Frictional Pressure Drop Modeling Exercise

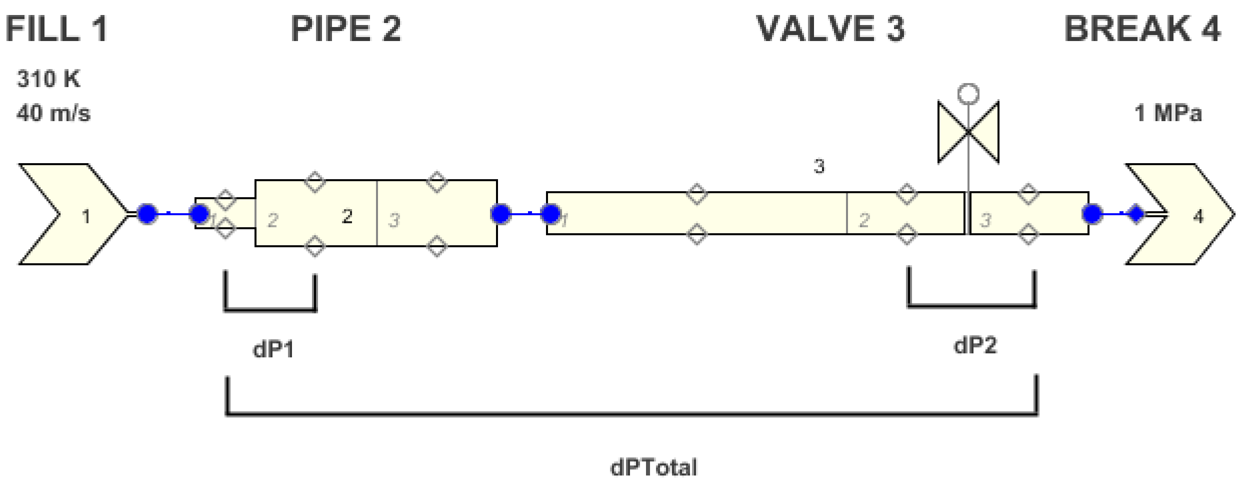
OBJECTIVES

- Illustrate modeling considerations important for correctly simulating frictional pressure drops in TRACE system models.
- Evaluate the influence of the assumed pipe wall roughness on differential pressure.
- Evaluate the influence of reducing the flow area in a system.
- Evaluate the influence of the abrupt area change flow loss.
- Evaluate the influence of flow loss coefficients at an abrupt expansion.
- Evaluate the influence of the TRACE default internal flow loss from a valve component.

MODEL BACKGROUND AND DESCRIPTION

The model represents a simple horizontal piping network for steady, subsonic, adiabatic flow of cold water with a constant outlet pressure boundary condition of 10 bar (in BREAK 4). The features of the model are set up to allow investigations of changes in model parameters affecting the frictional pressure drops and not to represent any particular physical flow network system.

The model and its input are provided below:



Component	L (m)	Vol (m^3)	Acell (m^2)	Aedge (m^2)	Dh (m)	K Loss
FILL 1	1.0	0.2	0.2	0.2	--	--
PIPE 2	1.0	0.2	0.2	0.2	0.5046	0.0
	2.0	2.0	1.0	0.2	1.4616	1.0 + Abrupt
	2.0	2.0	1.0	1.0	1.1284	0.0
				0.4	0.9602	1.0
VALVE 3	5.0	2.0	0.4	0.4	0.9602	1.0
	2.0	0.8	0.4	0.4	0.7136	1.0
	2.0	0.8	0.4	0.2	0.5046	0.0 + Abrupt + VALVE Internal Loss
				0.4	0.7136	0.0
BREAK 4	2.0	0.8	0.4	0.4	--	--

Flow is forced into the left side of the model by FILL 1 at a constant velocity of 40 m/s. Wall friction is calculated using a wall absolute roughness of 4.572e-5 m, which is typical for commercial steel pipe.

The flow through the network encounters an expansion between Cells 1 and 2 of PIPE 2 and a contraction between PIPE 2 and VALVE 3. A constant flow area is used for the three cells of VALVE 3. VALVE Face 3 represents the valve action with a fully-open flow area that is 50% of the adjacent cell flow areas. The valve flow area is held constant at its fully-open position. An abrupt area change flow loss is calculated by TRACE for the expansion in PIPE 2. At the valve face in VALVE 3, the TRACE model input is set up to calculate an abrupt area change flow loss for the contraction/expansion in addition to the default internal flow loss that is associated with flows through valves in general. Constant user-input K loss coefficients are also specified at two other faces of the flow network model.

Control blocks are included to calculate the three differential pressures (in MPa) shown in the diagram:

- dP1 = Control Block 1,
- dP2 = Control Block 2,
- dPTotal = Control Block 3.

This exercise consists of running the base model (Friction.med) to obtain the three differential pressures and then running five variations of the base model (Friction-1, Friction-2, Friction-3, Friction-4 and Friction-5) to evaluate changes in the differential pressure responses to variations in the TRACE model friction-related inputs. The model is run in transient mode for 100 seconds to obtain a steady solution.

An animation model "FrictionAnim.med," which displays the TRACE differential pressure outputs, is available to facilitate extracting data from the multiple TRACE runs. FrictionAnim displays the calculated differential pressures at the end of the run on the animation screen which are the key output parameters from the TRACE runs.

Overview of Steps

1. Friction: Make a Base Calculation
2. Friction-1 Sensitivity Run: Evaluation of the Pipe Wall Roughness
3. Friction-2 Sensitivity Run: Evaluation of the Valve Flow Area
4. Friction-3 Sensitivity Run: Evaluate the Abrupt Area Change Model
5. Friction-4 Sensitivity Run: Evaluate Flow loss Coefficient at Pipe Expansion
6. Friction-5 Sensitivity Run: Evaluate Valve Internal Flow Loss

Step 1 Friction: Make a Base Calculation

1. Locate and double-click on the Friction.med file located in:

   Day2\Morning\TRACE_Modeling_Issues\Friction

2. In the Model Editor click on the Job Submission tab at the bottom of the View canvas.
   1. Assure that the correct code application has been selected
   2. Assure the "FrictionAnim.med" animation model is connected (located in the Day2\Morning\TRACE_Modeling_Issues\Friction folder). The animation shows the differential pressure that will be recorded in the table below.
   3. Click Yes to view the Job Status
   4. Click "Immediately" to Open the animation
   5. turn on the "Start Paused" feature
   6. Demultiplex the plot file
3. Submit the base calculation
   1. Lock the view
   2. Click on the submit button.

4. After the calculation has finished record dP1, dP2, and dPTotal in the table below.

Calculations	dP1 (MPa)	dP2 (MPa)	DPTotal (MPa)
Base case			
Friction-1 (change to smooth wall friction)			
Friction-2 (close valve from 1.0 to 0.8 area fraction)			
Friction-3 (remove abrupt loss at PIPE 2, Face 2)			
Friction-4 (remove 1.0 K loss at PIPE 2 Face 2)			
Friction-5 (remove VALVE 3 internal flow loss)			

Discussion: About 1/3 of the total differential pressure results from the user-input and abrupt area change flow losses at PIPE 2, Face 2 and another 1/3 results from the abrupt area change and default valve internal flow losses (at VALVE 3, Face 3). The remaining 1/3 of the total differential pressure is the combined result of the user-input K loss at the junction between PIPE 2 and VALVE 3, the user-input K loss at VALVE 3 Face 2, and the wall friction pressure drop from flow through PIPE 2 and VALVE 3.

Step 2 Friction-1 Sensitivity Run: Evaluation of the Pipe Wall Roughness

Evaluate the influence of the pipe wall roughness.

1. Implement the following changes to the Friction input model:
   a) Change the wall roughness input for the fluid cells in PIPE 2 from 4.572e-5 m (commercial steel pipe) to 0.0 m (smooth wall)

b) Make the same change to VALVE 3

2. Submit the sensitivity calculation

3. After the calculation has finished record dP1, dP2, and dPTotal in the table above for the Friction-1 sensitivity run.

Discussion: Changing from commercial steel pipe roughness to completely-smooth pipe reduces the total differential pressure for flow through this piping network by only ~2%. The effect would be larger for networks more dominated by wall friction and smaller for networks more dominated by lumped flow losses. **Errors occasionally result from misunderstanding that a "smooth wall" and a "frictionless wall" are not the same thing.** Considerable pressure drop can result even if the wall is completely smooth while no pressure drop results if the wall is modeled to be frictionless.

> Frictionless walls can be set with Options NFF = 0 and NFF = -100. In SNAP, these options are called the Friction Factor Correlation Option for a component and are found under the Friction tab within the Properties Window.

As an aside, it was found that changing from smooth wall to a frictionless wall results in an additional ~3% reduction in total pressure drop. The differential pressure for the piping network used in this example problem is therefore dominated by the lumped flow losses and not by the wall friction loss.

Step 3 Friction-2 Sensitivity Run: Evaluation of the Valve Flow Area

Evaluate the influence of reducing the valve flow area.

1. Implement the following changes to the Friction input model:

   a) Add back the wall roughness of 4.572e-5 m to PIPE 2 and VALVE 3.

   b) Change the initial flow area fraction (i.e. the normalized valve face area) in VALVE 3 from 1.0 to 0.8.

Note that because the valve is held at its initial position, this effectively reduces the valve face area from 50% to 40% of the adjacent VALVE 3 cell flow areas throughout the transient calculation

4. Submit the sensitivity calculation
5. After the calculation has finished record dP1, dP2, and dPTotal in the table above for the Friction-2 sensitivity run.

Discussion: A relatively small (20%) reduction in the valve flow area results in a large (~102%) increase in the differential pressure across the valve face. The velocity at the valve face increases by 25% (1.0/0.8) which, for a constant flow loss coefficient, is expected to result in an increase in the differential pressure across the valve face of approximately 56% ($1.25^2 - 1.0^2$). The remaining approximately 46% of the valve face differential pressure increase results from the TRACE-calculated abrupt area change and default valve internal flow losses, which are not constant but increase along with the reduction in the valve face flow area.

Step 4 Friction-3 Sensitivity Run: Evaluate the Abrupt Area Change Model

Evaluate the influence of removing the abrupt area change flow loss calculated at the expansion in PIPE 2.

1. Increase the valve flow area fraction back to 1.0.

2. Implement the following changes:

   a) Remove the optional TRACE-calculated abrupt area change flow loss specified in the base model for the expansion between Cells 1 and 2 of PIPE 2 (i.e. Cell Edge 2). This is accomplished in the Friction input (SNAP) of PIPE 2.

> Note that this change can be done by clicking in the cell edge 2 box, expanding the cell edge options and selecting [1] Flow Factor + FRIC or by copying that option in fro another cell face that contains the same option.

3. Submit the sensitivity calculation

4. After the calculation has finished record dP1, dP2, and dPTotal in the table above for the Friction-3 sensitivity run.

<u>Discussion</u>: Because the differential pressure across the expansion at PIPE 2, Face 2 significantly declined in this calculation, the total loss at this face appears to be dominated by the TRACE-calculated abrupt area change flow loss. Removing the abrupt loss lowers dP1 by ~93%. This result seems questionable because the wall friction and K = 1.0 losses at PIPE 2, Face 2 remain in the model, suggesting that the TRACE calculated abrupt area change K loss coefficient is >>1.0. That large of a loss coefficient is unreasonable because the K loss for an infinite expansion is only 1.0 and (using handbook data) the K loss for a flow area expansion from 0.2 m^2 to 1.0 m^2 is approximately 0.92.

STEP 5 FRICTION-4 SENSITIVITY RUN: EVALUATE FLOW LOSS COEFFICIENT AT PIPE EXPANSION

Evaluate the influence of removing the user supplied flow loss of K = 1.0 at the expansion in PIPE 2.

1. Reinstate the abrupt area change model at Cell Edge 2 of PIPE 2.
2. Change the user supplied k-loss of 1.0 to 0.0 at Cell Edge 2 of PIPE 2.
3. Submit the sensitivity calculation
4. After the calculation has finished record dP1, dP2, and dPTotal in the table above for the Friction-3 sensitivity run.

Discussion: The cause for the difficulty in resolving the results seen in Step 3 now becomes clear. Removing the K = 1.0 flow loss (and leaving the abrupt area change model active) results in a *negative* value for dP1. In other words, the pressure upstream of the expansion face is lower than the pressure downstream of the expansion face. Note from the animation mask, the liquid velocity upstream of the expansion (40 m/s) is 5 times higher than the velocity downstream of the expansion (8 m/s). The TRACE-calculated cell pressures include velocity head effects and the slowdown of the flow as it passes through the expansion results in an increase in the downstream pressure, which causes dP1 to become negative in the Step 4 sensitivity calculation. The pressure increase caused by slowing the flow from 40 m/s to 8 m/s is estimated to be:

$$\text{Delta Pressure} = 0.5 \text{ X } 995 \text{ kg/m}^3 \, (40^2 \text{ m}^2/\text{s}^2 - 8^2 \text{ m}^2/\text{s}^2) = 764{,}160 \text{ Pa} = 0.764 \text{ MPa}$$

The conclusion is that consideration of velocity head effects is significant for the evaluation of pressure drop effects in this simple test problem.

Depending on specific flow network configurations and flow conditions, considerations related to elevation head effects also have a potential to be significant. One can see that sensitivity and hand calculation evaluations of two-phase problems (involving separate liquid and vapor phase velocities) can be expected to be particularly difficult.

Step 6 Friction-5 Sensitivity Run: Evaluate Valve Internal Flow Loss

Evaluate the influence of removing the TRACE default internal flow loss from the VALVE component. All TRACE valves include an internal flow loss coefficient. This internal flow loss can be toggled on or off.

1. Reinstate the user input flow loss coefficient of K = 1.0 at Cell Edge 2 of PIPE 2
2. Remove the default valve internal flow loss from the VALVE component.
   a) Highlight the VALVE 3 component in the view window of the Friction SNAP file.
   b) In the component navigator window locate the Internal loss model box and toggle the model off.
   c) Note that by toggling off the internal loss requires the user to input values into a Form Loss Table. Input a small form loss coefficient (1.0e-6).
3. Submit the sensitivity calculation
4. After the calculation has finished record dP1, dP2, and dPTotal in the table above for the Friction-3 sensitivity run.

Discussion: Removing the valve default internal flow loss reduces the differential pressure across the valve face by 91% (from 0.435 MPa to 0.037 MPa). The effective default flow loss coefficient (**K_{eff}**) is estimated as follows:

> Removing the default internal loss lowered the differential pressure across the valve face by 0.435 – 0.037 = 0.398 MPa.
>
> The fluid density and velocity at the valve face are 995 kg/m^3 and 40 m/s, respectively.
>
> The differential pressure is: $0.5 * K_{eff} * 995\ kg/m^3 * (40\ m/s)^2 = 398000\ Pa$

Thus the $\mathbf{K_{eff}}$ is:

$\mathbf{K_{eff} = 0.5}$, based on the 0.2-m^2 full-open valve face area.

The conclusion is that it is important to recognize the valve default internal flow loss coefficient can be significant and to consider that when determining what additional flow loss coefficients should be included in the valve model. The significance of the valve default internal flow loss grows as the valve face area is reduced below the flow areas of the adjacent cell faces and the velocity at the valve face increases.

Additionally, the 91% reduction in the differential pressure at the valve face from removing the default internal flow loss is surprising because the TRACE abrupt area change model is also active at the valve face. The remaining pressure drop of 0.037 MPa at the valve face looks to result only from wall friction, therefore suggesting that there is no abrupt area change flow loss included in the model. Rerunning the Step 5 model with the abrupt area change model disabled at the valve face does not change the results. This demonstrates that the TRACE abrupt area change model requires that there be an area change between the upstream and downstream *cells*, not just at the connecting *face* between the cells in order for a flow loss to be calculated.

Calculations	dP1 (MPa)	dP2 (MPa)	DPTotal (MPa)
Base case	0.548	0.435	1.566
Friction-1 (change to smooth wall friction)	0.545	0.420	1.542
Friction-2 (close valve from 1.0 to 0.8 area fraction)	0.547	0.878	2.009
Friction-3 (remove abrupt loss at PIPE 2, Face 2)	0.039	0.435	1.058
Friction-4 (remove 1.0 K loss at PIPE 2 Face 2)	-0.247	0.435	0.772
Friction-5 (remove VALVE 3 internal flow loss)	0.548	0.037	1.169