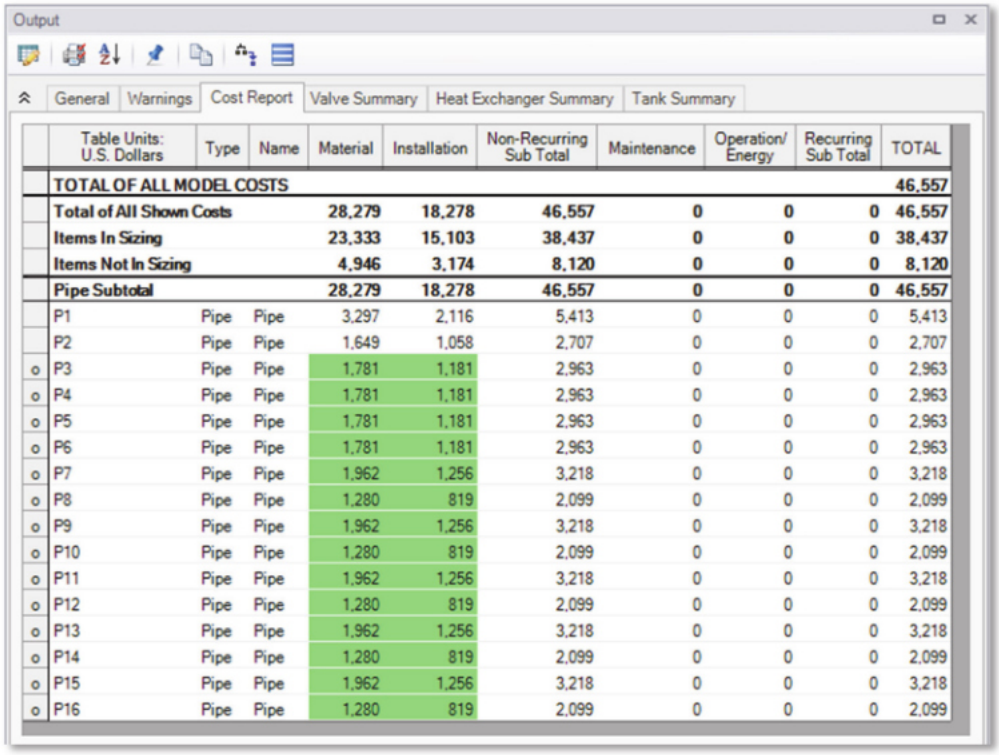


	Table Units: U.S. Dollars	Type	Name	Material	Installation	Non-Recurring Sub Total	Maintenance	Operation/ Energy	Recurring Sub Total	TOTAL
	TOTAL OF ALL MODEL COSTS									**46,557**
	Total of All Shown Costs			**28,279**	**18,278**	**46,557**	**0**	**0**	**0**	**46,557**
	Items In Sizing			**23,333**	**15,103**	**38,437**	**0**	**0**	**0**	**38,437**
	Items Not In Sizing			**4,946**	**3,174**	**8,120**	**0**	**0**	**0**	**8,120**
	Pipe Subtotal			**28,279**	**18,278**	**46,557**	**0**	**0**	**0**	**46,557**
	P1	Pipe	Pipe	3,297	2,116	5,413	0	0	0	5,413
	P2	Pipe	Pipe	1,649	1,058	2,707	0	0	0	2,707
o	P3	Pipe	Pipe	1,781	1,181	2,963	0	0	0	2,963
o	P4	Pipe	Pipe	1,781	1,181	2,963	0	0	0	2,963
o	P5	Pipe	Pipe	1,781	1,181	2,963	0	0	0	2,963
o	P6	Pipe	Pipe	1,781	1,181	2,963	0	0	0	2,963
o	P7	Pipe	Pipe	1,962	1,256	3,218	0	0	0	3,218
o	P8	Pipe	Pipe	1,280	819	2,099	0	0	0	2,099
o	P9	Pipe	Pipe	1,962	1,256	3,218	0	0	0	3,218
o	P10	Pipe	Pipe	1,280	819	2,099	0	0	0	2,099
o	P11	Pipe	Pipe	1,962	1,256	3,218	0	0	0	3,218
o	P12	Pipe	Pipe	1,280	819	2,099	0	0	0	2,099
o	P13	Pipe	Pipe	1,962	1,256	3,218	0	0	0	3,218
o	P14	Pipe	Pipe	1,280	819	2,099	0	0	0	2,099
o	P15	Pipe	Pipe	1,962	1,256	3,218	0	0	0	3,218
o	P16	Pipe	Pipe	1,280	819	2,099	0	0	0	2,099

Figure 4.13 Cost Report shown in the Output window

By applying different pressure and flow requirements between the two cases, we performed an automated sizing that selected the best pipe size which simultaneously met the requirements of both cases.

Other possibilities

To obtain the best possible design for the system, one can allow each pipe to be sized independently by removing all pipes from the Common Size Groups. While not shown here, it is possible to reduce the overall cost for this system to about $41,000 by using the Genetic Algorithm search method.

This final automated sizing takes much longer to run (a few minutes vs. a few seconds previously). Since all the pipes are sized independently, the practical result is that ordering and installing the pipe is more complicated because there are so many more sizes involved.

Alternatively, this sizing could be performed by using weight as the objective instead of monetary cost to simplify the setup. Using a non-monetary objective can result in reduced savings in cases where the energy costs or costs of equipment such as compressors will make up a significant portion of the costs. However, for this natural gas system we are only sizing for the pipes. Though not shown here, changing the objective to pipe weight for this example produces identical results to those shown in Figure 4.12.

CHAPTER 5

Other AFT Arrow ANS Module Capabilities

This Quick Start Guide necessarily omitted coverage of a number of AFT Arrow ANS module capabilities. This chapter briefly describes some of the important capabilities not covered.

Size with operating costs spread over multiple cases

For systems with multiple design cases, the system may operate a significant portion of the time in each design case mode. The ANS module allows one to assign a percentage of the operating cost to each relevant design.

For example, assume you are designing a two-compressor air supply system which uses both compressors in the summer but only one in the winter. The winter operating cost is thus much less than in the summer. You can account for this by assigning the percentage of the time the compressor operates in each design case. This allows a proper accounting of annual operating costs and a proper life cycle automated sizing to be performed.

Vary recurring costs over time

Through "scale tables" the ANS module allows you to input recurring data for pipes or junctions that vary over time. For instance, perhaps the maintenance cost of a piece of equipment is low at first but requires

increased maintenance over some time period. The cost for maintenance can be varied over time to match the anticipated maintenance schedule.

Time value of money

An important consideration in evaluating recurring cost items is the cost of money for future expenses. The ANS module allows you to enter an interest rate and inflation rate to account for actual value of future expenses based on today's currency value. This data is entered in the Sizing Objective panel of the Sizing window.

Determine cost effectiveness of replacing existing pipe

The ANS module can determine the cost effectiveness of leaving existing pipe in place or replacing it with new pipe. This can be defined on the Size/Cost Assignments panel.

Working with different currencies

Cost data can be entered in any currency you wish. Different currencies can be defined in the Parameter and Unit Preferences window, and then used as a basis for cost databases.

Costs vs. size

Scale tables can be used to model how equipment costs vary with pipe diameter. For instance, a 4-inch valve costs more than a similar 2-inch valve. This can be accounted for in the cost database with scale tables.

Generic compressor and fan costs can be modeled as a function of power, and generic control valve costs can be modeled as a function of maximum Cv.

Sizing rectangular duct systems

The ANS module can size systems with only rectangular ducts or a combination of rectangular and cylindrical ducts. Rectangular ducts have

two space dimensions, and thus two design variables are required for each independent duct size.

Compare VFD vs. FCV sized systems

Variable Frequency Drive (VFD) control methods are frequently compared to Flow Control Valve (FCV) methods. However, this is typically only evaluated in the context of a given pipe system. The ANS module allows one to size the system for each of these methods. This allows a more meaningful comparison.

Maximum cost groups

When evaluating multiple operating cases, one of the compressor or fan operating modes will drive the compressor or fan selection for all cases. This is by virtue of the fact that the cost will be based on the mode requiring the most power. This can be modeled in the ANS module with Maximum Cost Groups. A Maximum Cost Group allows one to couple costs together for all compressors or fans that will eventually be of the same design (and thus cost the same). This allows the proper cost information to be used for each design case.

Maximum cost groups can also be used for control valves.

Discrete costs

For sizing items such as compressor motors, a discrete cost table can be created so that the costs will be reported based on the discrete motor sizes available, rather than reporting an interpolated cost, which assumes that motors are available for purchase at any capacity.

Network databases

Engineering and cost databases can be located on local PCs or deployed across local or wide area networks. The Database Manager allows users to connect to relevant databases for their specific pipe system design.

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Additional AFT Arrow Modules

Goal Seek & Control

Identifies input parameters that yield desired output values and simulates control functions

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