JAVA-BASED HEAT TRANSFER VISUALIZATION TOOLS

HAISHAN ZHENG, JASON M. KEITH
Michigan Technological University • Houghton, MI 49931

There have been extensive technological advances in computer technology applied to engineering education, but one area that has yet to develop fully in this capacity is use of the World Wide Web. In this manuscript, we describe two particular JAVA applet programs that were developed to simulate the classical problem of transient conduction/diffusion within a solid. A student who uses the tools can capture the basic principles of heat or mass transport by observing the dynamic phenomena and exploring the effect of changing problem parameters on the solution. The applets and sample problems are available at <http://www.chem.mtu.edu/~jmkeith/webtools/>.

DESCRIPTION OF JAVA APPLETS

One-Dimensional Unsteady-State Heat Conduction Movie

Heat conduction is a key concept in transport phenomena because of the large number of heating and cooling problems occurring in industrial processes. It is also analogous to many cases of mass diffusion. The classic example presented in textbooks is unsteady-state heat conduction in various geometries, but to estimate a local temperature, a student must either refer to a cumbersome analytical solution containing an infinite series or interpolate data from charts. Usually, the student fails to visualize the actual heat-transfer process.

Consider unidirectional unsteady-state heat transfer in an object with constant material properties. The object is initially at a uniform temperature T_0. At time $t = 0$, the object is exposed to an environment at temperature T_1. If the object is a slab of thickness 2L, the thermal energy conservation model balances the accumulation of thermal energy with heat conduction by

$$\rho C_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2} \tag{1}$$

subject to the following boundary and initial conditions:

$$\text{at } t = 0 \qquad\qquad T = T_0 \tag{2}$$

$$\text{at } x = 0 \qquad\qquad \frac{\partial T}{\partial x} = 0 \tag{3}$$

$$\text{at } x = L \qquad h(T - T_1) = -k \frac{\partial T}{\partial x} \tag{4}$$

Similar models can be developed for a long cylinder and for a sphere.

As can be seen in Figure 1, this applet has an easy-to-follow graphical user interface (GUI) design. To use the applet, the student first chooses the geometry where heat conduction occurs (slab, cylinder, or sphere) and enters a set of initial

Haishan Zheng *is a PhD candidate in chemical engineering at Michigan Technological University. He received his BS in 1993 and his MS in 1996 from Beijing University of Technology, China. Before studying at Michigan Technological University, he worked as a chemical engineer at Guangdong Petrol-Chemical Research Institute in China.*
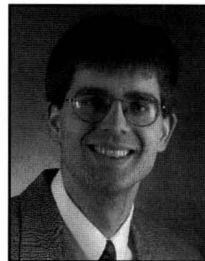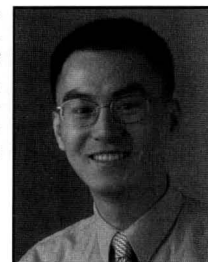
Jason Keith *is Assistant Professor of Chemical Engineering at Michigan Technological University. He received his BS in chemical engineering in 1995 from the University of Akron and his PhD from the University of Notre Dame in 2000. He teaches transport phenomena, reactor design, and a project-based elective design course in alternative fuels and fuel cells.*

conditions and parameters. The software automatically computes the following quantities:

- *Biot number (Bi = hL/k), the only dimensionless parameter in this system. This allows the user to determine if external convection or internal conduction is the dominating heat-transfer process.*

- *The characteristic time for thermal diffusion, $t_c = L^2/(k/\rho C_p)$. This allows the user to estimate the time for the solid to reach thermal equilibrium with its environment.*

The simulation can be started, paused, or stopped by pressing the appropriate button. The most unique feature of this applet is that a colored bar represents the cross section of the slab and a colored circle represents the cross section of a cylinder or a sphere. The color is graduated to represent temperatures between T_0 and T_1. A red color (R = 255, G = 0, and B = 0) always represents the higher temperature between T_0 and T_1, and blue (R = 0, G = 0, and B = 225) always represents the lower temperature. Therefore, there are two instances for the color representing any temperature, T, between T_0 and T_1. (Although Figure 1 is shown in grayscale here, the online applet shows the colors.)

If

$$T_0 > T_1 \quad R = 225 \times \frac{T_1 - T}{T_1 - T_0} \quad G = 0 \quad B = 255 \times \left(1 - \frac{T_1 - T}{T_1 - T_0}\right) \quad (5)$$

If

$$T_0 < T_1 \quad R = 225 \times \left(1 - \frac{T_1 - T}{T_1 - T_0}\right) \quad G = 0 \quad B = 255 \times \frac{T_1 - T}{T_1 - T_0} \quad (6)$$

To further strengthen the visual effect, the temperature profile is shown below the color bar.

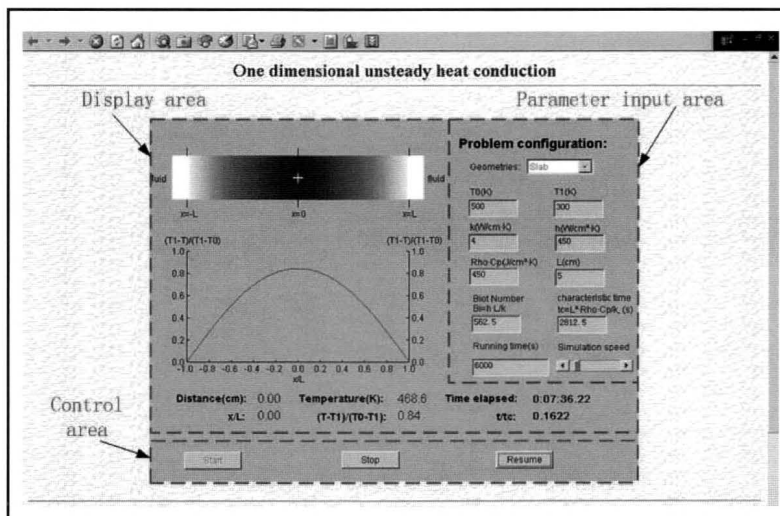Another novel feature of this applet occurs when the simulation is

In this manuscript, we describe two particular JAVA applet programs that were developed to simulate the classical problem of transient conduction/diffusion within a solid. . . [The students] seemed to enjoy using the applets and to better understand the concept of transient heat conduction. They also felt motivated to simulate some different problems by changing the parameters.

paused—the cursor can then be placed within the color bar or circle and the program outputs the dimensional distance (x), the temperature (T), and the time elapsed (t) as well as the corresponding dimensionless quantities ($x^* = x/L$, $T^* = (T_1 - T)/(T_1 - T_0)$, and $t^* = t/t_c$).

The input parameter interface allows the student to input different heat transfer coefficients, thermal conductivities, and heat capacities. The user can also enter dimensionless parameters in one of two ways: 1) enter values as length L = 1, thermal capacity $\rho C_p = 1$, thermal conductivity k = 1, and heat transfer coefficient h = Bi. The final time chosen would then be an increment of the characteristic thermal diffusion time t_c; 2) the user can directly enter the Biot number and characteristic thermal diffusion time t_c. In either case, the dimensionless initial temperature, $T_0 = 1$, and fluid temperature, $T_1 = 0$, should be entered.

Students can learn how these parameters affect the heat conduction by comparing simulation results. For example, they can verify when the internal resistance is negligible (Bi < 0.1), which is the classical low Biot number approximation that students encounter in most undergraduate heat-transfer textbooks, sometimes without much justification. The student can also show that the temperature profile of a slab of width w at time t is identical to that for a slab of width 2w at time 4t when the Biot number is constant, which is the classical result showing the power of dimensionless groups.

Heisler Charts

for Unsteady-State Heat Transfer[1]

Infinite series solutions are available for the heat-conduction problem given by Eqs. (1) through (4). These solutions are presented graphically in Heisler charts in Textbooks,[1] but an online implementation is easier to use because of JAVA's power to determine the exact coordinates on the graph.

Figure 1. *Screenshot of the unsteady-state heat conduction applet.*

Figure 2 shows the GUI of this applet. The user can choose a slab, a cylinder, or a sphere and can also adjust the key parameters m (m is the inverse of the Biot number, m = k/hL) and n (a dimensionless distance, n = x/L). These parameters are also used in the charts in Geankoplis.[1] A user can directly enter the desired value of m or n in the text field or increase/decrease the value by pressing the buttons. Unlike the charts in the textbook that show many lines simultaneously, the JAVA chart shows only one line at a time. More importantly, the user does not need to interpolate between lines on the chart as is often the case in the textbook.

This applet also allows the student to move the graph by pressing the "Up," "Down," "Left," or "Right" buttons. As can be seen in Figure 3, double-clicking the chart calls up an axes-properties dialog box. This allows the student to zoom in and out on the graph. Another distinct advantage of this applet is that the student can obtain the values of the dimensionless time, $X = t/t_c$, and the dimensionless temperature, $Y = (T_1 - T)/(T_1 - T_0)$, from the X and Y text field simply by moving the cursor to the desired position on the line. This applet can also be used as a calculator. A relative value of X can be obtained by entering a value in the Y text field and pressing "Enter," and vice versa.

IMPACT ON LEARNING

The web-based tools create possibilities for students to learn effectively. Felder[2] gives a good review of four learning-style models (Myers-Briggs Type Indicator, Kolb's Learning Style Model, Hermann Brain Dominance Instrument, and the Felder-Silverman Learning Style Model). The Kolb Learning Style Model separates students into those taking in information by either *concrete experience* or *abstract conceptualization* and internalizing information by *active experimentation* or *reflective observation*.[3-6] These two preferences give way to four learning types:

- Concrete and reflective (answers the question, *"Why?"*)
- Abstract and reflective (answers the question, *"What?"*)
- Abstract and active (answers the question, *"How?"*)
- Concrete and active (answers the question, *"What if?"*)

Felder[2] states that traditional engineering instruction (lecturing on the basic information and methods associated with a particular topic) almost exclusively teaches to the abstract and reflective. Having access to web-based tools allows students to work on a problem and learn by trial-and-error without concern for failure (answering the question, *"How does*
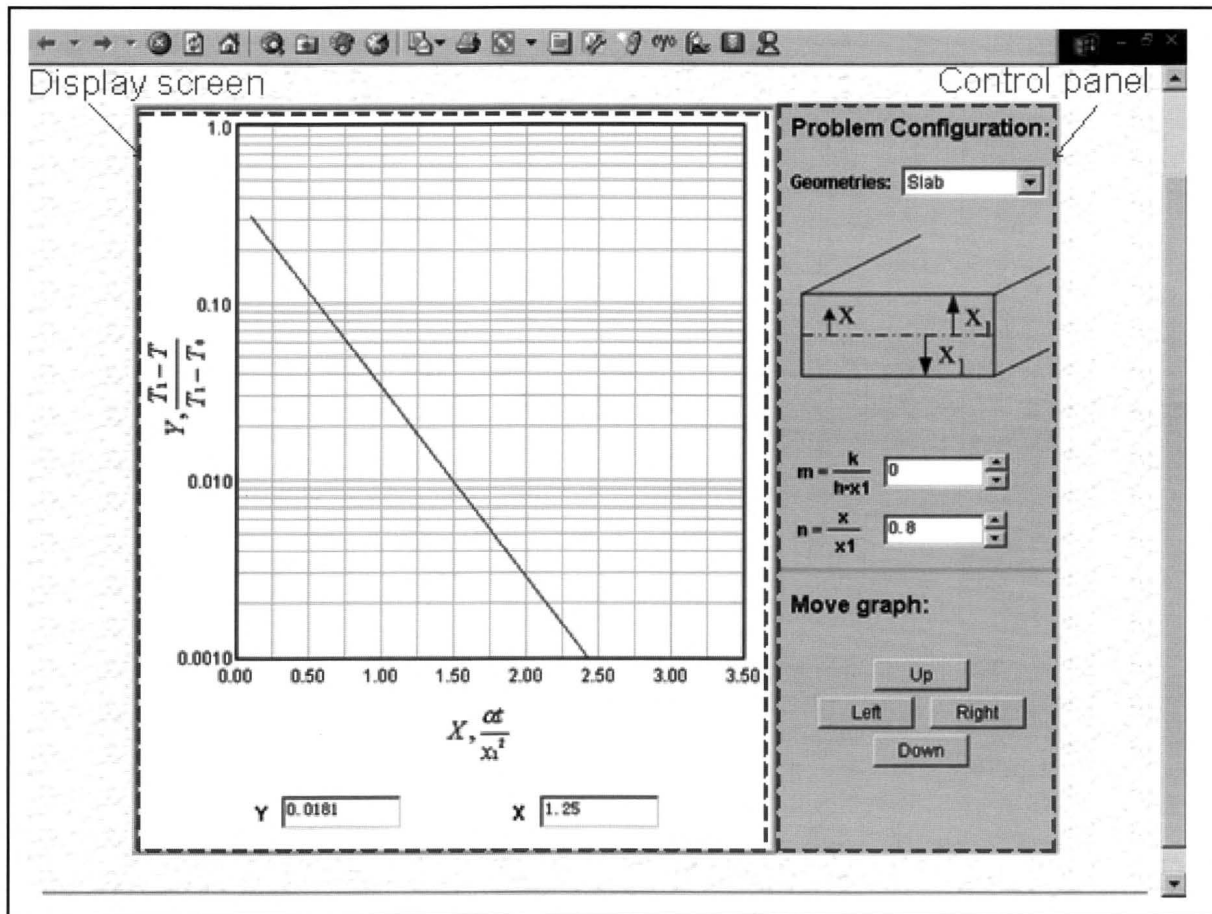

Figure 2. Screenshot of Heisler Chart applet.

this work?") and to discover things for themselves (answering the question, *"What if I change these parameters?"*). Thus, this tool expands instruction beyond that contained in traditional material.

The web-based tools are currently being used by J. Keith as auxiliary teaching tools in a transport/unit operations course that is required of all junior students and which focuses on the fundamentals of heat and mass transfer. An in-class demonstration and homework assignment using these web-based tools are applied during the course. The JAVA applet website also contains example homework problems.

CONCLUSION

This paper describes two web-based instructional tools for heat and mass transfer that are based on JAVA applets and which can be accessed for free at <http://www.chem.mtu.edu/~jmkeith/webtools>. Educators can use these tools in the classroom to instruct students and enhance their understanding. The tools were first used in the 2003 spring semester at Michigan Technological University. Student feedback has been extremely positive. They seemed to enjoy using the applets and to better understand the concept of transient heat conduction. They also felt motivated to simulate some different problems by changing the parameters. Although the treatment presented here is limited to symmetrical, steady, boundary data, students who use the applets are now prepared to solve more complex problems (perhaps by writing a numerical finite difference method).

ACKNOWLEDGMENTS

REFERENCES

1. Geankoplis, C.J., *Transport Processes and Unit Operations,* 3rd ed., Prentice Hall, New Jersey (1993)

2. Felder, R.M., "Matters of Style," *ASEE Prism,* **6**(4), 18 (1996)

3. Kolb, D.A., *Experiential Learning: Experience as the Source of Learning and Development,* Prentice Hall, New Jersey (1984)

4. McCarthy, B., "The 4MAT System: Teaching to Learning Styles with Right/Left Mode Techniques," *EXCEL, Inc.,* Barrington, IL (1987)

5. Stice, J.E., "Using Kolb's Learning Cycle to Improve Student Learning," *J. Eng. Ed.,* **77**, 291 (1987)

6. Harb, J.N., S.O. Durrant, and R.E. Terry, "Use of the Kolb Learning Cycle in the 4MAT System in Engineering Education," *J. Eng. Ed.,* **82**(2), 70 (1993) ❐
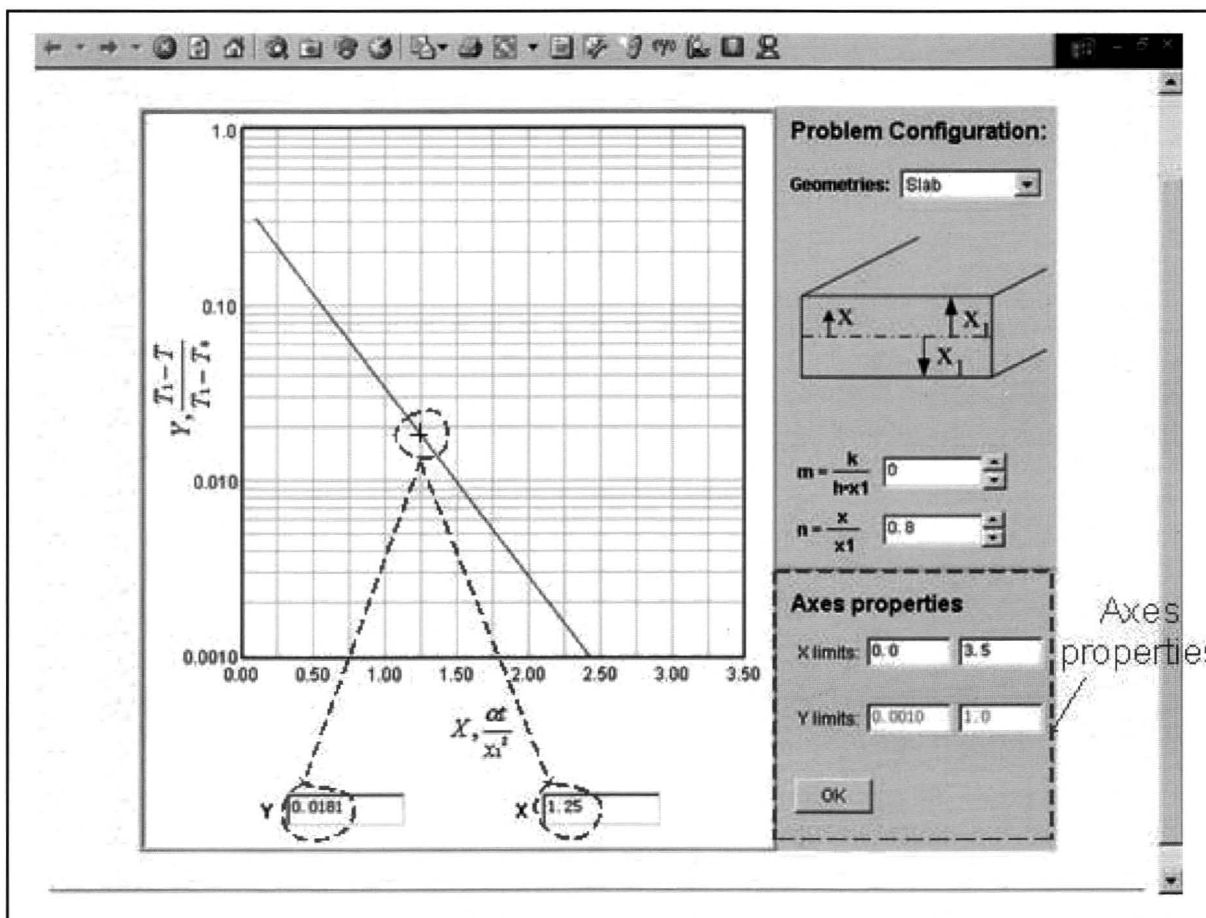
Figure 3. Interpolating data from the JAVA Heisler chart.