Chapter 7 of [4] outlines a steady state thermal analysis of an assumed pipeline junction. Here alternate points of view and additional post-processing features will be presented. The first difference is to recognize that the geometry, material properties and boundary conditions have a plane of symmetry. Therefore, a half model can be employed. That lets the full mesh be efficiently applied to non-redundant results. The half model is seen in Figure 1, where each pipe hot end surface has been color coded light red, the original interior is green, and the material exposed on the symmetry plane is in yellow. This is one of those problems where the temperature solution depends only on the geometry and is independent of the material used. The actual material is brass and its thermal properties from the material library files are listed in Figure 2. Of course, the heat flux vectors and the thermal reactions will always depend on the thermal conductivity, $k$.

![Figure 1](image1.png)

![Figure 2](image2.png)

Most experimental properties are known only to two or three significant figures. However, the library table values can be misleading because the properties sometimes were measured in a different set of units and multiplied by a conversion factor and incorrectly displayed to 7 or 8 significant figures. Here the conductivity of brass is displayed (Figure 2, top) in its experimentally measured units as $k = 110$ W/m-K, but had you used English units it would be converted and displayed (Figure 2, bottom) to 8 significant figures instead of a realistic value of about $k = 1.47e-3$ BTU/in-s-F.
This pipe junction has four sets of restraints, or “essential boundary conditions”, where the temperature is specified at each pipe end ring surface. The first is applied by selecting the hottest end area and assigning it a given value of 400 C. The other three ends are treated in a similar way. The first restraint is illustrated in Figure 3 (left). That figure also shows that the default restraint names have been replaced with more meaningful ones. That practice often saves time later when a problem has to be reviewed.

![Figure 3](image)

The boundary condition on the (yellow) symmetry plane must be introduced to account for the removed material. Since it is a plane of symmetry it acts as a perfect insulator. That is, there is no heat flow normal to the plane ($q_n \equiv 0$). That is the “natural boundary condition” in a finite element analysis and is automatically satisfied. The original interior surface also has not yet been specifically addressed. Neither has the remaining exterior (gray) surface. They both also default to insulated (or adiabatic) surfaces having no heat flow across them. That is probably not realistic and convection conditions there will be considered later in the appendix. All that remains is to generate a mesh, compute the temperatures and post-process them.

The automatic mesh generator does a good job. When the solution is run the default temperature plot (in Figure 4) shows two hot pipe regions and two cooler ones. However, in the author’s opinion, the default continuous color plots hide some useful engineering checks of the temperatures. Therefore, in Figure 5, the plot settings are changed to first show discrete color bands. The new inner and outer surface temperature displays are seen in Figure 6. They make it a little easier to check that the contours are perpendicular to the flat symmetry plane, and nearly parallel to surfaces having constant temperatures. Another alternative is to change the settings to line contours to obtain the results of Figure 7. You can also change the number of color segments to reduce or increase the number of contours lines displayed in either mode.
It is common to make technical reports more specific by graphing the results along selected lines or curves. That is done by utilizing the “List Selected” option after the temperature has been plotted. Then you select an edge, of model split line, pick update and then plot. The selected line, at an inner edge adjacent to the hottest inlet (and seen previously in Figure 6), is seen in Figure 8. The resulting temperature graph versus the non-dimensional position along the line is given on the left in Figure 9, while its continuation along the curved cylinder intersection curve is shown on the right.

Since there is no convection, heat generation, or non-zero heat flux conditions the temperature results and contours are the same for all materials. However, the heat flux does change magnitude with different materials.
The heat flux magnitude contours are given in Figure 10 (left). The contour lines are less smooth than the previous ones for the temperature because the heat flux is always less accurate than the temperatures. Had these contours shown larger wiggles it would be a signal that a finer mesh should be utilized. Since the heat flux is a vector quantity it should also be plotted as a vector. That setting change is also shown on the right in Figure 11. The resulting vector plot is shown in Figure 11 (after changes with “Vector Plot Options”). The heat flux vectors show that heat flows into the junction at the 400 C surface and out at the 80 and 100 C ends. The 250 C end has some inflow and some heat outflow.
Here you can also have CosmosWorks compute the thermal reactions necessary to maintain the specified temperatures. To do that use the “List selected” option and select each of the four pipe ends in order. At each one, you pick update to list and sum all the individual nodal heat flux values. Figure 12 shows those four total heat flows. They show that about 850 W of power in at the two hottest surfaces and out the two coolest pipe ends. Since a half symmetry model was used here, that figure
needs to be doubled to determine the required input power of about 1700 W to maintain the specified temperature restraints. If the current example were changed to steel with a conductivity of about \( k = 51.9 \text{ W/m-K} \) then the heat flux magnitudes and required power would drop by about a factor of two while the temperature distribution would be unchanged.

**References**

Appendix: Adding convection

Convection conditions or known heat flow on the boundaries will change the temperature distribution in the original problem. To illustrate this point, assume the outer surface convects to air at a temperature of 30°C (303 K) with a convection coefficient of about $h = 5 \text{ W/m}^2$. Also let the pipe interiors convect to oil at 70°C (343 K) with an assumed convection coefficient of about 600 W/m². You simply have to apply two convection conditions (seen in Figure 13), and recomputed the solution.

Figure 13
The resulting discrete temperatures are shown in Figure 14. There are steeper temperature gradients than seen in Figure 6 of the original problem. Likewise, the original graph of temperatures in Figure 9 shows less temperature drop than the new graph in Figure 15. The new heat flux vectors are given in Figure 16. There you note that the location of the maximum heat flux has changed. If you again compute the reaction heat flow (given in Figure 17) you need 2 * 2070 W/s = 4140 w/s.