

Numerical Analysis of One-Dimensional Unsteady State Heat Transfer Through a Plane Wall Using Visual Basic

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Abstract: In present work a teaching module for teaching unsteady state heat transfer using visual basic has been presented. A Visual Basic computer program has been written to solve the unsteady state heat transfer through a plane wall and has been shown with the help of computer graphics. The governing equation has been modelled using finite difference numerical procedure in which the wall is divided into a number of nodes and temperature at each node has been calculated using Visual Basic code. The program returns the values of temperature at each node into excel sheet and a coloured plot of these temperatures with time and space on the Graphical User Interface. With this module parametric study of different parameters affecting the unsteady state heat transfer such as diffusivity, time difference, number of nodes, distance between two nodes etc. can be performed.

Index Terms: heat transfer; Visual Basic; excel; unsteady state; plane wall; one-dimensional; numerical methods; Graphical User Interface

1. INTRODUCTION

Heat transfer is defined as rate of exchange of thermal energy between two physical systems from one equilibrium state to another on account of temperature difference between the two systems. There are three basic mechanisms of heat transfer conduction, convection and radiation. If temperature distribution is a function of both time and space then it is known as unsteady state heat transfer. The partial differential equation governing the unsteady state heat transfer can be solved by analytical and numerical methods. Analytical methods are limited to highly simplified problems and these are extremely tedious and time consuming, so computer and numerical methods are ideally used for such calculations. The numerical methods used for solving the differential equations are based on replacing the differential equation by algebraic equations. If the derivative is replaced by the differences of the variable then it is known as Finite difference method. In this the medium is subdivided into small regions forming nodal network and the value of variable is calculated at each node. As these methods are iterative so computer programs are helpful in solving these iterative problems. Visual Basic is a 3rd generation, event-driven programming language. Visual Basic was derived from BASIC and enables the Rapid Application Development (RAD) of Graphical User Interface (GUI) applications. Its features like Graphical User Interface and solving complex mathematical problems within short time ideally suit it for educational purposes. Modules prepared under Visual Basic allow us to "see" and help in understanding the physics underlying a particular process.

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Visual Basic provides many advantages as compared to other software's due to which it is being widely in the field of education. Ribando et al. [13] developed a PC-based teaching module for laminar and turbulent forced convection over a flat plate. In this the boundary layer equations are solved using finite-difference numerical methods using Visual Basic. Yeh [14] used Visual Basic programming language to solve problems of radiation heat transfer. Hassan et al. [14] used Visual Basic programming language for simulating numerical iterations. Kothare [7] designed shell and tube heat exchanger by VB Language for educational purpose. Mandal [9] developed a software for designing a dairy heat exchanger and for its performance evaluation. He used Visual Basic for heat transfer studies in various types of heat exchanger geometries. Obuka et al. [11] developed a computer application using Visual Basic to calculate the cooling load of a non-residential building taking all influential factors into consideration. The objective of this work is to develop a module using Visual Basic for the numerical analysis of one-dimensional unsteady state heat transfer through a plane wall. In this the thickness of wall is divided into a number of nodes and after finite difference procedure temperature variation at each node with time has been calculated and has been shown graphically. The program returns the values of temperature at each node into excel sheet and a coloured plot of these temperatures with time and space on the graphical user interface. The module prepared consists of full color visualization and straight forward user input through user interface.

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2. METHODOLOGY

This module is based on unsteady state one-dimensional heat transfer through a plane wall of thickness (l) which is initially at initial temperature (Te). The wall suddenly comes into contact with a hot fluid having a temperature (Tw) from both sides, as fluid temperature is higher so the wall is going to heat. The objective is to show the temperature distribution within the wall as a function of time and space. At equilibrium state the whole wall will attain the temperature of the hot fluid.

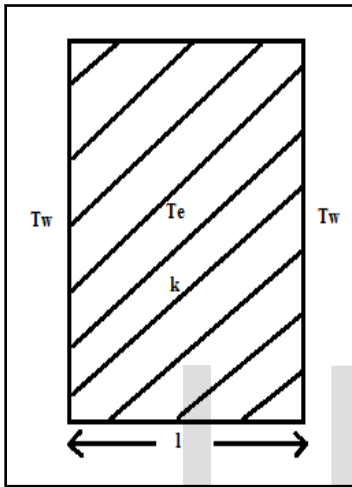


Fig. 1 One-dimensional heat conduction through a plane wall

General 3-D heat conduction equation for no heat generation and unsteady state is given as:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{\alpha} \frac{\partial T}{\partial t} \quad (1)$$

For one dimensional heat conduction:

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha} \frac{\partial T}{\partial t} \quad (2)$$

The wall is discretized into nodes as shown in fig. 2, central and forward difference is applied to the equation.

For $\frac{\partial^2 T}{\partial x^2}$ central difference is applied and for $\frac{1}{\alpha} \frac{\partial T}{\partial t}$ forward difference is applied.

$$\frac{T_{(i-1,j+1)} + T_{(i-1,j-1)} - 2T_{(i-1,j)}}{\Delta x^2} = \frac{1}{\alpha} \frac{T_{(i,j)} - T_{(i-1,j)}}{\Delta t} \quad (3)$$

$$t = i \times \Delta t, m = \frac{\alpha \times \Delta t}{\Delta x^2} \text{ and } \Delta x = \frac{l}{n-1}$$

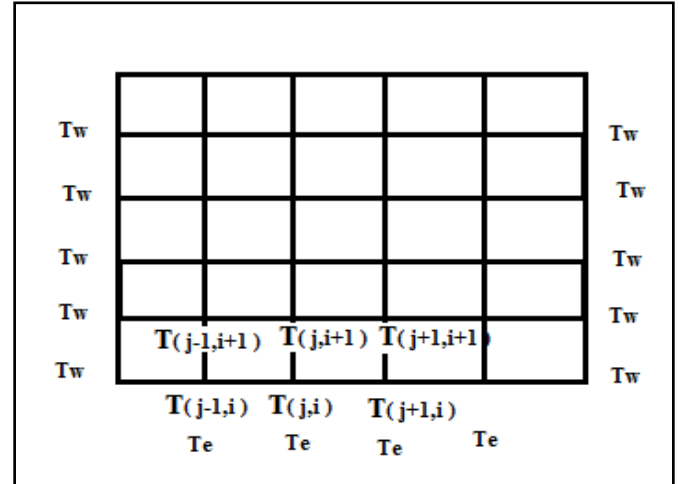


Fig. 2 Schematic for the finite difference formulation for conduction in rectangular coordinates

The final iterative equation obtained is given below:

$$T_{(i,j)} = m(T_{(i-1,j+1)} + T_{(i-1,j-1)} - 2T_{(i-1,j)} + T_{(i-1,j)}) \quad (4)$$

$$T_{(i,0)} = T_{(i, n-1)} = T_{(0, n-1)} = T_{(0,0)} = T_w$$

$$T_{(0, j)} = T_e \text{ For } j = 1 \text{ to } n-2$$

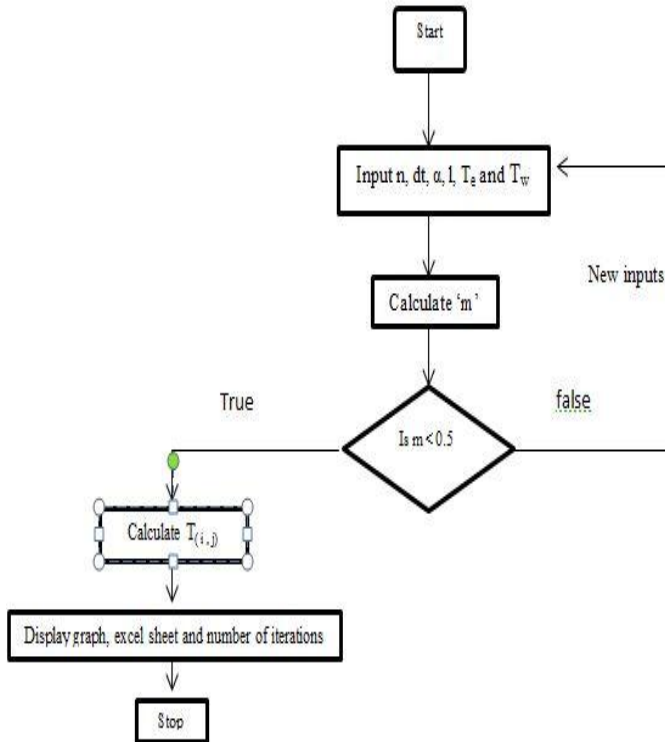


Fig. 3 Flowchart for Visual Basic program for temperature calculation at each node

If $m > 0.5$ the iterative procedure will not converge so it must be less than 0.5, it is the limitation of this iterative formula. Initial temperature of wall and hot fluid is known so temperature at each node after time 't' can be calculated easily.

In this module number of nodes, time interval, diffusivity, thickness of wall, initial temperature of wall and hot fluid temperature has been given as input. A Visual Basic program has been written to calculate the temperature at each node for each time interval until the whole wall comes in equilibrium with the surrounding hot fluid. The results obtained for each iteration have been shown on excel sheet directly with the help of program and the temperature distribution for every 50th is shown in the Visual Basic chart on the user interface.

3. RESULTS AND DISCUSSION

The following outputs obtained from the study:

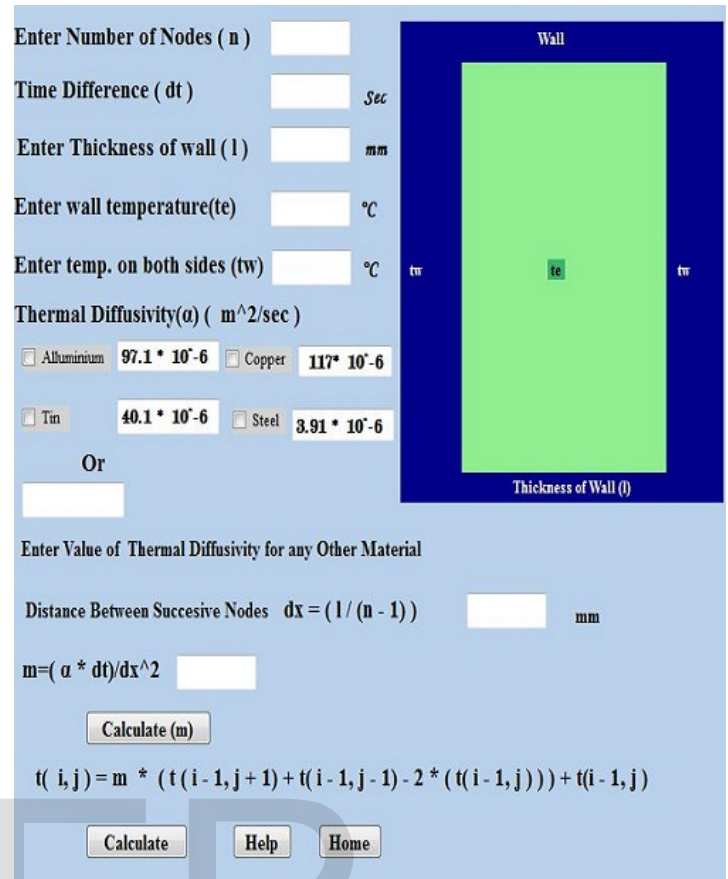


Fig. 4 Initial Visual Basic user interface before execution of program

Figure 4 shows the graphical user interface of Visual Basic, the input variables such as number of nodes, time difference, diffusivity, thickness of wall, initial temperature of wall and hot fluid temperature can be given as input from user interface. Value of 'm' can be calculated by clicking the button calculate(m), the value of m should be

less than 0.5 for the convergence of iterative formula. And after that on clicking the calculate button the program runs and the following interface will be generated showing graph for every 50th iteration and the number of iterations.

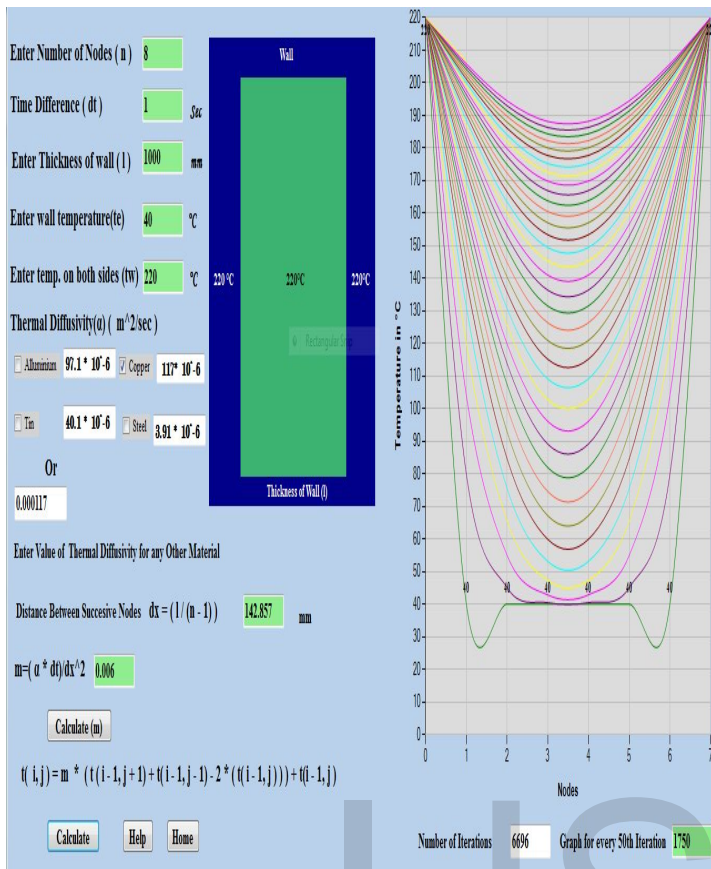


Fig. 5 Visual Basic interface during run time of program with output and graph for temperature distribution

With time the temperature at each node increases and at equilibrium it will attend the temperature of hot fluid, as the wall approaches the temperature of hot fluid the slope of curve decreases and at equilibrium state it will become flat. The colour of wall will also change from light green to dark green during run time simultaneously. Fig. 5 shows graph for 8 nodes, initial temperature 40°C, fluid temperature 220 °C and diffusivity of copper is selected, the number of iterations are are found to be 6696, the number of iterations indicates the time taken to attain the equilibrium. So with the help of this module we can do parametric study between different variables and their effect on temperature distribution and time to attain the equilibrium state.

Graph obtained separately shown in fig. 6 and it is clearly seen that with time the slope of graph decreases tending and will become flat when the entire wall attain the temperature of fluid.

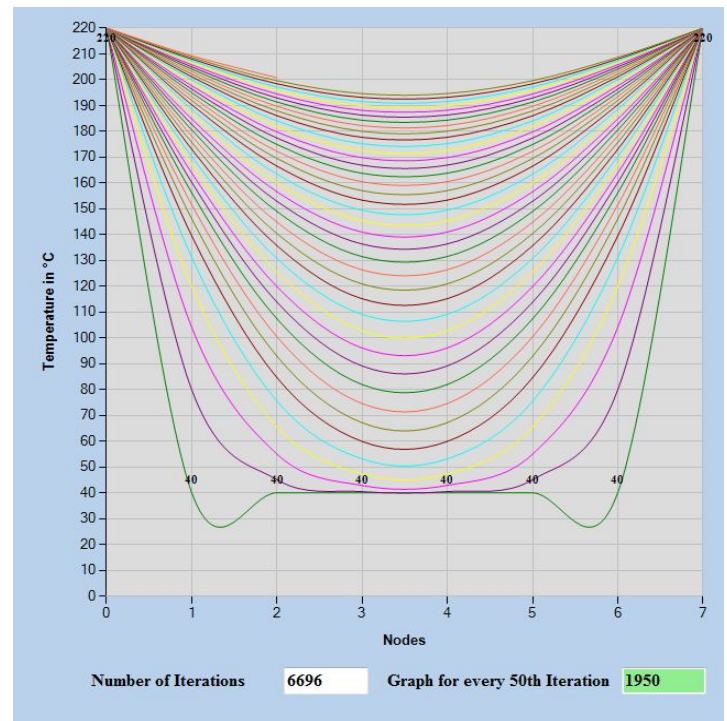


Fig. 6 Visual Basic chart for temperature distribution

Results obtained for temperature distribution for eight nodes in excel sheet has been shown in fig. 7, here only few iterations have been shown.

1	2	3	4	5	6	7	8
220	40	40	40	40	40	40	220
220	41.03194	40	40	40	40	41.03194	220
220	42.05205	40.00592	40	40	40.00592	42.05205	220
220	43.06049	40.01761	40.00003	40.00003	40.01761	43.06049	220
220	44.05744	40.03496	40.00013	40.00013	40.03496	44.05744	220
220	45.04306	40.05782	40.00033	40.00033	40.05782	45.04306	220
220	46.01751	40.08607	40.00066	40.00066	40.08607	46.01751	220
220	46.98095	40.11959	40.00115	40.00115	40.11959	46.98095	220
220	47.93353	40.15825	40.00183	40.00183	40.15825	47.93353	220
220	48.87541	40.20192	40.00272	40.00272	40.20192	48.87541	220
220	49.80674	40.25051	40.00386	40.00386	40.25051	49.80674	220
220	50.72768	40.30388	40.00528	40.00528	40.30388	50.72768	220
220	51.63836	40.36193	40.00699	40.00699	40.36193	51.63836	220
220	52.53893	40.42454	40.00903	40.00903	40.42454	52.53893	220
220	53.42953	40.49161	40.01141	40.01141	40.49161	53.42953	220
220	54.3103	40.56303	40.01416	40.01416	40.56303	54.3103	220
220	55.18139	40.6387	40.01731	40.01731	40.6387	55.18139	220
220	56.04292	40.71851	40.02087	40.02087	40.71851	56.04292	220
220	56.89503	40.80236	40.02487	40.02487	40.80236	56.89503	220
220	57.73785	40.89017	40.02932	40.02932	40.89017	57.73785	220
220	58.57151	40.98182	40.03426	40.03426	40.98182	58.57151	220
220	59.39614	41.07723	40.03969	40.03969	41.07723	59.39614	220
220	60.21186	41.1763	40.04564	40.04564	41.1763	60.21186	220
220	61.0188	41.27895	40.05212	40.05212	41.27895	61.0188	220

Fig. 6 Results of temperature distribution in excel sheet

4. CONCLUSIONS

A Visual basic program has been developed to show the temperature distribution for a unsteady state heat transfer through a plane wall. So Visual Basic with its Graphical User Interface (GUI) and its fast computing ability can be effectively used to solve and present the heat transfer concepts. Modules prepared using Visual Basic consists of full color visualization, straight forward user input and thorough documentation, which makes Visual Basic an efficient tool for heat transfer study.

NOMENCLATURE

dt	time interval (s)
t	time at any instant(s)
n	number of nodes
T	temperature (K)
Δx	distance between two successive nodes
x,y,z	axial coordinates in X, Y and Z direction
i	integer for discretizing time
j	integer for discretizing thickness

Greek Symbols

α	thermal diffusivity (m ² /s)
Δ	difference operator

Subscripts

e	initial
w	wall/fluid

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