

Interactive SS-T-CONDUCT Software

The **SS-T-CONDUCT** (Steady State and Transient Heat Conduction) software was developed by Ghajar and his co-workers and is available from the online learning center (www.mhhe.com/cengel) to the instructors and students. The software is user-friendly and can be used to solve many of the one- and two-dimensional heat conduction problems with uniform energy generation in rectangular geometries discussed in this chapter. For transient problems the explicit or the implicit solution method could be used. The software has the following capabilities:

- (a) Full and easy control of key numerical parameters (nodes and grids), material properties, and boundary conditions and parameters.
- (b) The effect of parameter changes on the temperature distribution can be instantly viewed.
- (c) The effect of stability criterion (Fourier number) for the explicit method can be explored.
- (d) Several different ways of viewing the results on the screen or in print (output file):
 - Temperature results in a tabular form.
 - Temperature plots with time and distance for one-dimensional steady state and transient problems.
 - Shaded temperature plots for two-dimensional steady state problems.
 - Animation of shaded temperature plots for two-dimensional transient problems.
- (e) A library of material properties (thermal conductivity and thermal diffusivity) built in the software. With this feature the effect of material property on the nodal temperatures can be explored.

The current version of the software has the following limitations:

- (a) Rectangular geometries, expressed in Cartesian coordinates may be modeled.
- (b) Uniform grid spacing.
- (c) Boundary conditions for constant temperature, constant heat flux, and constant convection heat transfer coefficient.

The use of the software in solving heat conduction problems is illustrated in Examples 5–8 and 5–9.

EXAMPLE 5-8 Application of SS-T-CONDUCT Software to a Transient One-Dimensional Heat Conduction Problem

Solve Example 5-5 with the use of the SS-T-CONDUCT software.

SOLUTION On the SS-T-CONDUCT Input window, select the **1-Dimensional Transient Problem** tab (item (a) in Fig. 5-56). Enter the problem parameters in the appropriate text boxes listed in the **Problem Parameters** box (item (b) in Fig. 5-56).

To compute the nodal temperatures using the explicit method, the **explicit** scheme radio button is selected (item (c) in Fig. 5-56). The boundary conditions for this problem are specified in the **Boundary Conditions** box (item (d) in Fig. 5-56). The left boundary condition is entered in the **Left BC** box and the right boundary condition is entered in the **Right BC** box (items (e) and (f) in Fig. 5-56). Once all the necessary inputs are entered, the results are computed by clicking on the **Calculate Temperature** button (item (g) in Fig. 5-56).

The computed results are presented in the SS-T-CONDUCT **Tabular Output** window (Fig. 5-57). The nodal temperatures are tabulated as indicated by item (a) in Fig. 5-57a. As expected, the nodal temperatures match well with the values listed in Table 5-3.

To compute the nodal temperatures using the implicit method, the **implicit** scheme radio button should be selected in Fig. 5-56. Once again the temperature versus time results at different locations are comparable to the values listed in Table 5-4. This can be seen by viewing the temperature versus time for location $x = 0.04$ m shown in Fig. 5-57b. The graphical output was obtained by selecting the **Graphical Output** tab and the desired x location from the drop-down list (item (a) in Fig. 5-57b).

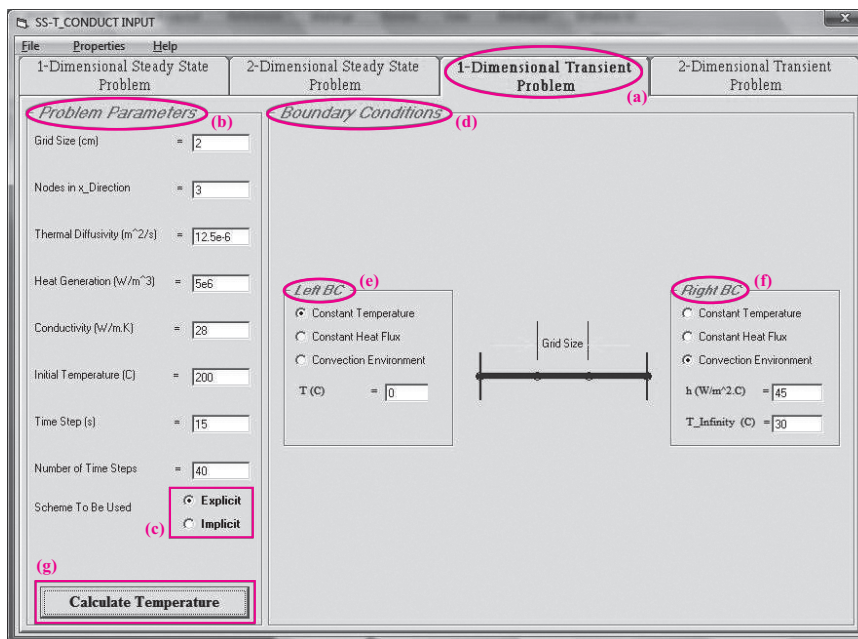
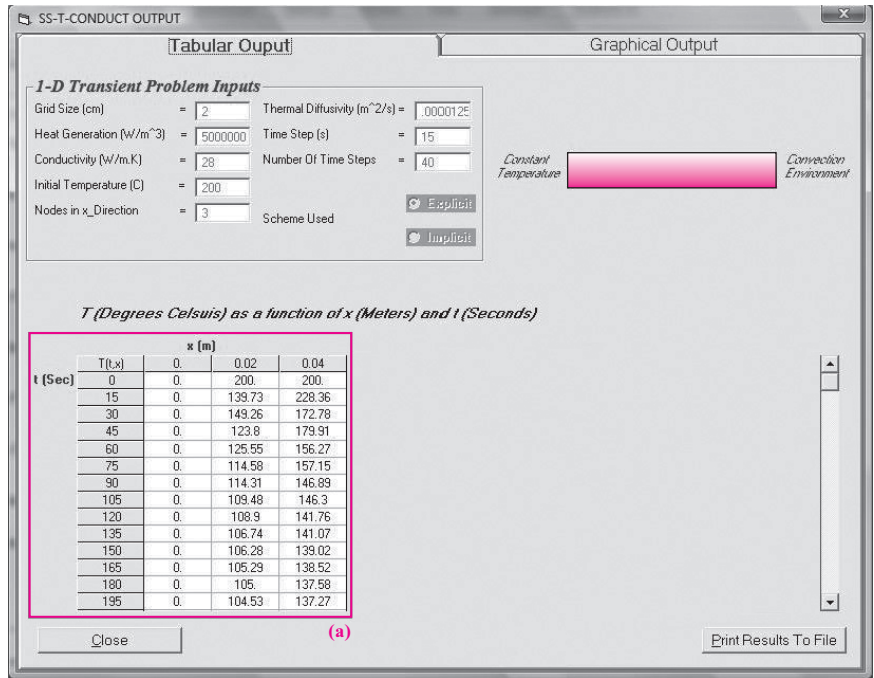
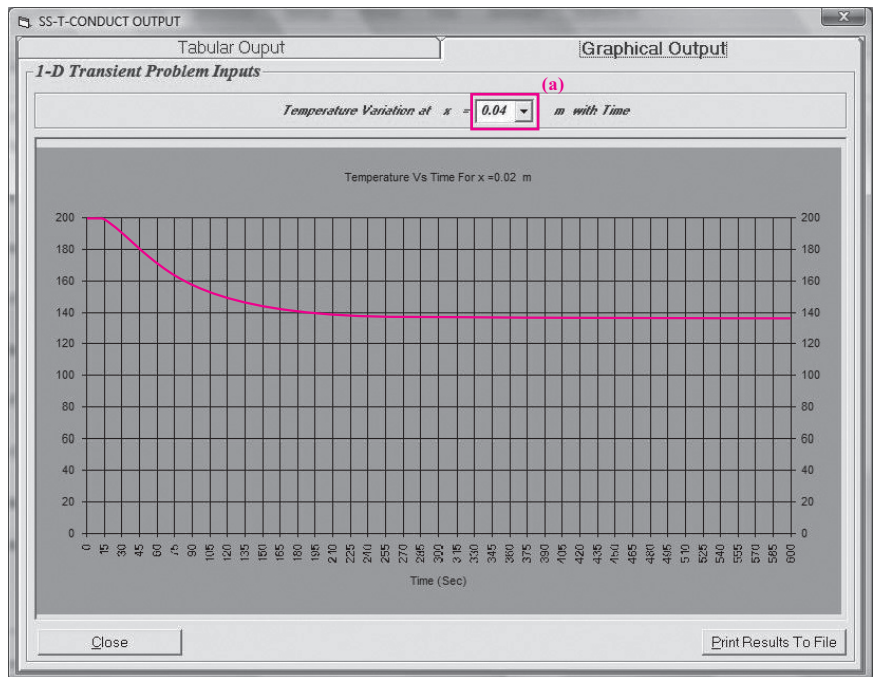


FIGURE 5-56
The SS-T-CONDUCT Input window



(a) Tabular Output window for explicit method



(b) Graphical Output window for implicit method

FIGURE 5-57

The SS-T-CONDUCT Tabular and Graphical Output windows

Discussion The limitation on the time step of the explicit method can be explored by simply changing the time step in item *a* of Fig. 5–56. The stability criterion for this problem requires a maximum time step of 15.5 s. By using time steps much larger than 15.5 s, the solution for the nodal temperatures will oscillate and at times become negative (violating the second law of thermodynamics). One can also see that no matter what time step is used for the implicit method, the solution remains stable.

EXAMPLE 5–9 Application of SS-T-CONDUCT Software to a Transient Two-Dimensional Heat Conduction Problem

Consider a long solid bar ($k = 28 \text{ W/m}\cdot\text{K}$ and $\alpha = 12 \times 10^{-6} \text{ m}^2/\text{s}$) of square cross section that is initially at a uniform temperature of 20°C (Fig. 5–58). The cross section of the bar is $20 \text{ cm} \times 20 \text{ cm}$ in size, and heat is generated in it uniformly at a rate of $\dot{e} = 8 \times 10^5 \text{ W/m}^3$. All four sides of the bar are subjected to convection to the ambient air at $T_\infty = 30^\circ\text{C}$ with a heat transfer coefficient of $h = 45 \text{ W/m}^2\cdot\text{K}$. Using the explicit finite difference method with a mesh size of $\Delta x = \Delta y = 10 \text{ cm}$, determine the temperature at the center of the bar (a) after 20 min and (b) after steady conditions are established.

SOLUTION A long solid bar is subjected to transient heat transfer. The center temperature of the bar after 20 min and after steady conditions are established are to be determined.

Assumptions 1 Heat transfer through the body is given to be transient and two-dimensional. 2 Thermal properties are constant. 3 Heat is generated uniformly in the body.

Properties The conductivity and diffusivity are given to be $k = 28 \text{ W/m}\cdot\text{K}$ and $\alpha = 12 \times 10^{-6} \text{ m}^2/\text{s}$.

Analysis The nodal spacing is given to be $\Delta x = \Delta y = l = 0.1 \text{ m}$. The explicit finite difference equations are determined on the basis of the energy balance for the transient case expressed as

$$\sum_{\text{All sides}} \dot{Q}^i + \dot{e}V_{\text{element}} = \rho V_{\text{element}} c_p \frac{T_m^{i+1} - T_m^i}{\Delta t}$$

There is symmetry about the vertical, horizontal, and diagonal lines passing through the center. Therefore, $T_1 = T_3 = T_7 = T_9$ and $T_2 = T_4 = T_6 = T_8$, and T_1 , T_2 , and T_5 are the only three unknown nodal temperatures. Thus, the finite difference equations for nodes 1, 2, and 5 are the only equations needed to determine all the nodal temperatures. Using similar methodology discussed in Example 5–7, the finite difference equations are

$$\text{Node 1: } T_1^{i+1} = \left(1 - 4\tau - 4\tau \frac{hl}{k}\right) T_1^i + 2\tau \left(2T_2^i + 2\frac{hl}{k} T_\infty + \frac{\dot{e}_1 l^2}{2k}\right)$$

$$\text{Node 2: } T_2^{i+1} = \left(1 - 4\tau - 2\tau \frac{hl}{k}\right) T_2^i + \tau \left(2T_1^i + 2T_5^i + 2\frac{hl}{k} T_\infty + \frac{\dot{e}_2 l^2}{k}\right)$$

$$\text{Node 5: } T_5^{i+1} = (1 - 4\tau)T_5^i + \tau \left(4T_2^i + \frac{\dot{e}_5 l^2}{k}\right)$$

Next we need to determine the upper limit of the time step Δt from the stability criterion, which requires the coefficient of T_m^i in the T_m^{i+1} expression

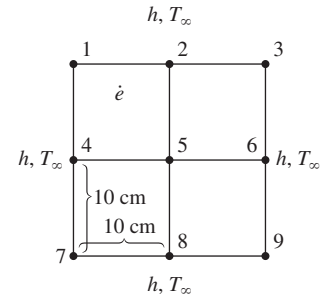


FIGURE 5–58

Schematic and nodal network for Example 5–9.

(the primary coefficient) to be greater than or equal to zero for all nodes. The smallest primary coefficient in the nine equations here is the coefficient of T_1^i in the T_1^{i+1} expression, and thus the stability criterion for this problem can be expressed as

$$1 - 4\tau - 4\tau \frac{hl}{k} \geq 0 \quad \rightarrow \quad \tau \leq \frac{1}{4(1 + hl/k)} \quad \rightarrow \quad \Delta t \leq \frac{l^2}{4\alpha(1 + hl/k)}$$

since $\tau = \alpha\Delta t/l^2$. Substituting the given quantities, the maximum allowable value of the time step is determined to be

$$\Delta t \leq \frac{(0.1 \text{ m})^2}{4(12 \times 10^{-6} \text{ m}^2/\text{s})[1 + (45 \text{ W/m}^2\cdot\text{K})(0.1 \text{ m})/(28 \text{ W/m}\cdot\text{K})]} = 179 \text{ s}$$

Therefore, any time step less than 179 s can be used to solve this problem. For convenience, let us choose the time step to be $\Delta t = 60 \text{ s}$. Then the mesh Fourier number becomes

$$\tau = \frac{\alpha\Delta t}{l^2} = \frac{(12 \times 10^{-6} \text{ m}^2/\text{s})(60 \text{ s})}{(0.1 \text{ m})^2} = 0.072 \quad (\text{for } \Delta t = 60 \text{ s})$$

Using the specified initial condition as the solution at time $t = 0$ (for $i = 0$), sweeping through the 3 finite difference equations will give the solution at a time step of 60 s.

The solution at the center node (node 5) can also be determined using the SS-T-CONDUCT software. On the SS-T-CONDUCT Input window, select the **2-Dimensional Transient Problem** tab (item (a) Fig. 5–59). Enter the problem

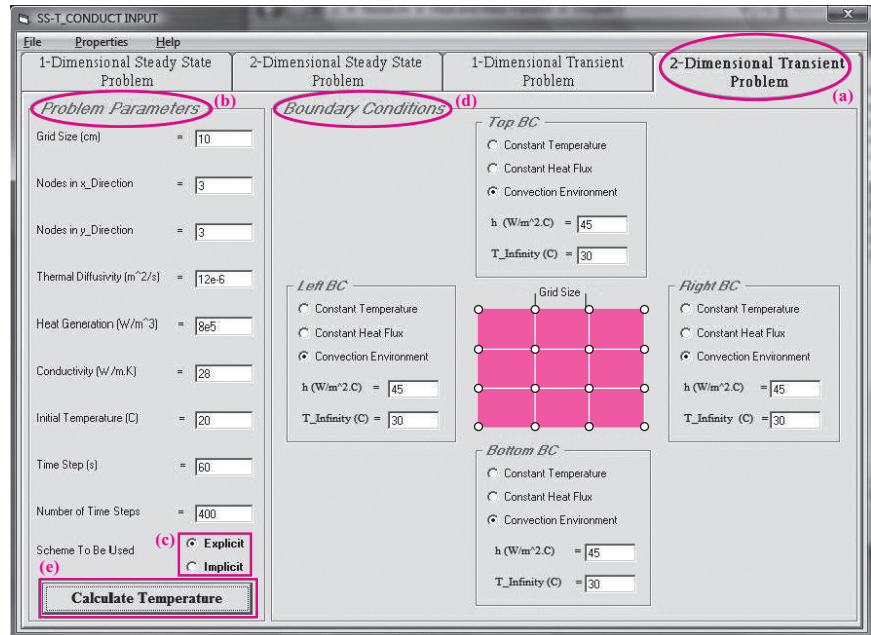
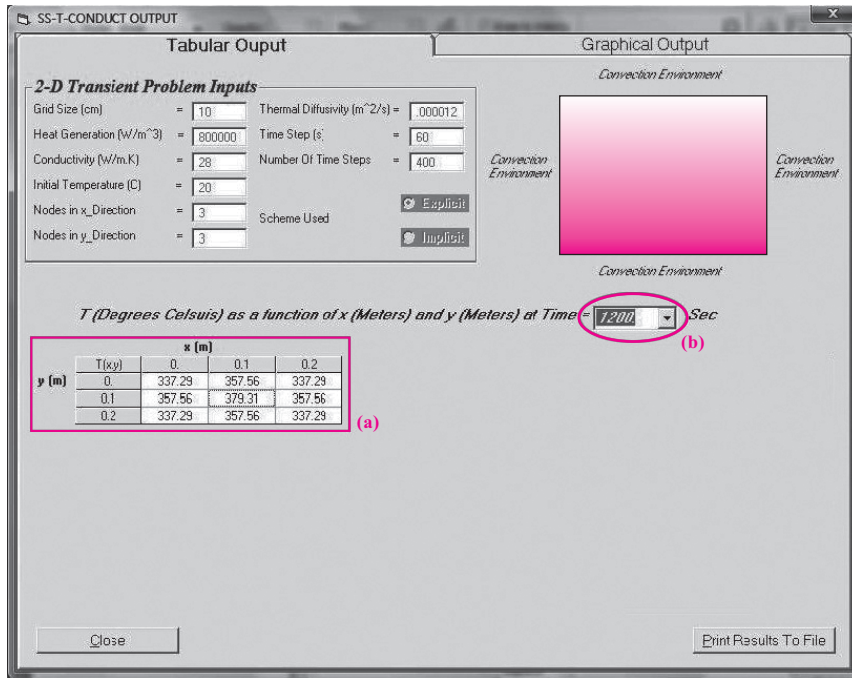
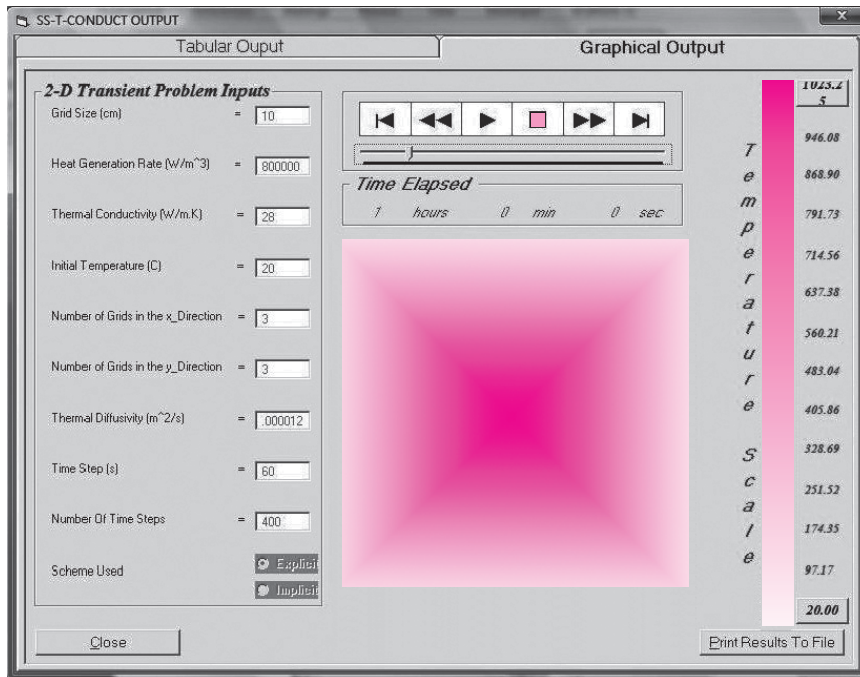


FIGURE 5–59
The SS-T-CONDUCT Input window for 2-Dimensional Transient Problem



(a) The SS-T-CONDUCT Tabular Output window



(b) The SS-T-CONDUCT Graphical Output window

FIGURE 5-60
 The SS-T-CONDUCT Tabular and Graphical Output windows

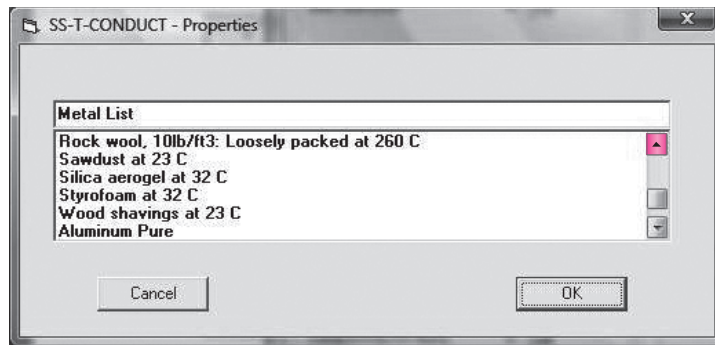


FIGURE 5-61

The SS-T-CONDUCT material properties list

parameters in the appropriate text boxes listed in the **Problem Parameters** box (item (b) in Fig. 5-59).

To compute the nodal temperatures using the explicit method, the **explicit** scheme radio button is selected (item (c) in Fig. 5-59). The boundary conditions for this problem are specified in the **Boundary Conditions** box (item (d) in Fig. 5-59). Once all the necessary inputs are entered, the results are computed by clicking on the **Calculate Temperature** button (item (e) in Fig. 5-59).

The computed results are presented in the SS-T-CONDUCT **Tabular Output** window (Fig. 5-60a.) The nodal temperatures are tabulated as indicated by item (a) in Fig. 5-60a. The temperature at the center of the bar after 20 min (or 1200 s) is **379.31°C**. The solution at different times can be viewed by selecting from the drop-down list (item (b) in Fig. 5-60a). In doing so, the temperature at the center of the bar, after steady conditions are established, is determined to be **1023°C**, after about 6 hours.

To view the graphical output, select the **Graphical Output** tab and the temperature contour for this problem is presented (Fig. 5-60b). User may view the temperature contour at different time by controlling the slider bar.

Discussion The SS-T-CONDUCT software also has a built-in feature for user to choose the properties (thermal conductivity and thermal diffusivity) of various materials or explore the influence of properties of different materials on the nodal temperatures. To select a material, click on the **Properties** menu on the menu bar on the SS-T-CONDUCT Input window (Fig. 5-59) to see the available list of materials (Fig. 5-61).