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The cooling of a pultrusion process simulator

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THE COOLING OF A PULTRUSION PROCESS SIMULATOR

by

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ABSTRACT

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Experimental and numerical modeling was done to analyze the thermal processes, focusing on the cooling rates, that occurred in a simulated representation of a composite material manufacturing process. The simulation apparatus was constructed similar to that of a compression molding device to represent the thermal process of the pultrusion machine. The simulation block utilized temperature variations and compaction pressure to create small samples that represented sections from a pultruded geometry. In this study, the thermal performance of this device was analyzed utilizing a numerical model. The effect of cooling passages and their location in the simulation block was also analyzed. The numerical results were then compared with the experimental measurements of sample centerline temperature, ambient temperature, die surface temperature, and die surface heat loss. Measured values were then compared with the initial predicted values. Experimental modeling was then done on the pultrusion machine which gave the transient temperature field experienced by a standard cross-section of material being pultruded. Comparisons

were then made between the two types of experimental measurements and numerical estimates. Conclusions were drawn about the ability of the simulant device to match the thermal conditions of the pultrusion machine, in particular the cooling rate, found in the actual pultrusion process.

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CHAPTER 1

INTRODUCTION

Composite materials show great promise for applications where light weights and high strengths are desired. While much work has been done on the development of these materials (see Appendix I), there is still a great deal of work that needs to be pursued. This thesis deals with some thermal aspects of processing pultruded products (see Appendix III). The objective of this thesis was to study the thermal cycle of the pultrusion simulator emphasizing the cooling rate that occurred within. It was desired to see if the addition of cooling passages, variation of the cooling passage locations, or external heat transfer variation would give the pultrusion simulator a cooling rate similar to that occurring in the pultrusion machine. Heat input was also evaluated to see what effects it would have on the cooling rate.

There were various works done pertaining to the thermoplastic pultrusion process and the compression molding process. Some of the more current works experimentally and numerically evaluated the thermal processes that occurred in a thermoplastic composite fiber as it traveled through the pultrusion line. None of the works found examined the thermal cycle, studied herein, of a compression molding device as a thermoplastic composite fiber was being manufactured.

Astrom (1991), Astrom et al. (1991), and Astrom and Pipes (1992 and 1993) presented works that were directly related to the experimentation used in this study to measure the cooling rate of a thermoplastic composite fiber as it traveled through a cooled

die. In Astrom (1991) a set of numerical models were developed to simulate temperature and pressure distributions and matrix flow in a thermoplastic composite material as it traveled through pultrusion dies. A numerical model was also created to give values of pull force in the pultrusion machine. The numerical models were developed using the fiber continuity equation, matrix viscosity, flow equations, fiber deformation equation, and thermal expansion equations. Conclusions were drawn on the ability of the models to replicate the conditions occurring in the pultrusion machine.

Astrom et al. (1991) also discussed the formulation of numerical models to determine pressure and temperature distributions, pull force, and matrix flow. They presented experimentally measured cooling rates and plotted them as a function of position in the cooled die. The material studied throughout this battery of experimentation was carbon fibers melt impregnated with PEEK. Conclusions were drawn on the influence of pull speed, consolidation die temperature, and pressure on the quality of the mechanical properties of pultruded carbon impregnated PEEK composite fiber.

A temperature model considered heat transfer occurring in an infinite slab with the condition of a prescribed heat flux from the surfaces or a prescribed boundary temperature. Astrom and Pipes (1992) also developed a pressure and pulling resistance model in this work. Conclusions were drawn on the ability of the models to replicate the conditions occurring in the pultrusion machine.

Astrom and Pipes (1993) expanded their experimental and numerical investigations of temperature and pressure distribution and pulling force by varying the range of different processing temperatures, pull speeds, die configurations, and material systems. Conclusions were drawn on the effects of these variables on the pultruded thermoplastic composite fiber.

Ruan et al. (1992) developed a steady-state, two-dimensional model of the pultrusion process. This model particularly focused on the temperature fields that occurred

in the die and pultruded geometry. A streamline diffusion approach was used to create the numerical model which analyzed the heat conduction of the die and pultruded geometry along with crystallinity effects of the pultruded geometry. Conclusions were drawn about the effects of temperature variation on the crystallinity of a pultruded geometry.

Another steady-state numerical model of a pultrusion process was developed by Ruan and Liu (1994). In this work, temperatures and heat fluxes were varied at several locations and presented as a function of pull speed. Conclusions were drawn on the effect of pull speed on crystallinity of the material and heat transfer in the die.

Yn et al. (1995) developed a mathematical model for the pultrusion of poly (ε - caprolactam) (NY6/ATBN) copolymers. A finite difference method was employed using the equations of continuity, energy balance, and the kinetic expression for NY6/ATBN. The temperature profile was analyzed in this mathematical model along with the extent of reaction time of the NY6/ATBN in a rectangular pultrusion die. Optimum processing parameters and the maximum thickness of pultrudates were found.

Numerical modeling was done to predict temperature, crystallinity, pressure, and consolidation inside a thermoplastic composite fiber along the axis of a die as a function of time. Pulling force was also evaluated as a function of time. Lee et al. (1991) developed a thermo-chemical, consolidation, and pulling submodel to evaluate the previously stated parameters. Conclusions were then drawn on the validity of the models presented.

Temperature profiles and the degree-of-cure in the axial and radial directions in a cylindrically shaped die configuration were evaluated with a mathematical model. This model simulated the effects on the pultrusion process if the characteristics of type of initiator, fiber reinforcement, resin, and dwell time were varied. Han et al. (1986) concluded that the model presented wasn't very reliable because too many intricate parameters had to be accounted for.

A two-dimensional computational model of the pultrusion process employed the finite element method to predict material temperature and degree of cure in thermoset plastics. Hackett and Zhu (1992) developed a heat transfer and curing process model utilizing the Galerkin weighted residual method solutions. Different die temperatures, pulling speeds, and cross-sections were used. Conclusions were drawn on the ability of one-dimensional and two-dimensional models to accurately represent the variation of temperature and degree-of-cure in experimentally investigated cases.

A mathematical model was developed which accounted for heat transfer and heat generation during curing of a blocked polyurethane based composite during the pultrusion of glass fiber reinforced composites. Yn et al. (1995) used the finite difference method to calculate the temperature and conversion profiles in the thickest direction of a rectangular pultrusion die. Effects of pulling speed, die temperature, and thickness of the polyurethane based composite on the curing process were also evaluated. Conclusions were drawn on the ability of the mathematical model to predict the temperature profiles. Experimentally and mathematically, the degree-of-cure was found to increase with decreased pulling speed.

Works done on the compression molding process mainly focused on the analysis of the flow, molding parameters, and the thermal effects on compression molded sheets and parts. None of the current works found discussed the cooling of a pultrusion process simulator.

Mathematical modeling based on the theory of flow in deformable porous materials and numerical simulations of a unidirectional compression molding process was done by Farina et al. (1997). Analysis of the compression molding system was done in the case of dynamics controlled by the velocity of the piston and dynamics controlled by the pressure applied to the piston. Equations for the mathematical modeling were developed using a set of Lagrangian coordinates fixed on the solid matrix. This gave two initial and boundary value problems of parabolic type in a fixed domain. Conclusions were drawn about the

pressure's ability to bring the material to its final state and the significance of piston and pile impact.

Yim and Im (1997) developed a three-dimensional rigid thermo-viscoplastic finite element program. This program evaluated the chemical reaction and fiber volume fraction of the compression molding of sheet molding compounds. The effects of dwell time, mold closing speed, friction, and mold temperature on mold filling and curing were evaluated at various mold parameters. Conclusions were drawn about the mold closing speeds' effect on flow at the free surface of the sheet molded compound. Increase in mold temperature was also found to increase the curing process. Numerical predictions of fiber volume fractions were found to be in good agreement with experimental observations.

Finite element computing and post analysis programming by Shilin et al. (1997) gave a computer simulation of phenolic sheet molding compound compression molding flow. Mold filling process, time and pressure were analyzed. Conclusions were drawn about the significance of the optimization of these parameters in the compression molding process of sheet molding compounds.

An experimental study of the effect of molding parameters was carried out to determine the effects of molding variables on the physical and mechanical properties on compression molded sheet parts. Kim et al. (1997) investigated the effect of molding parameters on the tensile and flexural properties of molded flat parts. The molding parameters used were mold temperature and mold closing speed. Conclusions were drawn about the fiber orientation and distribution, flow resistance, surface and mechanical qualities, and flow direction.

Kim and Im (1997) used a rigid-viscoplastic approach to analyze the compression molding of sheet molded compounds at room temperature. A three-dimensional finite element program was developed. Conclusions were drawn about the accuracy of the program to compare forming load and geometry changes. Friction effects were found to be

the most significant factors in determination of flow patterns. In an attempt to improve the accuracy of the previously developed program, an addition of a coupled analysis program was suggested which would include the curing reaction.

The purpose of this study is to analyze the thermal processes, focusing on the cooling rates, that occur in a simulated representation of a composite manufacturing process utilizing experimentation and numerical modeling. It is desired to achieve a cooling rate in the pultrusion simulator device that is similar to the rate occurring in the pultrusion machine, or at least within a satisfactory range. Auxiliary internal cooling channels will be added if additional cooling is necessary. Experimentation was done on the pultrusion simulator device to measure such things as centerline temperature, cooling rate, surface temperature, ambient temperature, and heat loss to the environment. Experimentation performed on the pultrusion machine will give the cooling rates occurring in a pultruded geometry at different consolidation temperatures and pull speeds.

CHAPTER 2

EXPERIMENTAL APPARATUS

Pultrusion Machine

The pultrusion line was broken up into five essential components. These components were the material feed, material guides, preforming area, curing, and clamping and pulling divisions (see Figure VII-I). Positioning of the carbon/PEEK fiber was extremely important to ensure that high-strength laminates were produced. Ten tows of carbon/PEEK composite fiber were utilized throughout each experiment. This positioning of the pre-pegs ensured that all reinforcements were properly placed in the composite. This process was also important because it guided the reinforcements into their desired positions within the pultrusion line. The initial process involved a roving creel, and a reinforcement rack where the carbon/PEEK composite fibers (discussed in Appendix II) were stored.

The material guides were also used to ensure the safe unspooling of the carbon/PEEK composite fibers through the pultrusion line. In this process two material guides were used, one was attached to the roving creel and the other was attached to the preheat oven. This was the location where one thermocouple was welded between several carbon/PEEK tows, utilizing a 1000 W soldering iron, to begin its travel through the pultrusion line. This led to the most challenging process of the pultrusion line, curing.

Curing is a continuous polymerization process that takes place in the die. This process was dependent on pull speed and consolidation die temperature. The curing

process occurred in the preheat oven, consolidation die, and cooled die. Temperatures of the carbon/PEEK composite fiber, as it traveled through the preheat oven, were monitored by an infrared thermometer located beneath a hole in the preheat oven located six inches from its end. The preheat oven was constructed from mild steel and insulated with alumina-silica. It was insulated with alumina-silica to minimize heat transfer to the environment. Heating was achieved utilizing eight 250 W cartridge heaters which were located on two steel platens, four were located on each platen. After the carbon/PEEK composite fiber exited the preheat oven, it went through the process of die curing. Before reaching the consolidation die, the carbon/PEEK composite fiber traveled through a 2 1/4 inch air gap.

The die curing process occurred when the carbon/PEEK composite fiber traveled through the three inch consolidation die (see Figure VII-II). The die was constructed of mild steel. Heating of the consolidation die was achieved with four 1000 W cartridge heaters, two located in the lower half of the die configuration and the other two located in the upper half. A 3/8 inch gap separated the consolidation die from the cooled die. Cooling of the cooled die was accomplished by the pumping of a recirculating fluid through four channels, positioned in a similar manner to that of the placement of the cartridge heaters in the consolidation die. This die (see Figure VII-II) was also constructed using mild steel. Both dies were fixed in nature, as opposed to having a floating die design.

An IBM compatable PC, a Macintosh IIci computer, and the LabVIEW data acquisition software were used to collect data. The IBM compatable PC and the LabVIEW data acquisition software were used to measure preheat temperature, consolidation temperature, and pull speed. The measured variable of pull force was also collected, but was a calculated property dependent upon only on time and pull speed. The preheat temperature was monitored by an infrared thermometer whereas the consolidation temperature was monitored with a glass/glass K-type thermocouple placed centerline of the

consolidation die in an opening located in its upper half. The pultrusion process could be controlled by one of the three process modes: pull speed, pull force, or consolidation temperature.

A Macintosh IIci computer and the LabVIEW 3 data acquisition software accompanied with a National Instrument SCXI-1000 chassis, a SCXI Terminal Block, and a SCXI-1300 multiplexer amplifier module were used to measure the temperature of the carbon/PEEK composite fiber as it traveled through the pultrusion line. Twenty-six gauge glass/glass K-type thermocouples were used throughout the entire experimental process to give the temperature of the carbon/PEEK fiber as it traveled through the pultrusion line. These thermocouples measured 0.0519 inches in diameter and had a resistance of 2.381 ohms per double foot at 68°F.

Some additional details about the pultrusion machine are given in Appendix VIII.

Pultrusion Simulator Block

The pultrusion simulator block was a two member matched die configuration developed to duplicate the consolidation phase of the pultrusion process (see Figure VII-III). It was constructed of mild steel and measured 15.1 cm x 5.1 cm x 12.7 cm. It consisted of eight 1000 W cartridge heaters, four located in the upper half of the die and the other four located in the lower half of the die. The positioning of the heaters was symmetrical about the centerline placement of the composite fiber. This system utilized pressure and temperature to compress and shape the composite fiber. Cooling in the pultrusion simulation block was achieved by applying steady streams of air to each side of the die with two diffuser nozzles set at 35 psi and positioned at approximately an angle of 45° and a foot away.

The equipment used in this experiment was a Macintosh IIci computer, an IBM compatible PC, and the LabVIEW 3 data acquisition software. The Macintosh IIci computer and the LabVIEW 3 data acquisition software measured the centerline temperature and surface temperature of the pultrusion simulator block and the ambient temperature. The IBM compatible PC and the LabVIEW 3 data acquisition software measured voltage. These voltage readings from the heat flow sensors were used to calculate the heat transfer from the pultrusion simulator block to the ambient.

The 26-gauge glass/glass K-type thermocouples were used throughout this experimentation along with a 27070-2 Micro-Foil Heat Flow Sensor and a 20452-3 Micro-Foil Heat Flow Sensor from RdF Corporation. One thermocouple was placed inside the groove of the pultrusion simulator block to measure the centerline composite material temperature, while the other two were attached at the centerline of the top and bottom half of the outside surface of the pultrusion simulator block to measure the surface temperature. Attachment of thermocouples and heat flow sensors was accomplished utilizing a high temperature silicon glue. The Micro-Foil Heat Flow Sensors were also attached at the centerline of the upper and lower half of the pultrusion simulator block.

Some additional details about the pultrusion simulator are given in Appendix VIII.

CHAPTER 3

EXPERIMENTAL PROCEDURE

Experimentation was performed on the pultrusion simulator block and the pultrusion machine to measure the cooling rate of carbon/PEEK fiber in each device. In both cases before the experimentation was initiated, 26-gauge glass/glass K-type thermocouples were calibrated using a 0°C ice bath and 100°C boiling hot water. Atmospheric pressure was also recorded to achieve the true boiling point and freezing points. Room temperature was recorded as well. The scan rate of the LabVIEW 3 software was manually set at 50 scans/second. The high and low voltage limits of the LabVIEW 3 software used to measure temperature were set at 0.050 and -0.050. The high and low limits of the LabVIEW software used to measure heat flow were set at 3 and -3 millivolts.

Pultrusion Machine

The control variables investigated in the pultrusion process were the pull speed and the consolidation die temperature values. The temperature of the preheat oven was set throughout every experiment at 120°C. The first experiment involved a consolidation die temperature of 370°C and a pull speed of 3 inches/minute. The second experiment involved a consolidation die temperature of 370°C and a pull speed of 6 inches/minute.

The third experiment involved a consolidation die temperature of 360 °C and a pull speed of 5 inches/minute. The fourth experiment involved a consolidation die temperature of 380°C and pull speed 6 inches/minute. The fifth experiment involved a consolidation die temperature of 360°C and a pull speed of 6 inches/minute. All experimentation was performed twice at the previously indicated consolidation die temperatures and pull speeds.

Pultrusion Simulator Block

The pultrusion simulator block was set to heat to a maximum temperature of 380°C. Upon reaching this set temperature, cooling was initiated by applying forced air convection on two sides of the block. The centerline and surface temperatures of the block along with the ambient temperature were recorded throughout the entire thermal cycle. Heat transfer from the block to the ambient was also calculated for the entire thermal cycle.

CHAPTER 4

NUMERICAL PROCEDURE

A numerical analysis was performed on the pultrusion simulator block to show the effects of various external coefficients on the sides of the blocks, heat input variations, the addition of cooling passages, and the variation of the cooling passage locations. This numerical analysis involved the formulation of a two-dimensional transient model solved by an explicit finite difference method. While the problem is clearly three-dimensional in form, it was thought that a unsteady two-dimensional analysis, appropriately modified for three-dimensional behavior, would be used.

As described in the Experimental Procedure section, the pultrusion simulator dies consisted of upper and lower portions. The differences between the portions were minor, and these differences were caused by the inclusion of the small groove where materials were formed. This structure was considered two-dimensional for analysis considerations, and symmetry lines were assumed. Schematic details of this are shown in Appendix IV. Along the symmetry lines, adiabatic surfaces were assumed to exist. Convective and radiative losses were assumed to be occurring through heat transfer from the block to the ambient temperature, and these were represented in the numerical modeling by a combined heat transfer coefficient. When results were found, comparisons of numerical calculations to experimentally collected data allowed for the adjustment of this heat transfer coefficient magnitude to account for three-dimensionality in the actual situation.

The heating elements were taken to exist at appropriate locations in the model. Heater nodes were located at x-y coordinates of (4,6) and (9,3). Nodes at these locations were formulated to allow the dissipation of a desired amount of heat there.

At the locations where cooling passages were incorporated, they were assumed to be filled with atmospheric pressure water under boiling conditions (100°C). Cooling passage location #1 had a radius of 0.00635 m and was located at x-y coordinates of (3,3), (3,4), (4,3), and (4,4). Cooling passage location #2 also had a radius of 0.00635 m and was located at x-y coordinates of (2,2), (2,3), (3,2), and (3,3). At high temperatures, the atmospheric pressure water will tend to vaporize. A large heat transfer coefficient (1000 W/m^2K) was assumed to exist inside the passages with a convecting fluid at 100°C present in the channel.

Equations (shown in Appendix V) were developed utilizing the finite difference form of the heat equation and applying the conservation of energy equations to each. A control volume was assumed for each node and an analysis was performed around each individual node. A ninety-seven nodal network was arranged to enable the determination of temperature at discrete points within the pultrusion simulator block. The nodal network was formulated as an 11 x 9 grid which contained nine nodes in the y-direction and eleven nodes in the x-direction. The nodal spacing in both the x-direction and y-direction was fixed at 0.00635 m.

At the start of heating a prescribed initial condition of 293K, room temperature, was given. A heat input was manually set into the numerical models to show its effects on the cooling rates within the pultrusion simulator block. No heat flux occurred on the insulated sides of the block. During the thermal cycle of the pultrusion simulator block, heat transfer was assumed to be occurring by external heat loss off the uninsulated sides of the pultrusion simulator block to the atmosphere. $T_{infinity}$ was given as a prescribed temperature

of 300K. The external heat transfer coefficient was assumed to be the same on both uninsulated surfaces of the pultrusion simulator block.

The calculations of the nodal temperatures were performed at successive time steps by the interval of Δt. The value of Δt used in this numerical model was 0.05 seconds. This value of Δt was determined by utilizing the stability requirements for an explicit method formulation. These requirements were necessary because explicit formulations are used when nonsteady states are considered. This stability criterion ensured that the nodal temperatures continuously approached steady-state with increasing time intervals. The stability criterion used to calculate Δt for this numerical modeling was

$$(1 - 2Bi_x Fo_x - 2Fo_x - 2Fo_y - 2Bi_y Fo_y) \geq 0.$$

Heating was initiated until the set processing temperature of 653K was reached at the centerline of the pultrusion simulator block or until a nodal temperature change of less than 0.1K per iteration occurred. If this nodal temperature change was less than the previously stated stipulation before the corner temperature of 653K was reached, the user was prompted either to continue heating or to begin cooling.

Cooling was initiated when the centerline temperature reached 653K which was the set processing temperature of the carbon/PEEK fiber in the pultrusion simulator block. Cooling continued within the numerical model until the centerline temperature reached T_g, 416 K for carbon/PEEK fiber, or 43,100 iterations had been reached, 2155 seconds or 36 minutes, had elapsed. This timed set point was arbitrarily chosen to end cooling if the system appeared to have an extremely slow cooling rate.

Three FORTRAN 77 programs were developed from the finite difference method to simulate the environment of the pultrusion simulator block. The first FORTRAN 77 program numerically simulated the actual thermal process occurring within the pultrusion simulator block when cooling was achieved with the method of forced external heat transfer

due to the application of air streams on the sides of the pultrusion simulator block. The final two FORTRAN 77 programs numerically simulated the heat transfer that would occur in the pultrusion block if the cooling involved the addition of specially designed passages and/or an increased external heat transfer coefficient. In the latter two numerical analysis, the position of the cooling passages was varied (shown in Appendix VI).

The input variables in these programs were the external heat transfer coefficient on the sides of the pultrusion simulator block and the heat input into the blocks. The set values of these programs were T_g for the carbon/PEEK composite fiber (which was set at 416 K), ideal processing temperature (which was set at 653 K), $T_{infinity}$ (which was set at 300 K), and initial temperature (which was set at 297 K). The external heat transfer coefficient, initial temperature, processing temperature, and T_g temperatures of the composite fiber in question could be adjusted for each individual case. The heat transfer coefficient of the fluid flowing through the cooling channels was set to equal 1000 W/m^2K.

CHAPTER 5

RESULTS AND ANALYSIS

Pultrusion Machine

Temperature within the carbon/PEEK composite fiber was measured as it traveled through the pultrusion line utilizing a glass/glass 26-gauge K-type thermocouple located inside of the fiber. The variables used throughout the experimentation of the pultrusion machine were those of consolidation die temperature and pull speed. Five cases were developed incorporating these two variables, only four cases are discussed herein. These four cases were the case of a consolidation die temperature of 633 K (360°C) at a pull speed of 6 inches/minute, a consolidation die temperature of 643 K (370°C) at a pull speed of 3 inches/minute, a consolidation temperature of 643 K (370°C) at a pull speed of 6 inches/minute, and lastly a consolidation temperature of 653 K (380°C) at a pull speed of 6 inches/minute.

At a pull speed of 6 inches/minute and a consolidation die temperature of 643 K the cooling rate of the carbon/PEEK composite fiber was measured, from the entrance to the exit of the cooled die, as 9.5 K/second. Figure 1 graphically represents the cooling rate of the carbon/PEEK composite fiber from a distance of 0 inches to 3, the traveled distance of the fiber through the cooled die. Figure 2 represents the cooling rate that occurred when

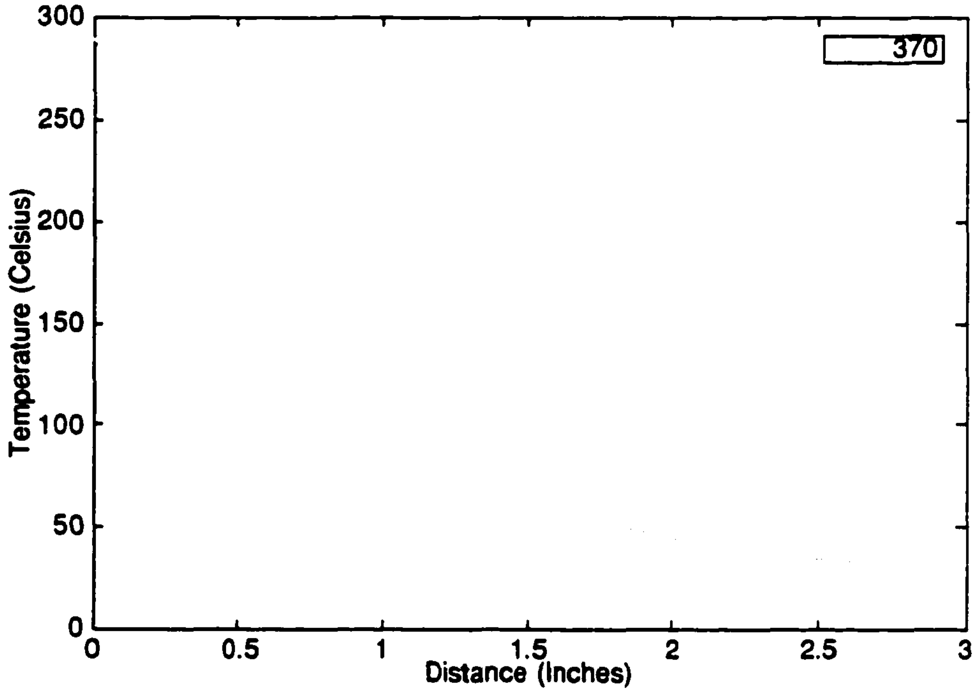

Figure 1 An experimental representation of the cooling rate in pultruded carbon/PEEK fiber with at a pull speed of 6 inches/minute and a consolidation die temperature of 370°C.

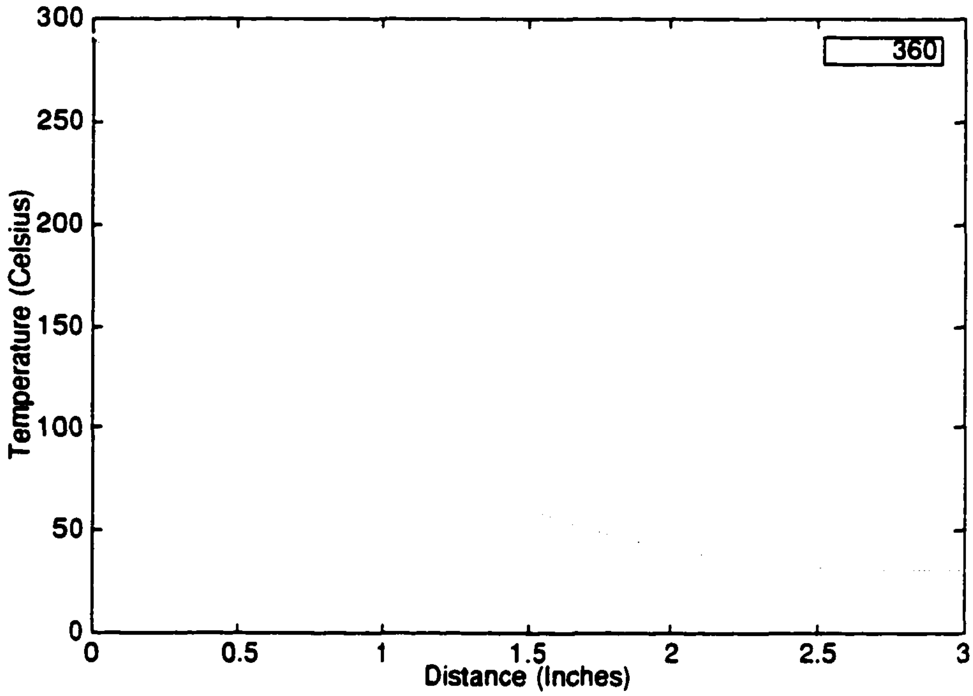

Figure 2 An experimental representation of cooling rate in pultruded carbon/PEEK fiber with a pull speed of 6 inches/minute and a consolidation temperature of 360°C.

the pull speed was held constant and the consolidation die temperature was decreased to a value of 633 K. The cooling rate measured at a pull speed of 6 inches/minute and 633 K was 9.4 K/second. Once again the pull speed was held constant with varying consolidation die temperature. At 6 inches/minute and 653 K a cooling rate of 9.8 K/second was measured and depicted in Figure 3. Lastly the pull speed was decreased by a factor of two giving a 3 inches/minute pull speed. This 3 inches/minute pull speed was coupled with a consolidation die temperature of 643 K. At this pull speed and consolidation die temperature the measured cooling rate was 4.8 K/second. This case yielded the lowest cooling rate during experimentation and is depicted in Figure 4. Graphically depicted in Figure 5 are the cooling rate variations that occur when the variable of pull speed is held constant at 6 inches/minute and the consolidation die temperature is varied.

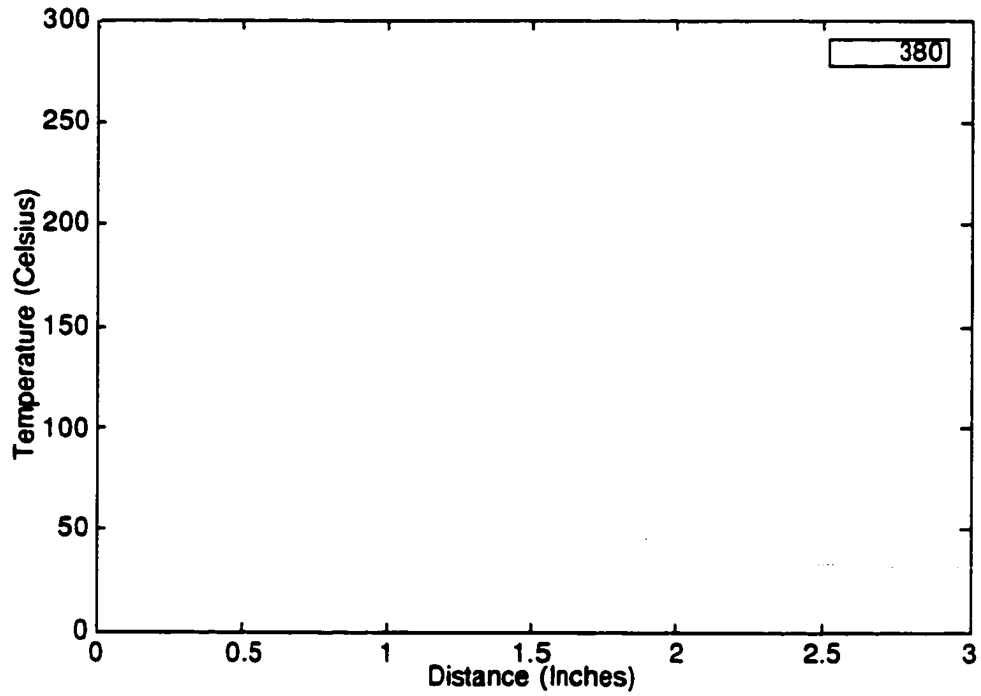

Figure 3 An experimental representation of cooling rate in pultruded carbon/PEEK fiber with a pull speed of 6 inches/minute and a consolidation temperature of 380 °C.

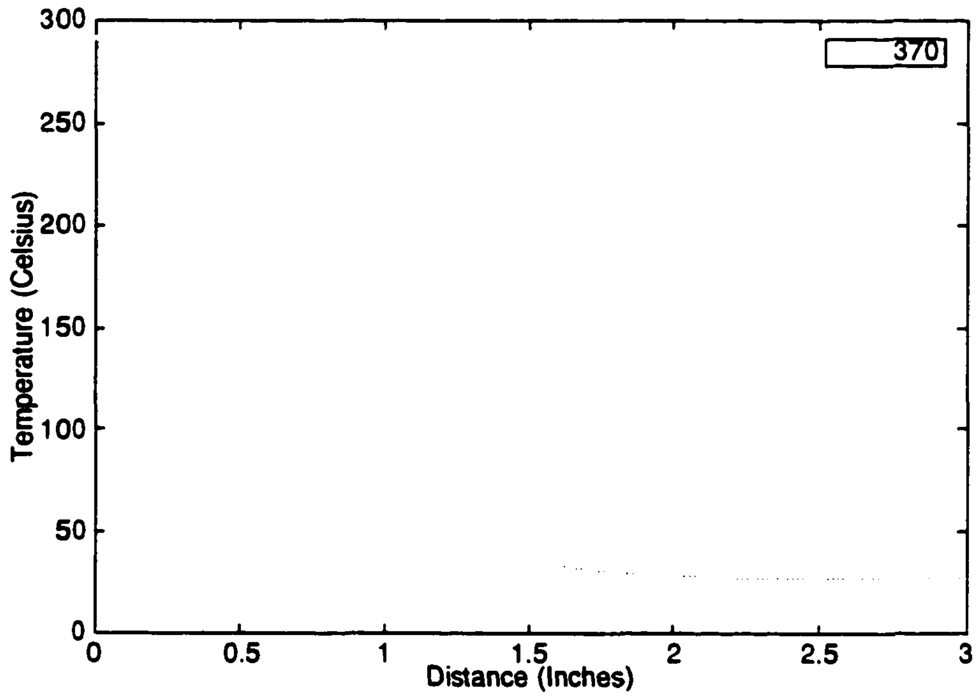

Figure 4 An experimental representation of cooling rate in pultruded carbon/PEEK fiber with a pull speed of 3 inches/minute and a consolidation temperature of 370°C.

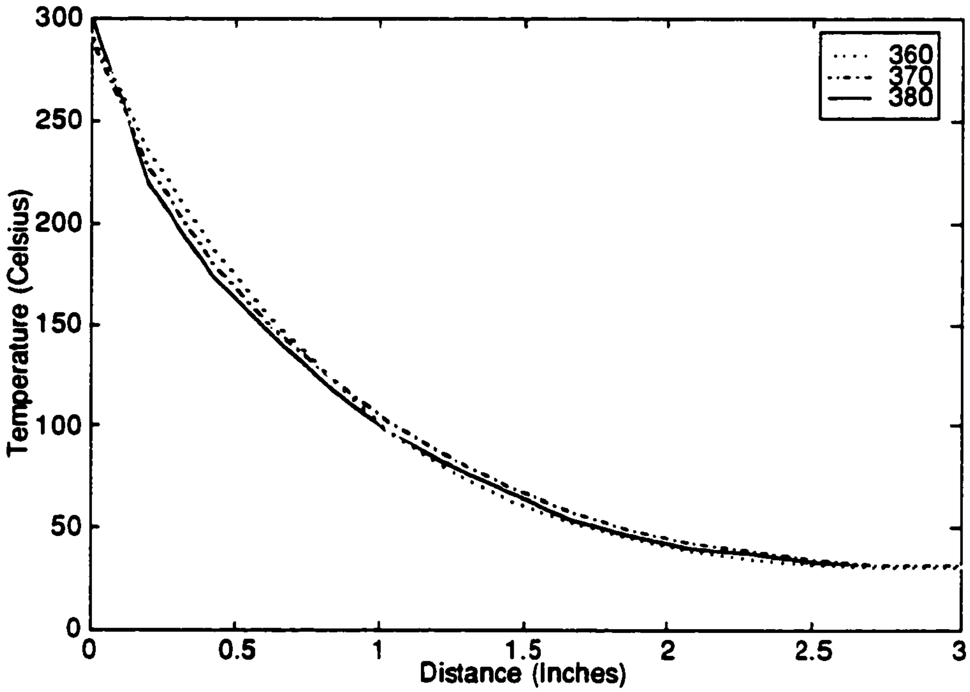

Figure 5 A comparison of experimentally found cooling rates at 6 inches/minute and various consolidation die temperatures.

Pultrusion Simulator Block

The cooling rate of the pultrusion simulator block was also measured with a glass/glass 26-gauge K-type thermocouple. The external heat transfer coefficient in this experiment was measured with Micro-Foil Heat Flux Sensors. Experimentally, the pultrusion simulator block yielded a cooling rate of 0.13 K/second, shown in Figure 6. This measured cooling rate was 4.67 K/second less than the lowest cooling rate experienced by the carbon/PEEK composite fiber pultruded in the pultrusion machine. To achieve optimum composite properties of carbon/PEEK composite fiber a cooling rate between 0.17 K/second and 11.66 K/second must be achieved (Schwartz, 1996). At a cooling rate of 0.13 K/second, the pultrusion simulator block fell short of the lowest optimum cooling rate value for carbon/PEEK composite fiber by a value of 0.04 K/second. The measured external heat transfer coefficient off the side of the pultrusion simulator block was 80 W/m^2K. Due to the large gap between the cooling rates of the pultrusion machine and the pultrusion simulator block and the inefficient method of cooling used by the pultrusion simulator it was decided to see if the variation of the heat transfer coefficient on the exterior or the addition of cooling passages inside the simulator blocks would help increase the cooling rate experienced in the pultrusion simulator block. It was also decided to see what effects the heat input had on the pultrusion simulator block and its cooling rate.

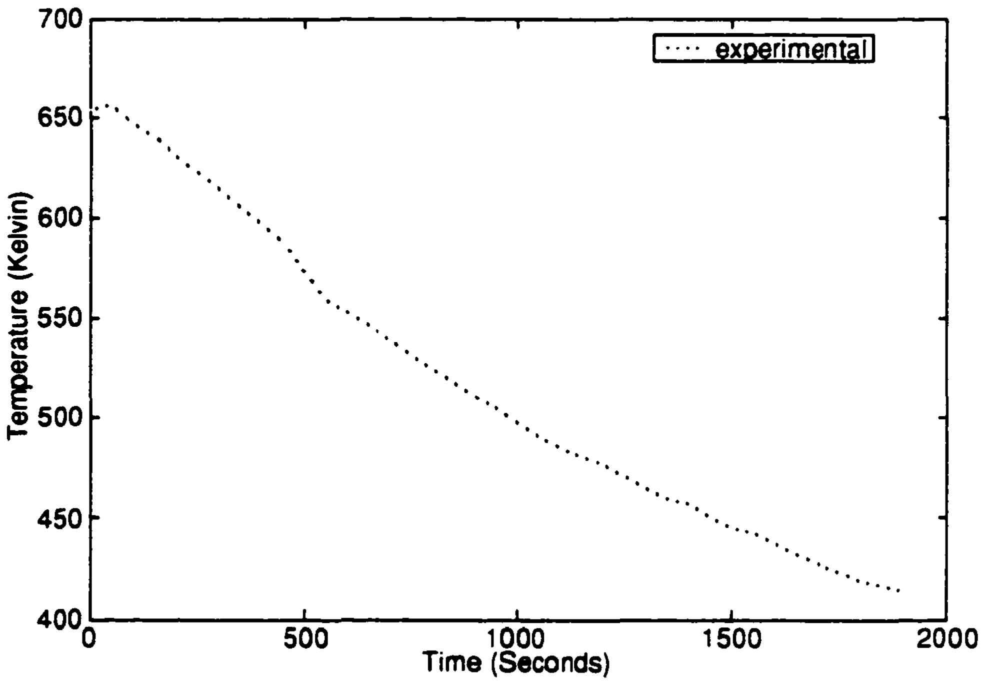

Figure 6 The experimentally measured cooling rate of the pultrusion simulator block at centerline.

Numerical Model

A numerical representation was done to simulate the heating and cooling processes occurring in the pultrusion simulator block. This numerical representation utilized the variables of internal cooling passages and/or external heat transfer coefficients during the cooling process. Prior to the measurement of the experimental values of the external heat transfer coefficient and cooling rate, the numerical representation utilized various values of external heat transfer coefficients, heat inputs, and cooling passages to better gauge the effectiveness of the range of loss coefficients, heat input, and cooling passage locations in increasing the cooling rate in the pultrusion simulator block. The external heat transfer coefficients used in this part of the numerical modeling were 10 W/m^2 K, 100 W/m^2 K, and 1000 W/m^2 K. These external heat transfer coefficients were then applied to the numerical representations of the pultrusion simulator block without cooling passages (the actual process occurring) and at two different cooling passage locations. The heat input variations used where 1 kW, 4 kW, and 8 kW. The major influence of heat inputs was that an overshoot of the desired temperature resulted with the higher values of input. This is because the location of interest was physically removed from the location of the heaters.

When the heat input used in the numerical model was 8 kW and no cooling passages were used, the cooling rate, shown in Figure 7, ranged from 0.016 K/second at a external heat transfer coefficient of 10 W/m^2 K to 1.08 K at a external heat transfer coefficient of 1000 W/m^2 K. When the various cooling passages were added while holding the above variables constant, the cooling rate ranged from 0.47 K/second found in cooling passage location #1 (shown in Figure VI-II) at 10 W/m^2 K to 1.7 K/second at 1000 W/m^2K, depicted in Figure 8. Figure 9 represents the cooling rate found when cooling passage location #2 (shown in Figure VI-III) was used. The cooling rate in this case ranged from 0.53 K/second at a external heat transfer coefficient of 10 W/m^2 K and 1.9 K/second at an external heat transfer coefficient of 1000 W/m^2 K, depicted in Figure 9.

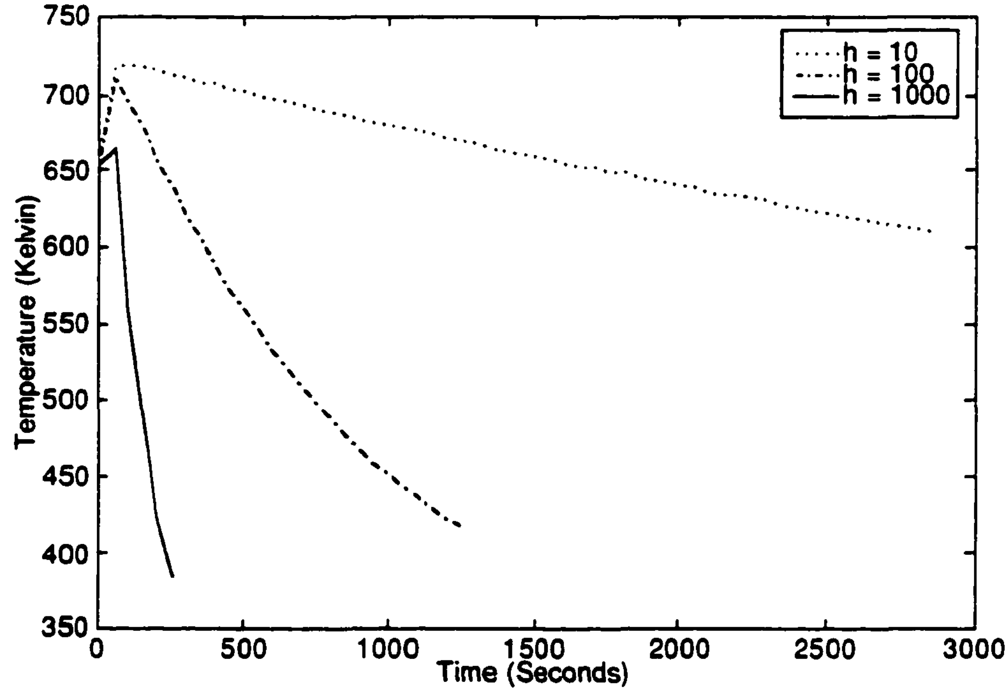

Figure 7 The numerical representation of the centerline cooling rate of the pultrusion simulator block when the heat input is 8 kW and no cooling passages are used.

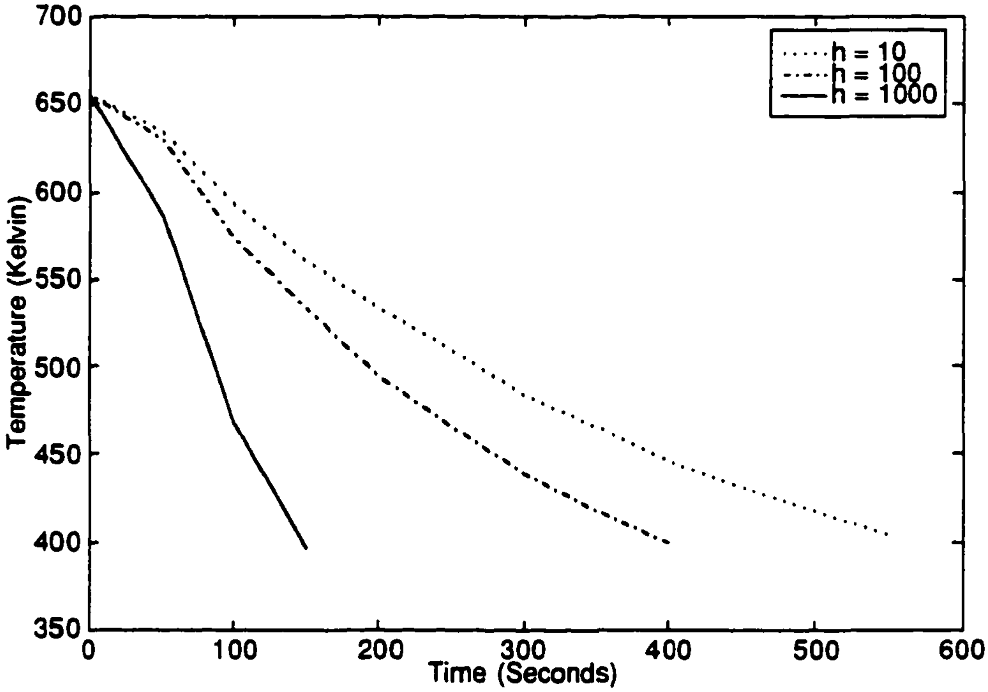

Figure 8 The numerical representation of the centerline cooling rate of the pultrusion simulator block when the heat input is 8 kW and cooling passage location #1 is used.

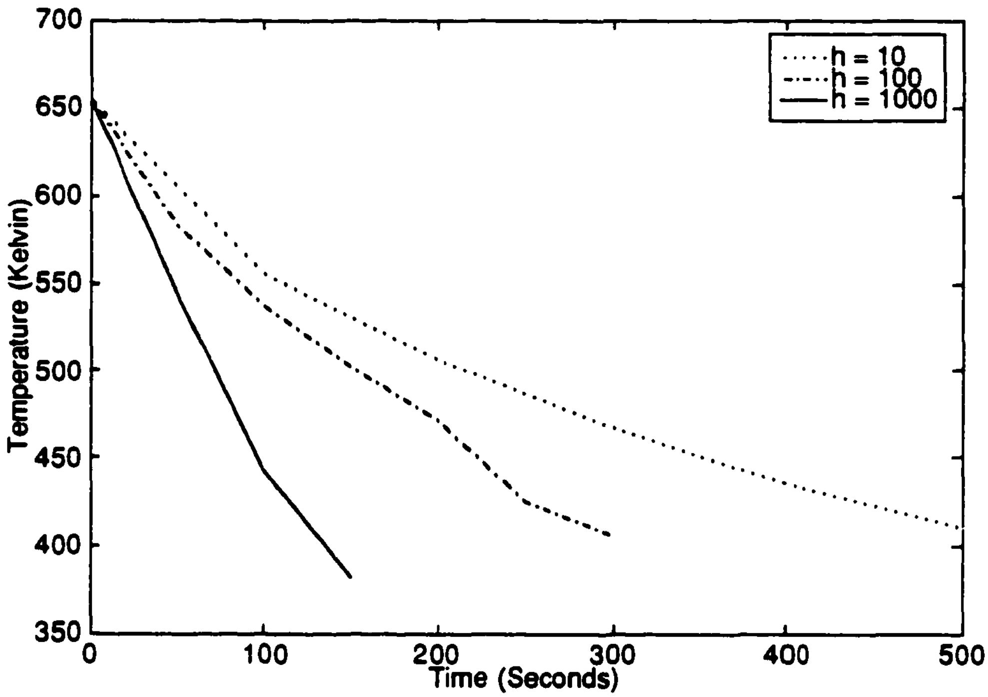

Figure 9 The numerical representation of the centerline cooling rate of the pultrusion simulator block when the heat input is 8 kW and cooling passage location #2 is used.

An apparent change of slope appeared in the plots depicting the calculated performance when cooling passages were present (here and in later figures). It is not clear why this change of slope occurred.

A heat input of 4 kW was also used with varying external heat transfer coefficients and options for no cooling passages and the two different passage locations. When the option of no cooling channels was considered the cooling rate, depicted in Figure 10, was found to vary from 0.03 K/second at an external heat transfer coefficient of 10 $W/m^2 K$ to 1.22 K/second at an external heat transfer coefficient of 1000 $W/m^2 K$. At cooling passage location #1 the cooling rate varied from 0.51 K/second to 1.81 K/second at 10 $W/m^2 K$ and 1000 $W/m^2 K$ respectively, shown in Figure 11. Figure 12 shows cooling rates that varied from 0.99 K/second to 1.42 K/second at cooling passage location #2 when the external heat transfer coefficients were 10 $W/m^2 K$ and 1000 $W/m^2 K$, respectively.

The heat input that occurred in the portion of the pultrusion simulator block represented in the numerical model was 1 kW. When this heating value was taken into consideration, cooling passage locations and external heat transfer coefficients were varied in a manner exactly similar to that previously discussed.

In the case of no cooling passages, the cooling rate was found to range from 0.031 K/second to 1.23 K/second with an external heat transfer coefficients of 10 $W/m^2 K$ and 1000 $W/m^2 K$, shown in Figure 13. At cooling passage location #1 the cooling rate was found to be 0.47 K/second at a heat transfer coefficient of 10 $W/m^2 K$ and 1.79 K/second at a heat transfer coefficient of 1000 $W/m^2 K$, depicted in Figure 14. Figure 15 depicts the numerical representation of the cooling rate in the case of cooling passage location #2. The cooling rate in this case ranged from 0.6 K/second to 1.9 K/second at a external heat transfer coefficient of 10 $W/m^2 K$ and 1000 $W/m^2 K$ respectively.

Once the experimental value for the external heat transfer was found, all numerical modeling was done utilizing the experimentally found value of 80 $W/m^2 K$ during cooling

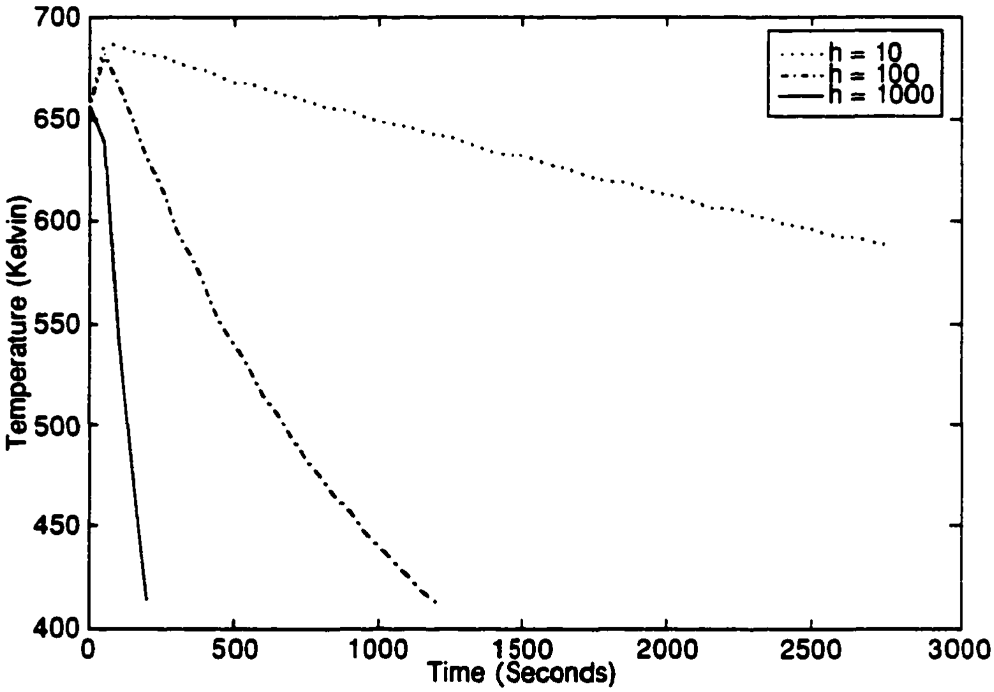

Figure 10 The numerical representation of the centerline cooling rate of the pultrusion simulator block when the heat input is 4 kW and no cooling passages are used.

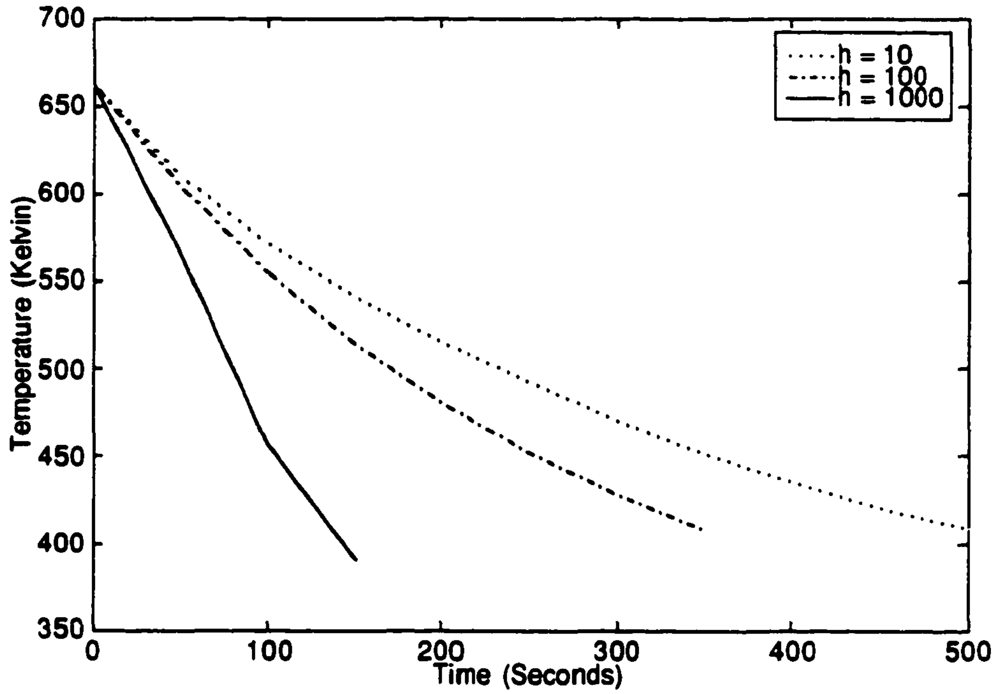

Figure 11 The numerical representation of the centerline cooling rate of the pultrusion simulator block when the heat input is 4 kW and cooling passage location #1 is used.

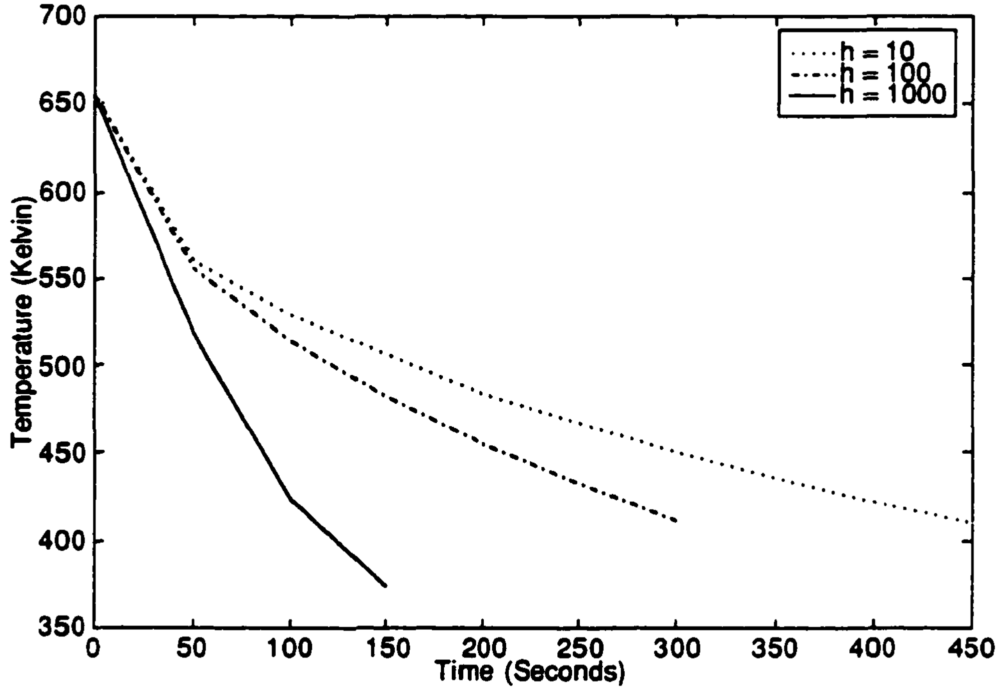

Figure 12 The numerical representation of the centerline cooling rate of the pultrusion simulator block when the heat input is 4 kW and cooling passage location #2 is used.

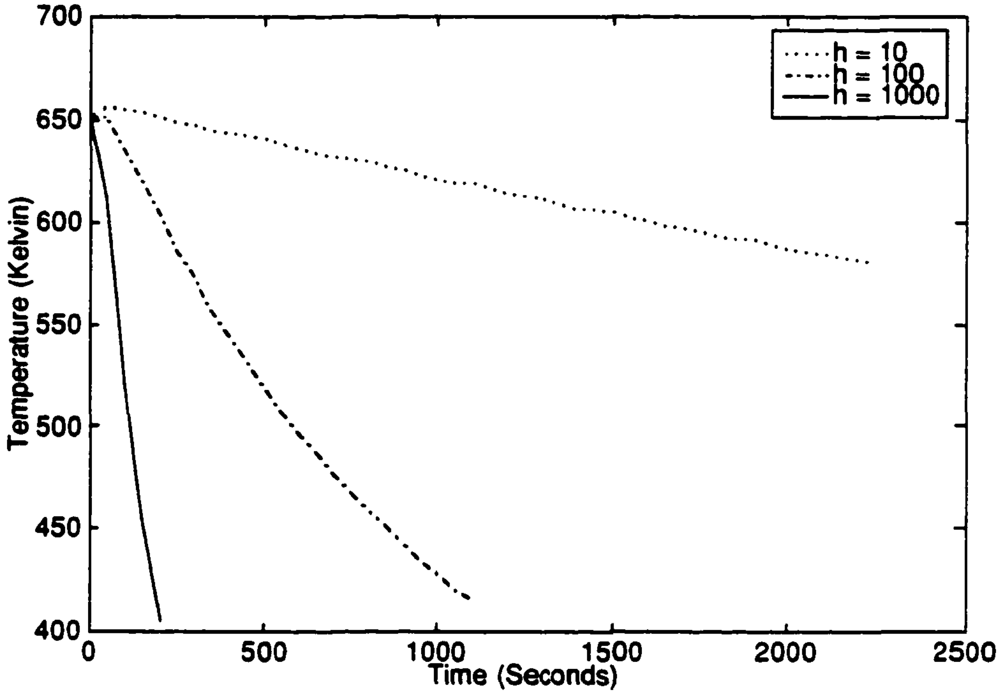

Figure 13 The numerical representation of the centerline cooling rate of the pultrusion simulator block when the heat input is 1 kW and no cooling passages are used.

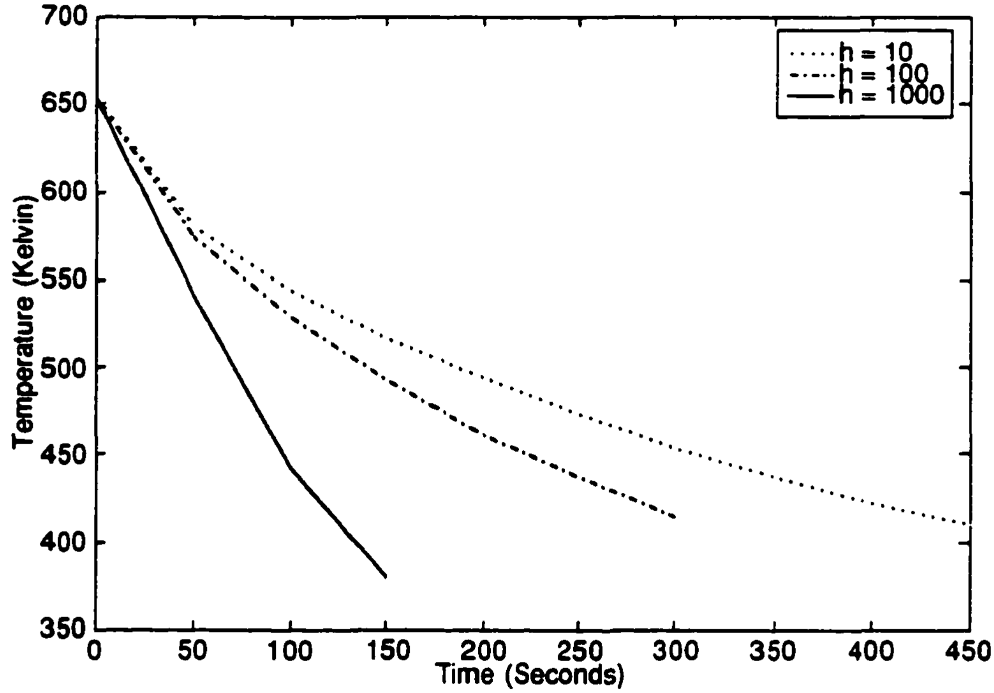

Figure 14 The numerical representation of the centerline cooling rate pultrusion simulator block when the heat input is 1 kW and cooling passage location #1 is used.

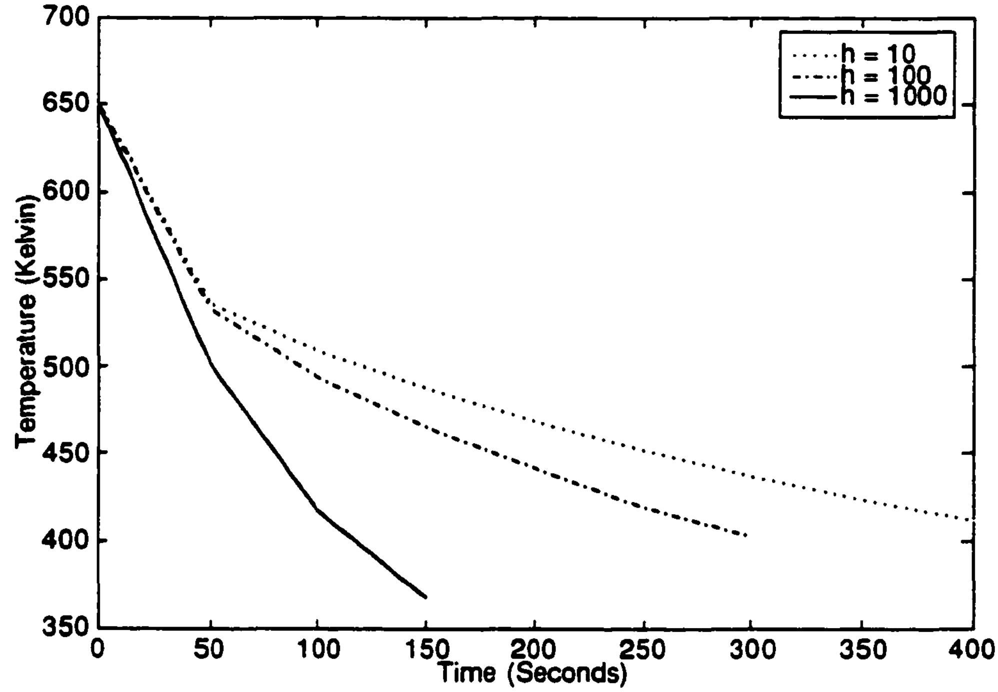

Figure 15 The numerical representation of the centerline cooling rate of the pultrusion simulator block when the heat input is 1 kW and cooling passage location #2 is used.

and the heat input was held constant at 1 kW. The numerical data yielded cooling rates of 0.11 K/second in the case of no cooling passages, 0.64 K/second in the case of cooling passage location #1, and 0.71 K/second in the case of cooling passage location #2, depicted in Figure 16.

Figure 17 graphically depicts the numerically evaluated cooling rate using the experimentally found external and initially assumed values of heat transfer coefficients. Figures 18 and 19 graphically depict the previous graphed information with the addition of cooling passage location #1 and cooling passage location #2.

Upon closer inspection of the data presented numerically for the cooling rate at the measured external heat transfer coefficient of 80 W/m^2K and the experimentally measured cooling rate, it was discovered that the actual cooling rate that occurred in the pultrusion simulator did not coincide with that of the numerically represented cooling rate. This discrepancy was attributed to the two-dimensional analysis done on the pultrusion simulator block as opposed to a three-dimensional numerical analysis. The overall heat transfer from the pultrusion simulator block appeared to be greater than that represented in the two dimensional modeling. Taking the increased heat transfer into account, a pseudo-external heat transfer coefficient was then calculated. This pseudo-external heat transfer coefficient was found to be 90 W/m^2 K. Figure 20 depicts graphically the cooling rates that occurred when the experimentally found external heat transfer coefficient, the pseudo-external heat transfer coefficient, and the experimentally measured cooling rate are used. The cooling rate found when no cooling passages were used along with the pseudo-external heat transfer coefficient was calculated as 0.13 K/second. Figures 21 and 22 give a graphical depiction similar to that of Figure 20 with the addition of cooling passage location #1 and cooling passage location #2. The cooling rate found in the case of cooling

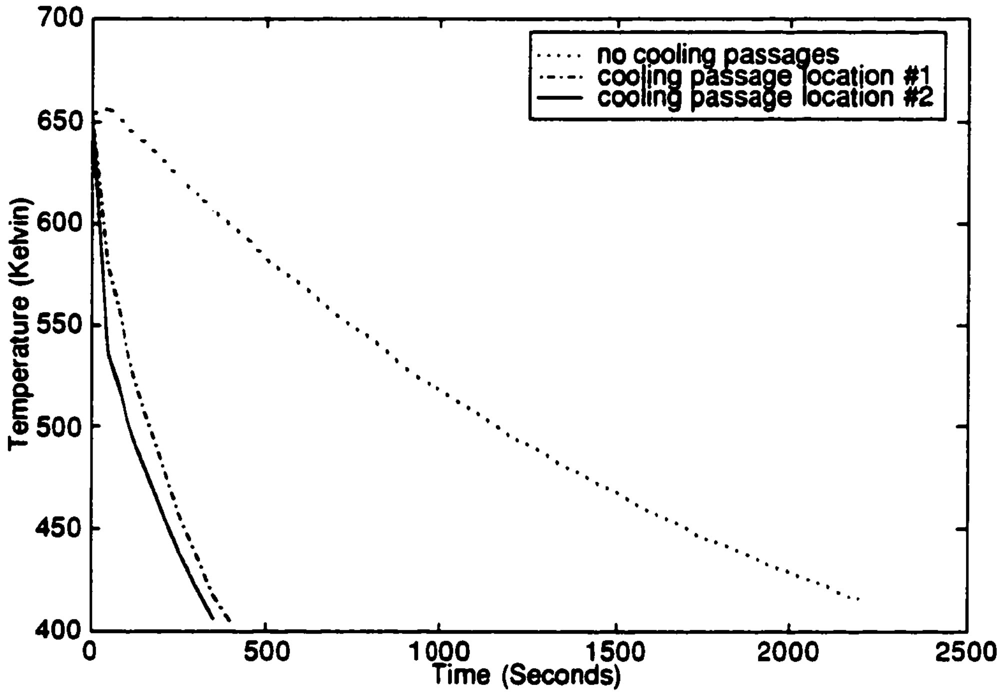

Figure 16 A comparison of the effects of cooling passages on the numerically represented centerline cooling rate of the pultrusion simulator block at the experimentally measured external heat transfer coefficient of $80W/m^2K$.

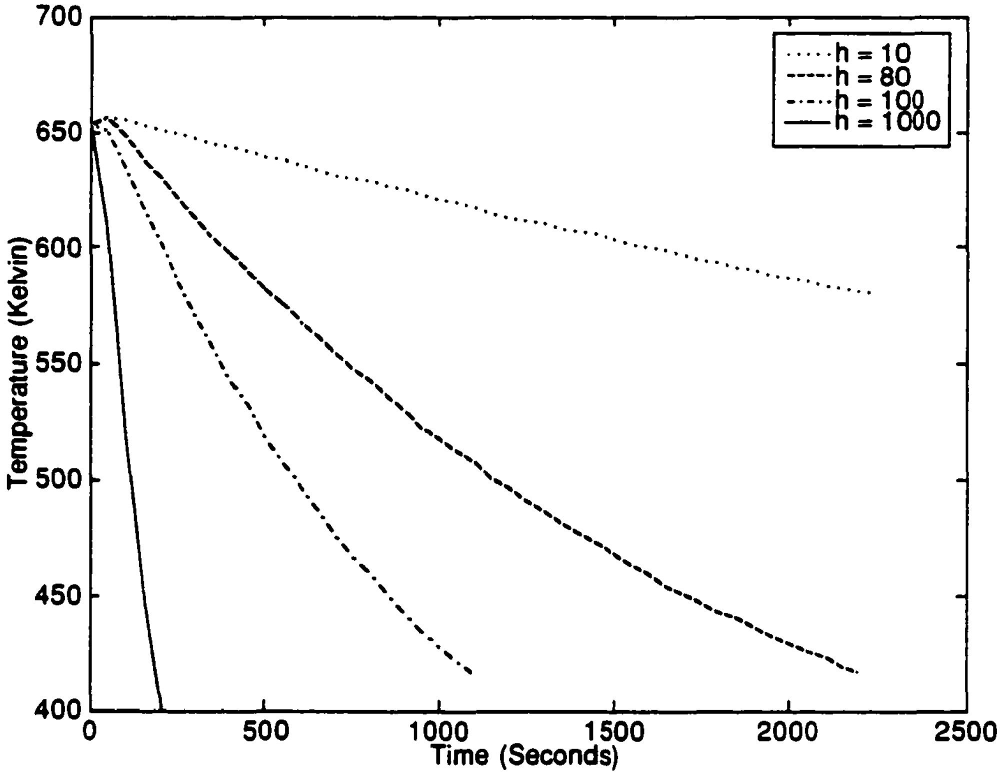

Figure 17 The numerical representation of the effect of different external heat transfer coefficients on the centerline cooling rate of the pultrusion simulator block when no cooling passages are used.

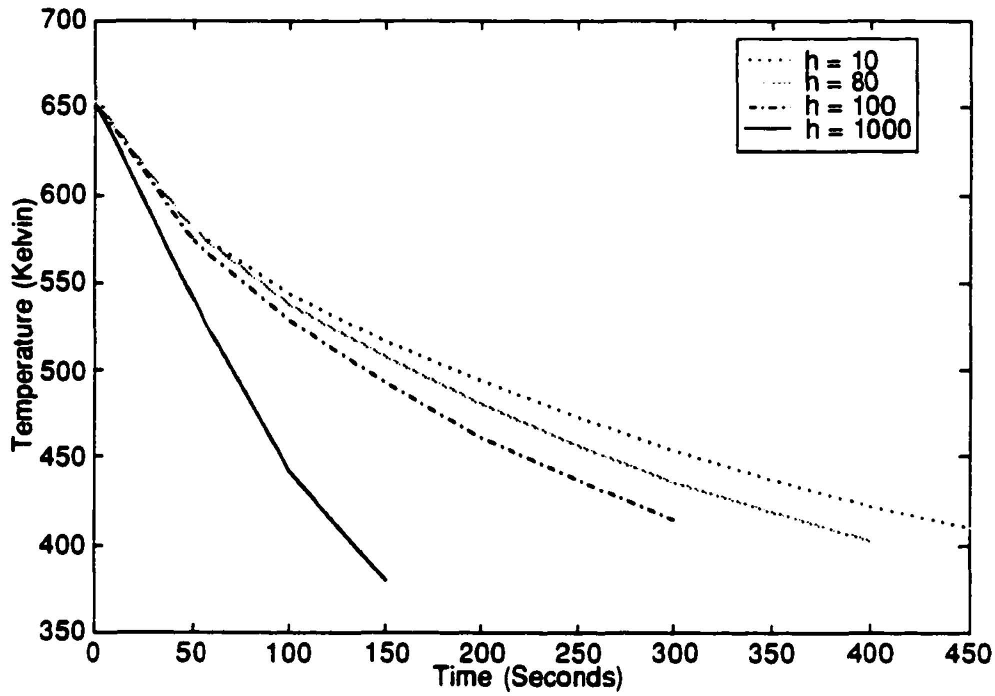

Figure 18 The numerical representation of the effect of different external heat transfer coefficients on centerline cooling rate of the pultrusion simulator block when cooling passage location #1 is used.

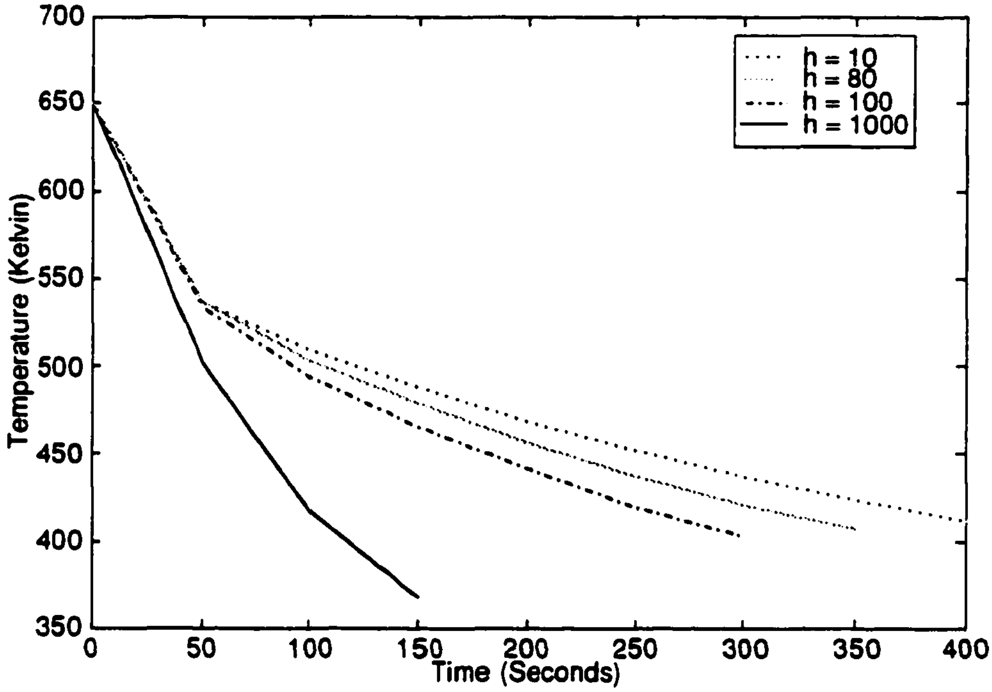

Figure 19 The numerical representation of the effect of different external heat transfer coefficients on centerline cooling rate of the pultrusion simulator block when cooling passage location #2 is used.

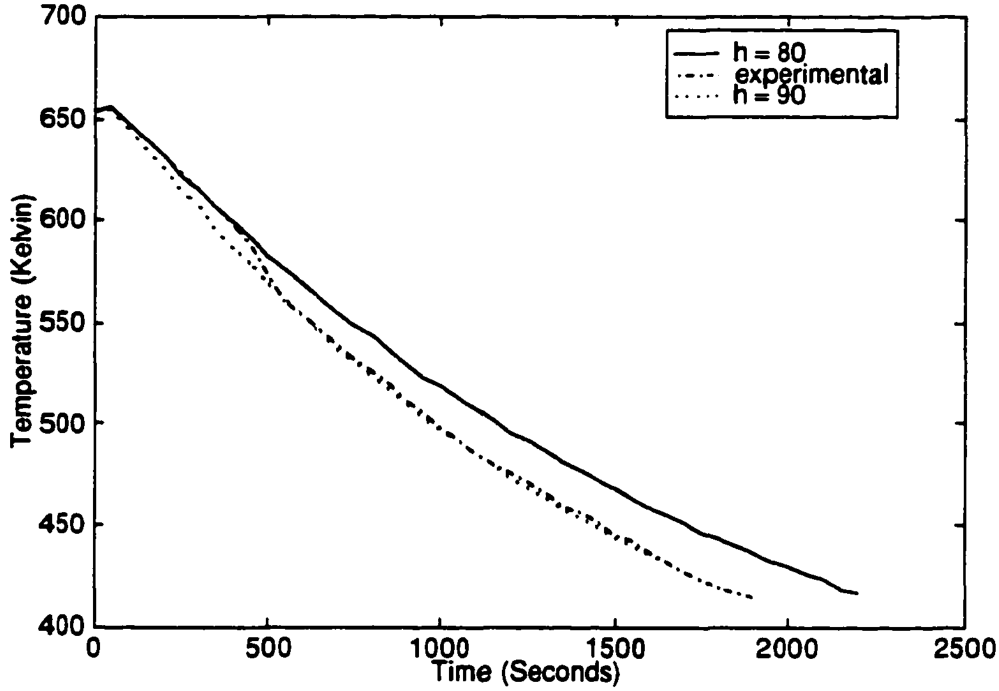

Figure 20 A comparison of the experimentally measured centerline cooling rate to the numerical representation of the cooling rate of the pultrusion simulator block when the experimentally measured external heat transfer coefficient and pseudo-external coefficient are used in the case of no cooling passages.

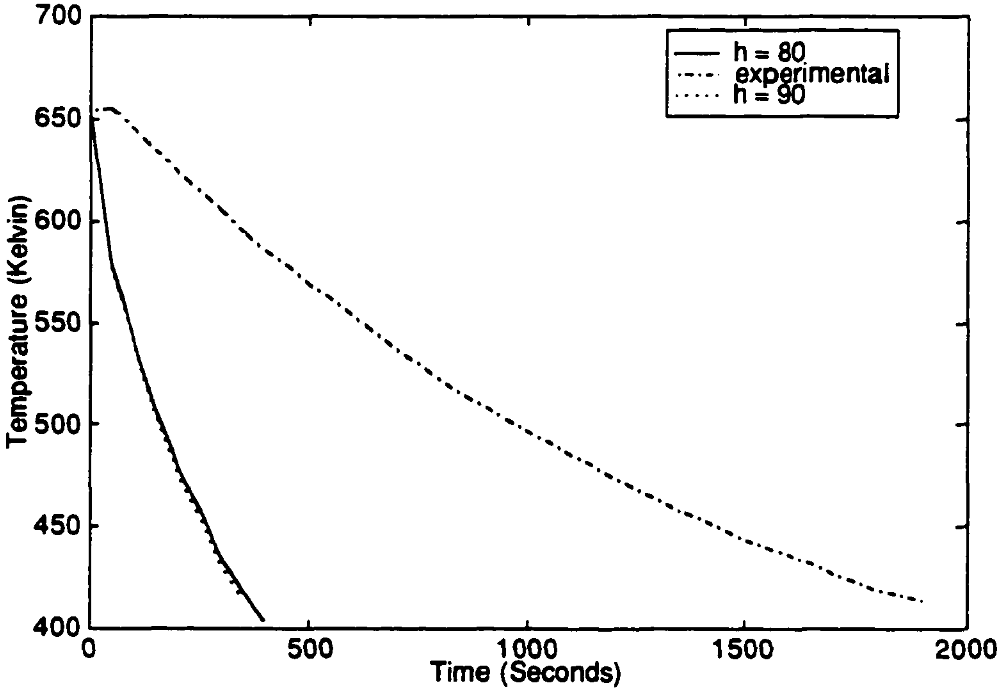

Figure 21 A comparison of the numerical representation of centerline cooling rate of the pultrusion simulator block when the experimentally measured external heat transfer coefficient is used in the case of no cooling passages to the centerline cooling rate when the experimentally measured external and pseudo-external heat transfer coefficients are used in the case of cooling passage location #1.

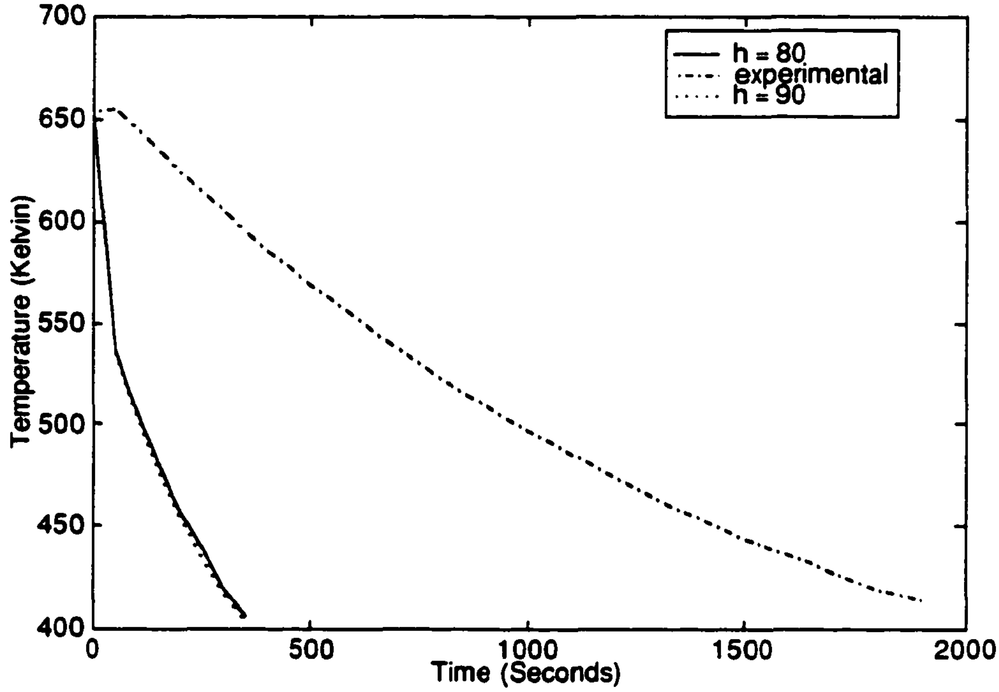

Figure 22 A comparison of the numerical representation of centerline cooling rate of the pultrusion simulator block when the experimentally measured external heat transfer coefficient is used in the case of no cooling passages to the centerline cooling rate when the experimentally measured external and pseudo-external heat transfer coefficients are used in the case of cooling passage location #2.

passage location #1 was 0.68 K/second and the cooling rate found in the case of the cooling passage location #2 was 0.71 K/second.

The pseudo-external heat transfer coefficient was used in all of the following numerically modeled cases. Figure 23 shows the graphically represented cooling distribution occurring in the block when no cooling passages and the two different cooling passage locations are utilized. Graphical representation of the isotherms were compiled using the MATLAB Program which because of the coarse matrix didn't give orthogonal lines at the insulated surfaces which was unrepresentative of the data collected within the numerical analysis. Figures 24, 25, and 26 show the isotherms of the calculated temperature in the pultrusion simulator block when no cooling passages were used. Figure 24 shows the isotherms of the calculated temperature in the pultrusion simulator block when cooling was initiated. Figure 25 shows the isotherms of the calculated temperature in the pultrusion simulator block after 350 seconds of cooling. Figure 26 shows the isotherms of the calculated temperature in the pultrusion simulator block 1900 seconds after cooling was initiated.

Contour graphs of the heat distribution throughout the pultrusion simulator block when cooling passage location #1 was utilized are portrayed in Figures 27, 28, and 29. Figure 27 is a contour plot showing temperature distribution throughout the analyzed portion of the pultrusion simulator block when cooling was initiated. Figure 28 is a contour plot when cooling occurred for 200 seconds. Figure 29 is a contour plot when cooling occurred for 350 seconds. Figures 30, 31, and 32 show the heat distribution in the pultrusion simulator machine at the same time intervals above utilizing cooling passage location #2.

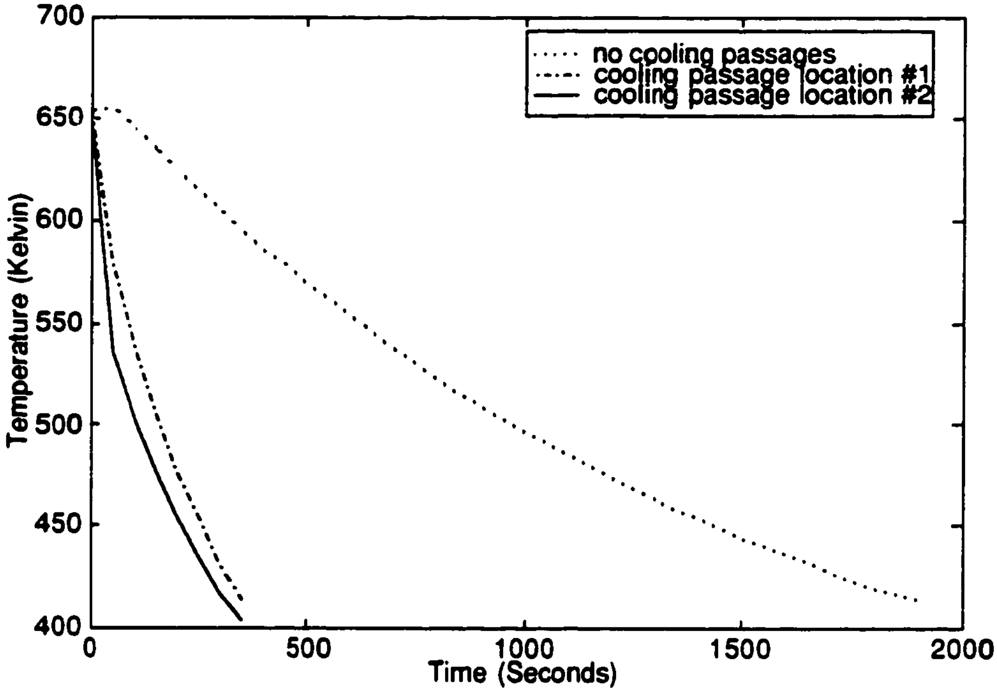

Figure 23 The numerical representation of centerline cooling rate of the pultrusion simulator block when the pseudo-external heat transfer coefficient is used in the case of no cooling passages and cooling passage locations #1 and #2.

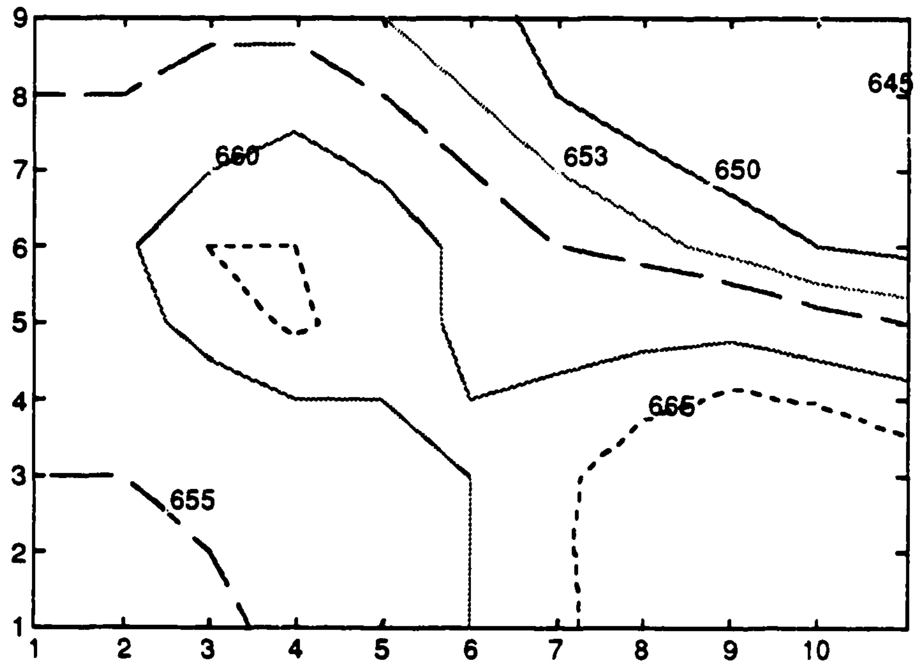

Figure 24 Isotherms of the calculated temperature distribution throughout the pultrusion simulator block when cooling is initiated in the case of no cooling passages and the external heat transfer coefficient is taken to be $90 W/m^2K$.

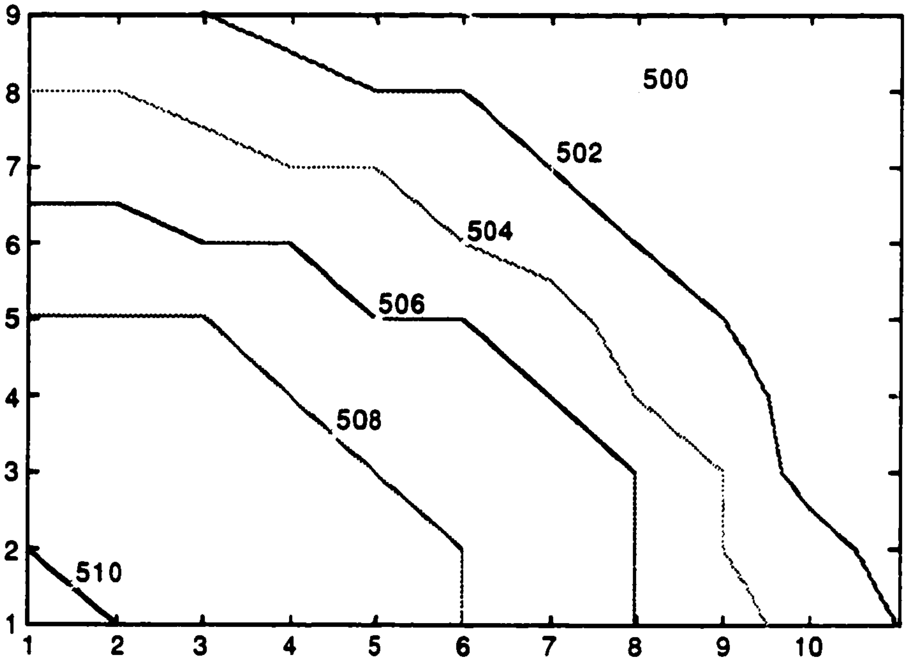

Figure 25 Isotherms of the calculated temperature distribution throughout the pultrusion simulator block 350 seconds after cooling is initiated in the case of no cooling passages and the external heat transfer coefficient is taken to be $90W/m^2K$.

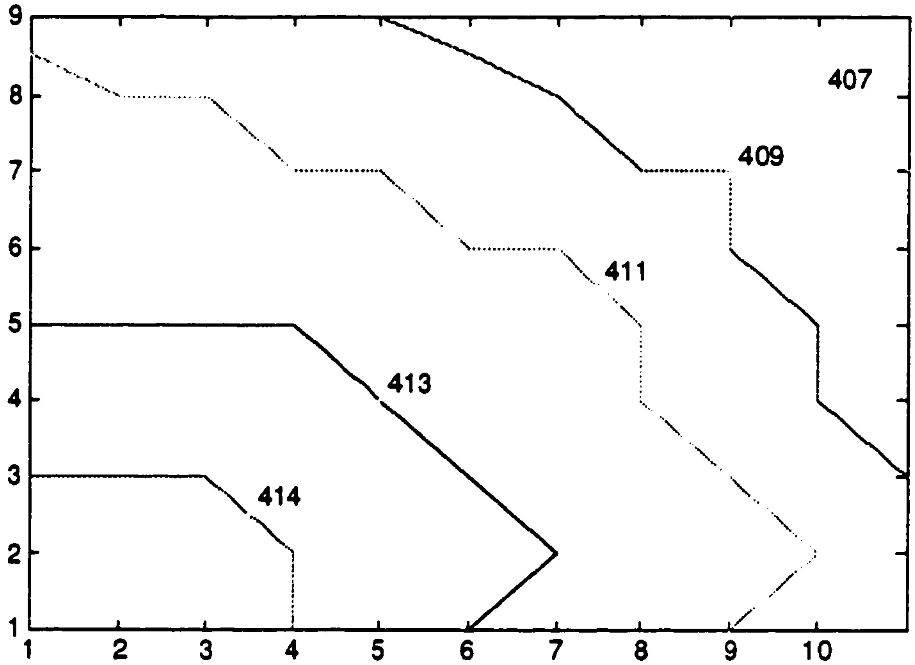

Figure 26 Isotherms of the calculated temperature distribution throughout the pultrusion simulator block 1900 seconds after cooling is initiated in the case of no cooling passages and the external heat transfer coefficient is taken to be $90 W/m^2K$.

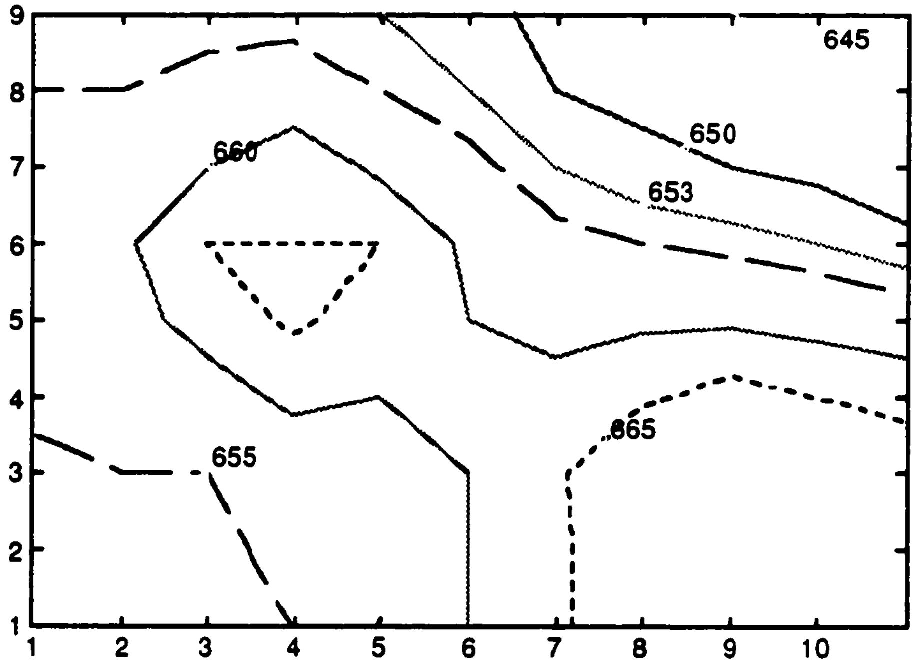

Figure 27 Isotherms of the calculated temperature distribution throughout the pultrusion simulator block when cooling is initiated in the case of cooling passage location #1 and the external heat transfer coefficient is taken to be 90W/m^{2}K.

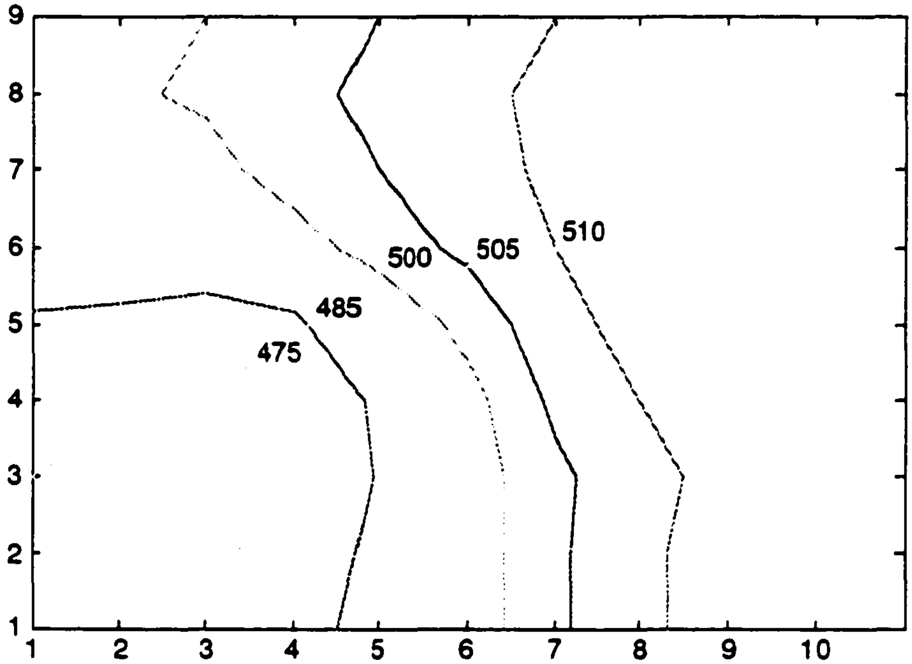

Figure 28 Isotherms of the calculated temperature distribution throughout the pultrusion simulator block 200 seconds after cooling is initiated in the case of cooling passage location #1 and the external heat transfer coefficient is taken to be 90W/m^{2}K.

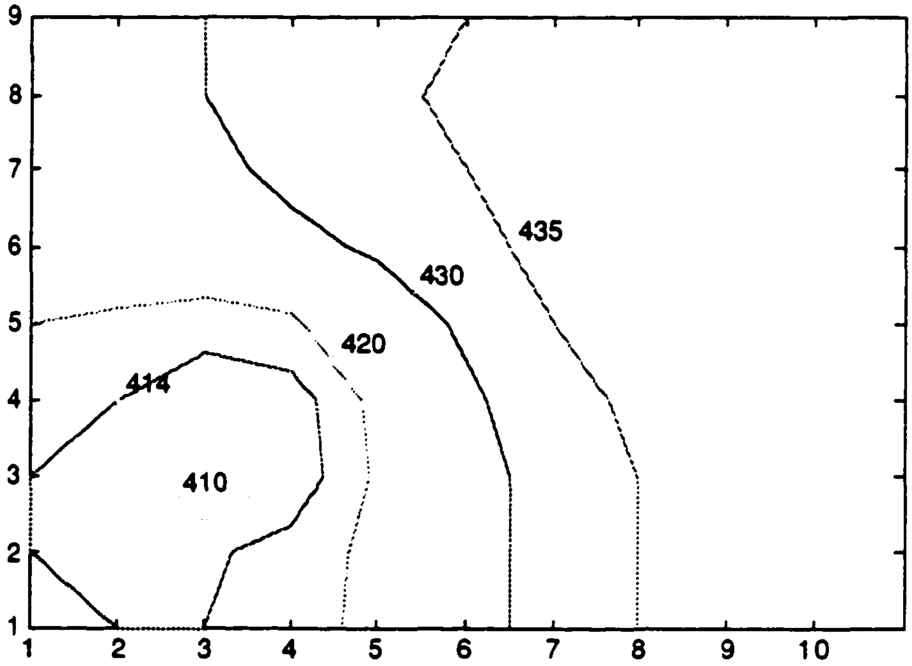

Figure 29 Isotherms of the calculated temperature distribution throughout the pultrusion simulator block 350 seconds after cooling is initiated in the case of cooling passage location #1 and the external heat transfer coefficient is taken to be 90W/m^{2}K.

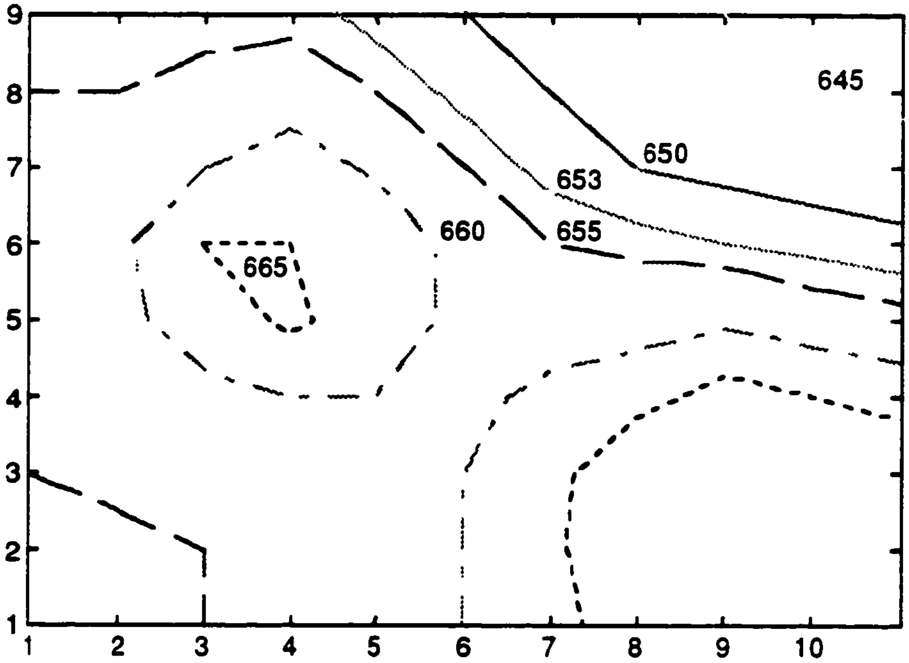

Figure 30 Isotherms of the calculated temperature distribution throughout the simulator block when cooling is initiated in the case of cooling passage location #2 and the external heat transfer coefficient is taken to be $90W/m^2K$.

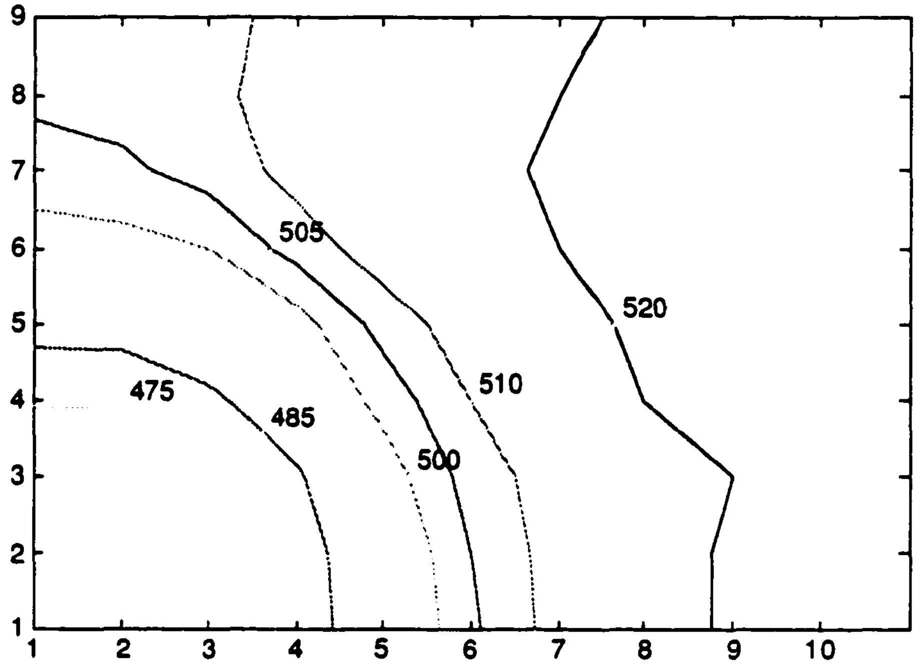

Figure 31 Isotherms of the calculated temperature distribution throughout the pultrusion simulator block 200 seconds after cooling is initiated in the case of cooling passage location #2 and the external heat transfer coefficient is taken to be $90W/m^2K$.

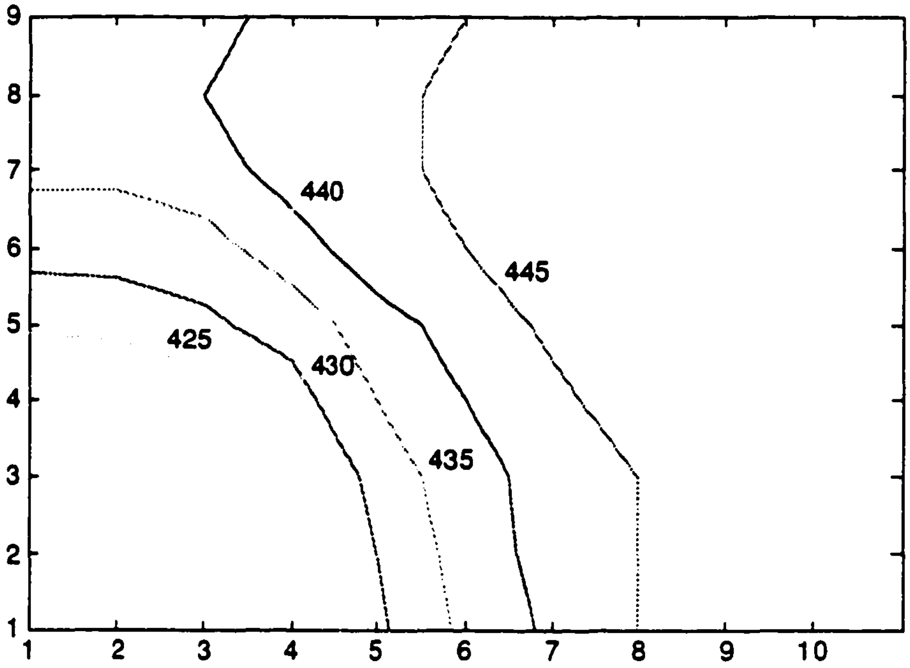

Figure 32 Isotherms of calculated temperature distribution throughout the pultrusion simulator block 350 seconds after cooling is initiated in the case of cooling passage location #2 and the external heat transfer coefficient is taken to be $90 W/m^2K$.

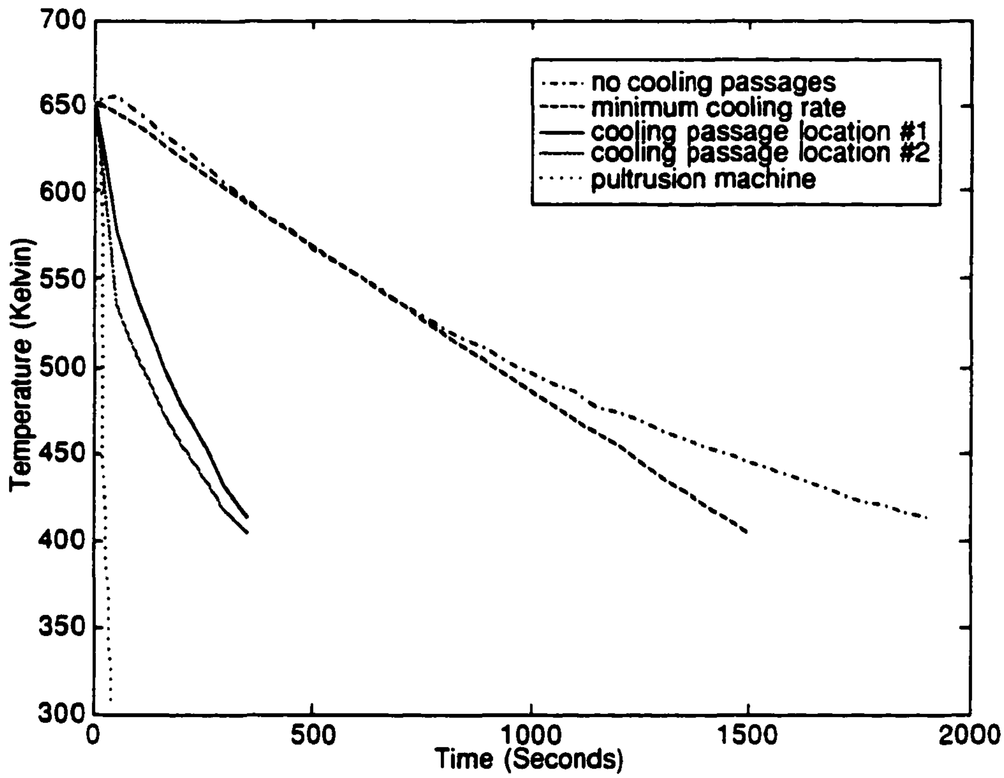

Figure 33 A comparison of the cooling rate that occurs in the pultrusion machine and the results from the numerical model in the cases of no cooling passages and cooling passage locations #1 and #2, assuming the external heat transfer coefficient of 90W/m^{2}K, with the minimal cooling rate required for optimum processing of carbon/PEEK composite fiber.

CHAPTER 6

CONCLUSIONS

Experimentation done on the pultrusion machine and pultrusion simulator block gave cooling rates occurring in each device. A numerical model done on the pultrusion simulator block was incorporated to measure the cooling rate if cooling passages were added to the existing structure.

It was found numerically that with an external heat transfer coefficient of 90 W/m^2K the experimental cooling rate of the pultrusion simulator block matched the cooling rate determined in the numerical model at the value of 0.13 K/second. It was also found that with the addition of cooling passage location #1 and cooling passage location #2 that the cooling rate within the pultrusion simulator machine increased to 0.68 K/second and 0.71 K/second respectively.

Variations in heat input didn't have any real bearing on what occurred in the cooling cycle of the pultrusion simulator block. Increased heat input caused an overshooting of centerline temperature, therefore making it hard to judge the temperature at which to manually set the heating device.

The addition of cooling passages would place the cooling rate of the carbon/PEEK composite fiber within the optimum range for cooling but still would fall short in cooling when compared with the slowest cooling rate of 4.8 K/second experienced in the pultrusion machine at 3 inches/minute and a consolidation die temperature of 643 K. Similar cooling rates to those which occur with the addition of cooling passages could be achieved with an

increase of the external heat transfer coefficient on the sides of the pultrusion simulator block.

The pultrusion simulator was a device that applied pressure and heat during the thermal cycle. Cooling of the pultrusion simulator blocks would have to be achieved by positioning of the cooling passages inside of the blocks to make sure that the applied pressure was continuous throughout the manufacturing process. The cooling that occurred in the pultrusion machine was achieved by using a cooled die which was held at a fairly constant temperature of 30°C (303 K). These differences in cooling methods contributed to the inability of the pultrusion simulator blocks to achieve a cooling rate similar to that occurring in the pultrusion machine.

APPENDIX I

COMPOSITE MATERIALS

As a direct reflection of the need to have a material that offers such advantages as wear resistance, faster assembly, corrosion resistance, and high fatigue strength, composites are becoming a more viable option. These types of materials are used today in such things as appliances, electrical and electronic parts, medical equipment, automotive parts, aircraft structures and space vehicles. Some specific examples of composite material usage are the National Aerospace Plane, the Corvette, Fiero and Avanti automobiles, Boeing Model 767, the Beech Starship, the Voyager aircraft, and the Lear Fan Model 2100. The Lear Fan Model 2100 was the first all-composites airplane. The Voyager aircraft was also an all-composite structure. It circled the world without stopping and without refueling. The Beech Starship is a commercial airplane which is composed of an all composite body. The Boeing Model 767 has an outer surface that is 30% covered by polymer-based composite material. The Corvette, Fiero, and Avanti automobiles had bodies made of composites, and some appeared over 45 years ago. The National Aerospace Plane uses carbon-carbon composites, ceramic matrixes, and metal matrixes for the principal materials of the skin of the plane because of the extremely high temperatures that will occur because of the re-entry of the plane into the atmosphere.

A composite is the combination of a reinforcement mateerial in a matrix or binder material. These reinforcements can be fibers, particles, and whiskers. The forms of

matrices are polymer, ceramic, and metal. Reinforcements can also be made of some matrix forms.

A range of commercial composites based on thermoplastic matrix resins have emerged for high-temperature applications. They have unlimited storage life at room temperature, shorter fabrication time, low moisture absorption, excellent thermal stability, high toughness and damage tolerance, and short and simple processing cycles. These composites offer these advantages over the traditionally used thermoset and metallic composite counterparts. Some disadvantages of composites are the high cost of the materials, the lack specific well defined design rules, and the lack of manufacturing methods that produced large quantities of composite materials at a time.

The matrix in a composite performs two major functions; it transfers loads to the reinforcement and protects the reinforcement from harmful environmental effects. The polymer matrix is the most common matrix form in comparison to the forms of ceramics or metals. These polymers are divided into two classes: thermoplastics and thermosets.

These classifications of polymers are based upon the behavior of the polymer upon heating. A thermoset polymer undergoes various degrees of cross-linking in its final state after being cured by heat. The cross-linking reactions lead to the formation of a "set" product in which a three dimensional chemical bond is formed. Thermoplastic materials are not generally cross-linked. In contrast, thermoplastic polymers do not undergo chemical changes during consolidation; changes are substantially physical. Generally, thermoplastics are solids which are melted, consolidated by the application of heat and pressure, and cooled to achieve their solid form. Thermoplastics can be processed using some metal-working devices as well as thermoplastic forming techniques, such as matched die forming, hydroforming, and thermoforming. Thermoplastics also can be repeatedly softened by heating and hardened by cooling.

Thermoplastic polymer and thermoset polymers are composed of molecular chains. Thermoplastics have individual molecules are linear in structure with no chemical linking between them as opposed to their thermoset counterpart which are interconnected with chemical bonds. Thermoplastics are held in place by weak secondary bonds (intermolecular forces), such as van der Waals bonds and hydrogen bonds. With the application of heat and pressure, these intermolecular bonds in a solid thermoplastic polymer can be temporarily broken, and the molecules can then be moved to form new intermolecular secondary bonds thus conforming to a new reprocessed shape after the thermoplastic freezes upon cooling. Thus a thermoplastic polymer can be heat softened, melted and reshaped (post-formed) as many times as desired. Thermosets cannot be remitted because of their cross-linking. Thermoplastics are usually less rigid than thermosets and exhibit low temperature performance in contrast to their counterparts. Thermosets usually require much longer processing times because of the curing process they must go through to achieve its desired shape. Thermoplastics can be reprocessed, have shorter cure cycles, excellent solvent resistance, indefinite shelf life, soften on heating and pressure, harden upon cooling, have higher fabrication temperatures, high melt viscosity, approximately 15 seconds to 6 hours processing cycles, processing temperatures of approximately 700° C, have good mechanical properties, exceptional durability , are easy to repair, and are not tacky and easy to handle. Some examples of thermoplastics are polyhenylene sulfide (PPS), polyethylene, poly-ether-ether-ketone (PEEK), and polystyrene.

Thermosets decompose upon heating, have a definite shelf life, can not be reprocessed, have lower fabrication temperatures, are tacky, have long cure cycle, easy fiber impregnation, low melt viscosity, have 1 - 6 hours processing cycle, approximate

processing temperature of 350° C , and only have a fair solvent resistance. Some examples of thermosets are epoxies, polyamide, polyesters, and phenolics.

Thermoplastics are usually divided into two categories; traditional industrial thermoplastics and high-performance thermoplastics. The traditional thermoplastics usually consist of those common in everyday usage. Some examples of these thermoplastics are polyethylene, nylon, polystyrene, polyester, polycarbonate, and acrylic. Picking the perfect traditional thermoplastic for usage depends on such factors as cost, environmental resistance, lubricity, resistance to creep, and processability. The number of methods used to process conventional thermoplastics is massive.

Thermoplastic resin materials have been developed for use in composite materials to improve thermal and mechanical capabilities above and beyond those of the conventional, industrial thermoplastics. These materials are usually much more costly than conventional, industrial thermoplastics. One of the most common known high-performance thermoplastic matrices is poly-ether-ether-ketone (PEEK).

The performance of high-performance thermoplastic composites are characterized by the glass temperature, T_g, of the matrix and its morphology. Their high T_g give these high-performance thermoplastic composites their inherently good mechanical performance. Below T_g a polymer is in a glassy state while above T_g, the material softens as the temperature increases and the material becomes rubbery. These materials have better impact resistance than thermoset materials. This is an important factor in the development of aircraft structures.

These high-performance thermoplastics are characterized chemically as being highly aromatic and semi-crystalline in structure. An increase in T_g will in turn give good thermal stability. These thermoplastics have long repeating chemical chains, high crystallinity, high modulus, low creep, and high solvent resistance. The prepegs of high-performance thermoplastics are generally stiff and do not conform to molds so therefore have to softened

by applying heat with heat guns, soldering irons, and other such heating devices. These devices make the high-performance thermoplastics sticky and malleable.

The morphology of a thermoplastic composite is concerned with the shape, arrangement, and function of crystals alone or embedded in the solid. It is important to know how the morphology of the matrix of the composite is affected by processing conditions and how mechanical properties are affected by the morphology of the polymer. Factors that affect morphology of semi-crystalline thermoplastics are molecular weight, presence of other materials (impurities), and processing conditions (temperature at melt and the time it is held at this temperature, cooling rate, etc.).

A high cooling rate leads to lower crystalline contents in the final product. Slower cooling rate produces a higher crystallinity in the matrix, which in turn may have some influence on the matrix properties, particularly its fracture toughness. Crystallinity of the solidified matrix depends very much on the cooling rate. Crystallinity is also influenced by other processing parameters such as the temperature to which the polymer is heated and it's dwell time. A temperature high enough to melt all the crystalline material formed during previous thermal treatments has to be chosen when processing semi-crystalline thermoplastics.

APPENDIX II

CARBON/PEEK COMPOSITE FIBERS

The thermoplastic composite used in this study was commingled carbon/PEEK (poly-ether-ether-ketone). PEEK is a semi-crystalline thermoplastic. It has a glass transition temperature, T_g, of 143°C and a crystalline melting point, T_m, of 335°C. The melt processing of PEEK requires a range of 370°C to 400°C (Schwartz, 1996). The maximum continuous use temperature of PEEK is 250°C. PEEK has outstanding properties such as high fracture toughness, low water absorption, and doesn't dissolve in most common solvents.

The normal recommended cooling rates to achieve optimum composite properties with a PEEK matrix are between 10°C /minute and 700°C /minute (Schwartz, 1996). In this range there is little variation in the degree of crystallinity, about 25 % to 30 %. At cooling rates lower than 10°C/minute, degrees of crystallinity in excess of 35 % will be achieved which will result in some reduction in toughness. At cooling rates greater than 700°C /minute, growth of spherlilites (crystalline) texture of melting crystallized polymer will be incomplete and the optimum level of crystallinity will not be reached which may result in some reduction in stiffness and resistance to hostile solvents. At cooling rates greater than 200 °C/minute, the PEEK matrix will be essentially amorphous.

Crystallinity of the PEEK matrix is also influenced by other processing parameters such as the maximum temperature attained in the polymer and the time it is held there. A lower level of crystallinity in the PEEK matrix will produce higher elongation and better toughness but with the trade-off of lower strength, thermal stability, and chemical resistance.

APPENDIX III

MANUFACTURING METHODS OF COMPOSITE MATERIALS

A method of making shaped thermoplastic matrices is to first shape the thermoplastic into fibers and intermingle the fibers with the normal reinforcement fibers. When these commingled fibers are heated and pressure is applied, the thermoplastic fibers melt and coat the reinforcement fibers. Also fibers can be intermingled with reinforcement fibers of thermoplastic resin powder. This gives a prepreg material that is easily processed.

In most cases the methods used to process and manufacture high-temperature thermoplastic matrices are similar to those of thermoset methods. Several methods used to process high-temperature thermoplastic matrices are pultrusion, compression molding, filament winding, automated tape laying, extrusion, and thermoforming.

Pultrusion is a continuous process that produces long, straight, cross-sectional profiles. This process can produce standard shapes such as rods, channels, and plates. It is also able to replicate different pressure and temperature combinations.

There are several advantages to using the pultrusion process. One advantage is that the die can have multi-cavities. Therefore, if needed, more than one composite structure can be pultruded at a time. Another advantage is that long lengths of composite structures can be pultruded. Adjustable dies allow for change in thickness of the thermoplastic composite being pultruded. Pultrusion combines several composite manufacturing steps into one process. This feature also minimizes the amount of material that has to be in cold

storage. The last advantage is the versatility of the process; it allows for various types of matrix resin to be used.

There are really no limitations to the pultrusion process; although there are several difficulties. The more complex and complicated the design of the composite part, the more difficult the part is to pultrude. Pultrusion has been mainly used to manufacture composite structures with constant cross-sectional profiles. Today there are pultruded structures with variable thickness. The sizes and shapes of pultruded parts also have no real boundaries. Equipment and dies have been built and are being built to pultrude long composite structures.

Compression molding, one of the oldest manufacturing techniques, is used for transforming sheet molding compounds into finished products in matched molds. It is considered the primary method for manufacturing many structural automotive components such as wheels and bumpers. The main advantage of compression molding is its ability to produce complex geometries in short periods of time. Very little material is wasted in a compression molding operation. It is performed using simple tooling. Composite parts of non-uniform thickness can be incorporated using the compression molding process. It is possible to eliminate the soldering or heat gun to post-form the high-temperature thermoplastic matrix because of the compression molding device's ability to produce parts of non-constant cross-sectional area. The compression molding process is also suitable for the high volume production of thermoplastic composite materials. The parameters involved in the compression molding process are molding parameters which consist of mold temperature, molding pressure, mold closing speed, and charge specification. Material parameters also affect the outcome and resin paste formulation, resin-catalyst-inhibitor reactivity, maturation time, sheet thickness, sheet temperature. Tool parameters which are the mold design, shear edges, vents, ejection system, parting line, draft, tool material, and surface finish.

The compression molding process can be divided into three molding operations. These three molding operations are the charge preparation and placement, mold closing, and curing processes. The pre-cut and weighed amount of sheet metal compound placed in the preheated mold is referred to as the charge. Usually the charge consists of a stack of sheet metal compound. The dimensions of the sheet metal compounds are such that they only cover 60% to 70% of the surface area of the compression molding device. The location of this sheet metal compound is very important, it's a factor that affects the quality of the material being molded. Once the charge has been placed in the bottom of the mold half, the top half of the mold is lowered at a constant rate until the pressure on the charge reaches the preset level. Mold closing speed also affects the quality of the sheet molded compound produced. The bottom half and the upper half of the compression molding device are usually heated to reach the target mold temperature. Once the mold has been closed, it remains closed for a predetermined amount of time while the curing process occurs. This predetermined time is the curing time. The temperature distribution of the sheet metal compound is extremely important as cooling occurs. Finished compression molded sheet metal compounds are used in numerous applications such as computer enclosures, light truck tailgates and wheels.

The filament winding process of thermoplastics usually involves prepreg bundles of material. Preheating is usually necessary for proper laying of the thermoplastic composite onto the mandrel. The usually process of wet impregnation becomes an impractical part of this process because of the astronomical temperatures and high resin viscosities.

The automated tape laying process is a process that can be used for thermoplastic prepregs. The traditional automatic lay-down machines have been adapted for the specific purpose of accommodating thermoplastic prepegs. The only difference between this machine and the machine used for thermoset prepegs is that a special heated shoe is

attached to the applicator head. As the thermoplastic prepeg tape comes between the head and the mold, the tape is heated by the shoe, which softens it and gives it the tack and drape necessary to stick to the mold or previously laid down layers. A cooling shoe is placed just after the heated shoe to resolidify the tape and insure that it remains in place.

The extrusion process is a high-volume production process that creates parts with constant cross-sectional areas. It is a process in which the high-performance thermoplastic is pushed through a die and shaped. After shaping, the thermoplastic is then cooled and cut into its final desired shape. This process doesn't necessarily produce a finished part, it can be considered more or less a blending process that incorporates the fibers and resins into one.

The thermoforming process utilizes an oven, vacuum, and a mold. A sheet of thermoplastic material is heated with the aid of an oven and then removed and placed over a mold. Then a vacuum is used to pull the thermoplastic sheet into the shape of the mold.

APPENDIX IV

DIAGRAMS RELATED TO THE PULTRUSION SIMULATOR AND ITS ANALYSIS

The pultrusion simulator consisted of two primary blocks. These blocks are shown schematically below. Symmetry considerations are taken into account to allow the smaller region shown at the right hand side of the Figure to be considered.

Because symmetry lines were assumed, those two locations were taken to be insulated in the analysis. A heat transfer coefficient (actually a combined convection and radiation heat transfer coefficient) was taken to exist on the other two sides.

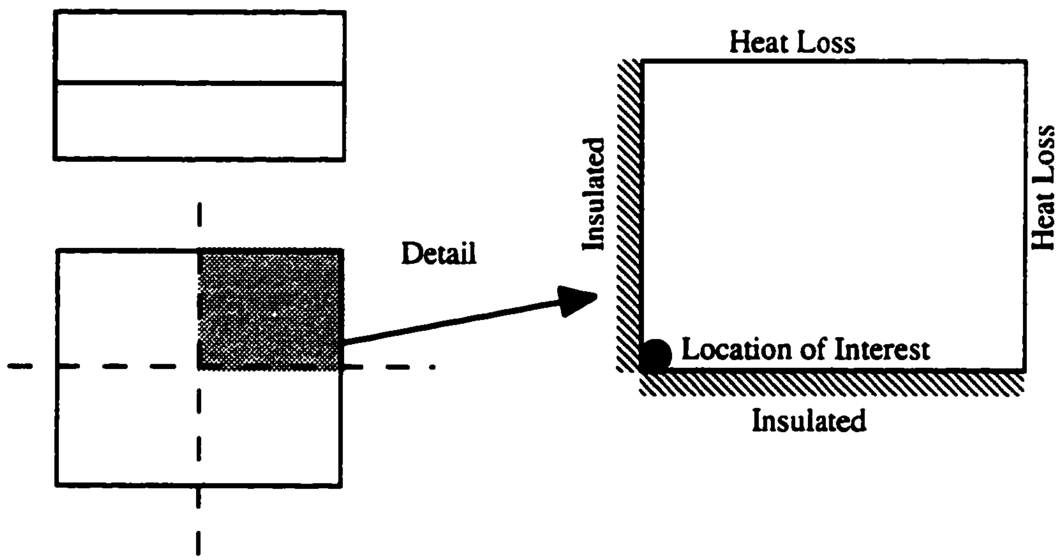

Figure IV-1. Schematic diagram of the pultrusion simulator blocks (left hand side). Details of the region of analysis are shown on the right. Not shown to scale.

APPENDIX V

EQUATIONS DERIVED FOR NUMERICAL MODELING

The general heat conduction equation for an isotropic solid is

$$\nabla^2 T + \frac{q}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t}.$$

Equations were derived using the explicit method to determine unknown nodal temperatures for the new time. The new nodal temperatures were determined from the known nodal temperatures at the previous time step. The transient temperature distribution is obtained with a marching solution with time.

(1) Internal Nodal Equation

$$T'_{m,n} = Fo_x(T_{m-1,n} + T_{m+1,n} - 2T_{m,n}) + Fo_y(T_{m,n-1} + T_{m,n+1} - 2T_{m,n}) + T_{m,n}$$

(2) Nodal Equation at Plane Surface with Insulation

$$T'_{m,n} = Fo_x T_{m+1,n} + Fo_y T_{m,n-1} + Fo_y T_{m,n+1} + (1 - 2Fo_x - 2Fo_y)\, T_{m,n}$$

(3) Nodal Equation at External Corner with Insulation and Convection

$$T'_{m,n} = 2Bi_x Fo_x T_{s,\infty} + 2Fo_x T_{m-1,n} + 2Fo_y T_{m-1,n} + (1 - 2Bi_x Fo_x - 2Fo_x - 2Fo_y)\, T_{m,n}$$

$$T'_{m,n} = 2Bi_xFo_xT_{s,\infty}+2Fo_xT_{m-1,n}+ 2Fo_yT_{m-1,n} +(1 - 2Bi_xFo_x - 2Fo_x - 2Fo_y)\, T_{m,n}$$

(4) Nodal Equation at External Corner with Insulation

$$T'_{m,n} = 2Fo_xT_{m+1,n}+2Fo_yT_{m,n-1} +(1 - 2Fo_x - 2Fo_y)\, T_{m,n}$$

(5) Nodal Equation at Plane Surface with Convection

$$T'_{m,n} = 2Bi_xFo_xT_{s,\infty}+2Fo_xT_{m-1,n}+ Fo_yT_{m,n+1} + Fo_yT_{m,n-1} + (1 - 2Bi_xFo_x - 2Fo_x - 2Fo_y)\, T_{m,n}$$

(6) Nodal Equation at External Corner with Convection

$$T'_{m,n} = 2Bi_xFo_xT_{s,\infty}+2Fo_xT_{m-1,n}+2Bi_yFo_yT_{s,\infty} + 2Fo_yT_{m,n+1} + (1 - 2Bi_xFo_x - 2Fo_x - 2Fo_y - 2Bi_yFo_y)\, T_{m,n}$$

(7) Nodal Equation Below the Heater

$$T'_{m,n} = Fo_xT_{m-1,n} + Fo_xT_{m+1,n}+Fo_yT_{m,n-1} +(1 - 2Fo_x - Fo_y)\, T_{m,n} + \frac{q}{4}$$

(8) Nodal Equation Above the Heater

$$T'_{m,n} = Fo_xT_{m-1,n} + Fo_xT_{m+1,n}+Fo_yT_{m,n+1} +(1 - 2Fo_x - Fo_y)T_{m,n} + \frac{q}{4}$$

(9) Nodal Equation Left of the Heater

$$T'_{m,n} = Fo_xT_{m-1,n} + Fo_yT_{m,n-1}+Fo_yT_{m,n+1} +(1 - Fo_x - 2Fo_y)T_{m,n} + \frac{q}{4}$$

(10) Nodal Equation Right of the Heater

$$T'_{m,n} = Fo_yT_{m,n-1} + Fo_yT_{m,n+1}+Fo_xT_{m+1,n} +(1 - 2Fo_y - Fo_x)\, T_{m,n} + \frac{q}{4}$$

(11) Nodal Equation at the Top Left Corner of Cooling Passage

$$T'_{m,n} = \frac{4}{3}Fo_xT_{m-1,n} + \frac{2}{3}Fo_xT_{m+1,n} + \frac{2}{3}Fo_yT_{m,n-1} + \frac{4}{3}Fo_yT_{m,n+1} - \frac{2}{3}Bi_yFo_yT_{s,\infty}+\frac{2}{3}Bi_yFo_yT_{m+1,n} - \frac{2}{3}Bi_xFo_xT_{s,\infty} +$$

$(1 - \frac{2}{3}Bi_xFo_x - 2Fo_x - 2Fo_y - \frac{2}{3}Bi_yFo_y)\ T_{m,n}$

(12) Nodal Equation at the Top Right Corner of Cooling Passage

$$T'_{m,n} = \frac{2}{3}Fo_xT_{m-1,n} + \frac{2}{3}Fo_yT_{m,n-1} + \frac{4}{3}Fo_yT_{m,n+1} + \frac{4}{3}Fo_xT_{m+1,n} - (\frac{2}{3}Bi_xFo_x + \frac{2}{3}Bi_yFo_y)\ T_{s,\infty} + (1 - \frac{2}{3}Bi_xFo_x - \frac{2}{3}Bi_yFo_y - 2Fo_x - 2Fo_y)\ T_{m,n}$$

(13) Nodal Equation at the Bottom Left Corner of Cooling Passage

$$T'_{m,n} = \frac{4}{3}Fo_xT_{m-1,n} + \frac{2}{3}Fo_xT_{m+1,n} + \frac{2}{3}Fo_yT_{m,n+1} + \frac{4}{3}Fo_yT_{m,n-1} - (\frac{2}{3}Bi_xFo_x + \frac{2}{3}Bi_yFo_y)\ T_{s,\infty} + (1 - \frac{2}{3}Bi_xFo_x - \frac{2}{3}Bi_yFo_y - 2Fo_x - 2Fo_y)\ T_{m,n}$$

(14) Nodal Equation at Bottom Right Corner of Cooling Passage

$$T'_{m,n} = \frac{4}{3}Fo_xT_{m-1,n} + \frac{2}{3}Fo_xT_{m-1,n} + \frac{2}{3}Fo_yT_{m,n+1} + \frac{4}{3}Fo_yT_{m,n-1} - (\frac{2}{3}Bi_xFo_x + \frac{2}{3}Bi_yFo_y)\ T_{s,\infty} + (1 - \frac{2}{3}Bi_xFo_x - \frac{2}{3}Bi_yFo_y - 2Fo_x - 2Fo_y)\ T_{m,n}$$

APPENDIX VI

GRID NETWORKS USED IN NUMERICAL MODEL

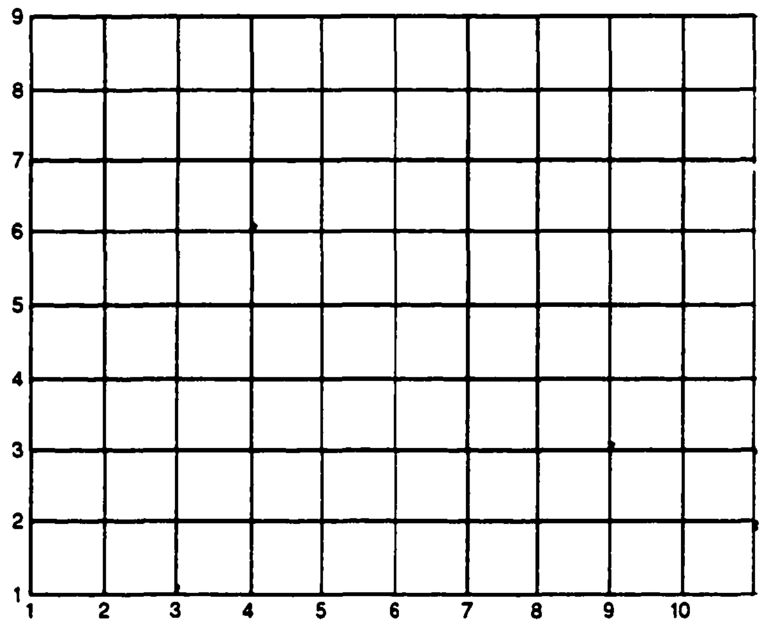

Figure VI-I Gridal network used for formulation of numerical model in the case of no cooling passages. The node points indicated by the symbol "*" denote the heater locations.

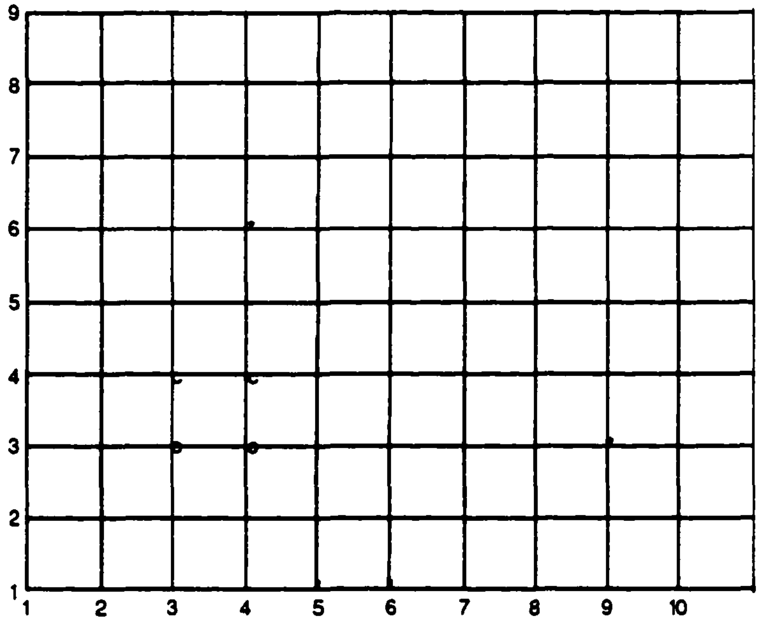

Figure VI-II Gird network used for formulation of numerical model in the case of cooling passage location #1. The node points indicated by the letter "c" denote the cooling passage. The node points indicated by the symbol "*" denote the heater locations.

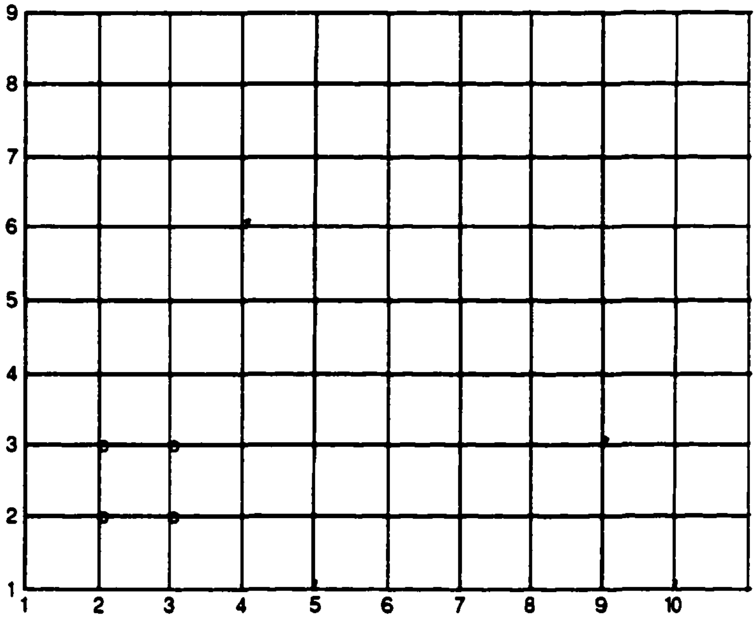

Figure VI-III Gird network used for formulation of the numerical model in the case of cooling passage location #2. The node points indicated by the letter "c" denote the cooling passage. The node points indicated by the symbol "*" denote the heater locations.

APPENDIX VII

THE PULTRUSION MACHINE AND THE PULTRUSION SIMULATOR DEVICE

The pultrusion line was broken up into five essential components. These components were the material feed, material guides, preforming area, curing and clamping, and pulling divisions. The curing process occurred in the preheat oven, consolidation die, and cooled die. The consolidation die and cooled die measured 3 inches in length and contained four channels within. In the consolidation die, these channels were used for the placement of the cartridge heaters. In the cooled die, these channels were used for the recirculation of fluid through the die.

The pultrusion simulator blocks measured 15.1 cm x 5.1 cm x 12.7 cm. It consisted of eight 1000 W cartridge heaters, four located in the upper half of the die and four located in the lower half of the die. It was constructed of mild steel. Cooling in the pultrusion simulator blocks was achieved by applying steady streams of air to each side of the die with two diffuser nozzles set at 35 psi and positioned at approximately an angle of 45° and a foot away.

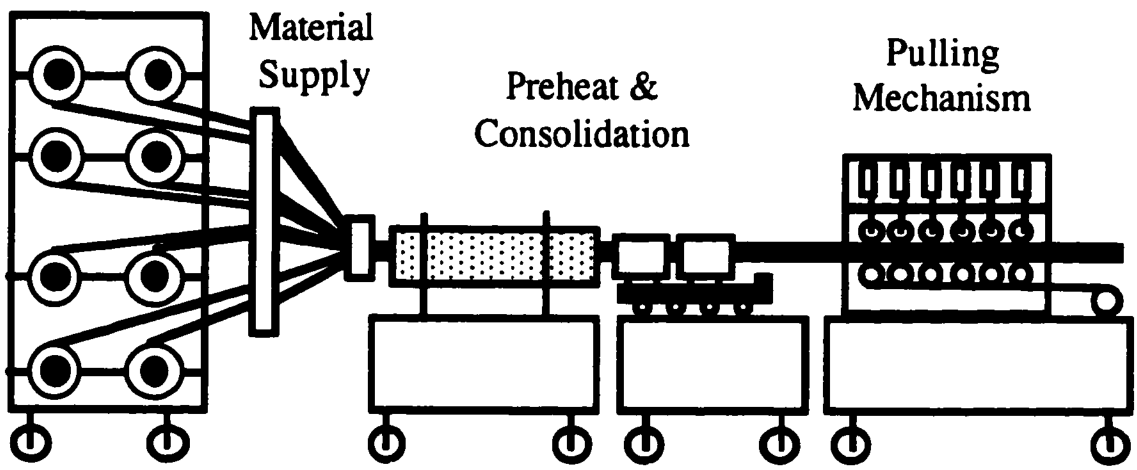

Figure VII-I. Schematic diagram of the pultrusion line. Not drawn to scale

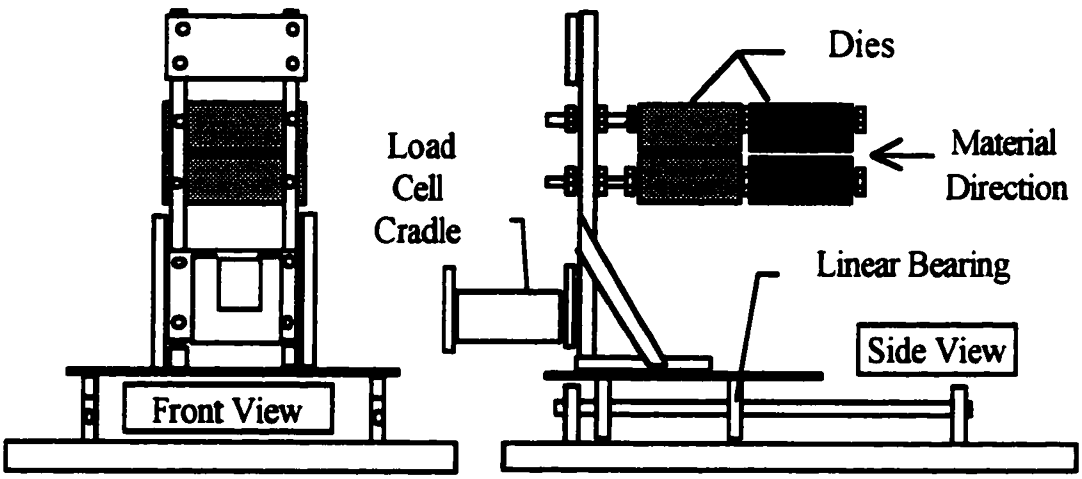

Figure VII-II. Schematic diagram of the consolidation die and cooled die. Not drawn to scale.

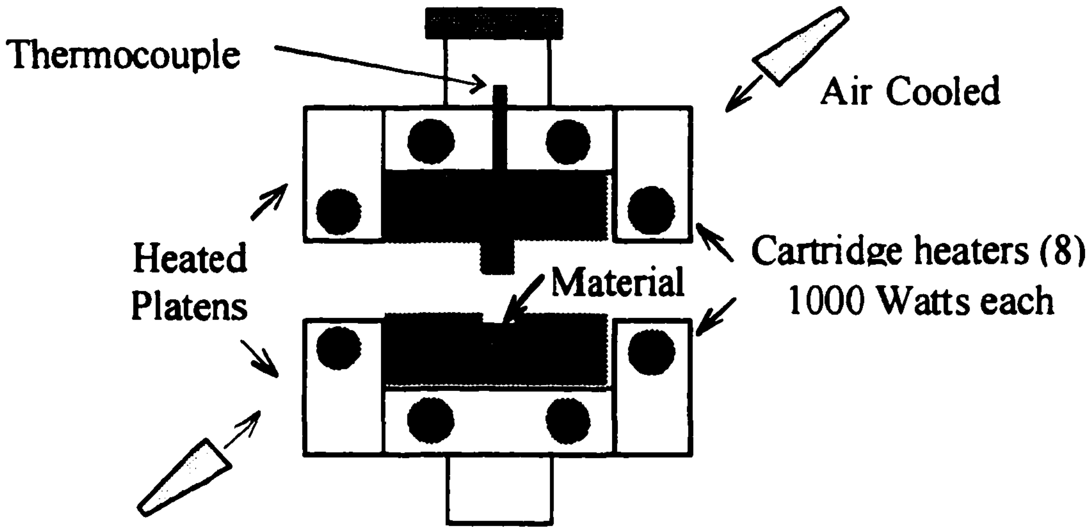

Figure VII-III. Schematic diagram of the pultrusion simulator blocks. Not drawn to scale.

APPENDIX VIII

FORTRAN 77 PROGRAMS DEVELOPED FOR NUMERICAL MODELING

Three FORTRAN 77 programs were developed from the finite difference method to simulate the environment of the pultrusion simulator block. The first FORTRAN 77 program numerically simulated the actual thermal process occurring when cooling was achieved within the block by the method of forced external heat transfer due to the application of air streams on its sides. The final two FORTRAN 77 programs numerically simulated the heat transfer that would occur in the pultrusion block if the cooling involved the addition of specially designed passages or/and an increased external heat transfer coefficient.

```
*
*     Program Explicit Method
*     no cooling passage locations
*
      real T(1:20000,1:100),dx,dy,fox,foy,k,biy,rho,cp,
     +     alpha,hl,hl,hb,hlco,hbco,bixl,bixlco,
     +     dt,Ta,q,Tinf,setpoint,ssetpoint,corner,cornert,
     +     biyb,biybco
      integer i,j,l,m,n,count,countt
      print*,'Enter the node spacing in the x direction in meters'
      read*, dx
      print*,'Enter the node spacing in the y direction in meters'
      read*, dy
      print*,'Enter the ambient temperature in kelvin'
      read*, Ta
      print*,'Enter the time step in seconds'
      read*, dt
      print*,'Enter the corner temperature desired before cooling is
     +     initiated in the pultrusion simulator block.'
      read*, corner
      print*,'Enter the desired corner temperature after cooling is
     +     initiated in the pultrusion simulator block.'
      read*, cornert
      print*,'Enter the external heat transfer coefficient on the
     +     right side of the pultrusion simulator block when the block
     +     is heating.'
      read*,hl
      print*,'Enter the external heat transfer coefficient on the
     +     bottom of the pultrusion simulator block when the block
     +     is heating.'
      read*,hb
      print*,'Enter the external heat transfer coefficient on the
     +     botom of the pultrusion simulator block when the block
     +     is cooling.'
      read*, hbco
      print*,'Enter the external heat transfer coefficient on the
     +     right side of the pultrusion simulator block when the block
     +     is cooling.'
      read*, hlco
*     biot number of the right side of block when program is heating
      bixl=(hl*dx)/k
*     biot number of the right side of block when program is cooling
      bixlco=(hlco*dx)/k
*     biot number of the bottom of block when the program is heating
      biyb=(hb*dy)/k
*     biot number of the bottom of block when the program is cooling
      biybco=(hbco*dy)/k
      alpha=k/(rho*cp)
      fox=(k*dt)/(rho*cp*dx**2)
      foy=(k*dt)/(rho*cp*dy**2)
      count=15900
      cp=400
      setpoint=0.10
      kprint=100
```

```
      jprint=1000
      k= 43
      rho=7833
      ssetpoint=0.1
      countt=59000
      i=1
      j=1
      print*,'Enter the value for temperature at measured at infinity.'
      read*, Tinf
      print*,'Enter the amount of heat input into the numerically
     +     portion of the pultrusion simulator block.'
      read*, q

 10   if(j.lt.98) then
      T(1,j)=Ta
      j=j+1
      goto 10
      else
      j=1
      endif
*     Initiate Initial temperature throuout the matrix
      print*,'Iteration 1'
*     row 1
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=12
*     row 2
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=23
*     row 3
      print 32,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9)
      j=33
*     row 4
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=44
*     row 5
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=55
*     row 6
      print 33,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9)
      j=65
*     row 7
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=76
*     row 8
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=87
```

```
*     row 9
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      iprint=0
      l=1
*     Calculating the Temperature to establish Steady State
 15   i=i+1
      iprint=iprint+1
      j=1
*     Row 1
      T(i,1)=(2*fox*(T(i-1,2)-T(i-1,1)))+(2*foy*(T(i-1,12)-T(i-1,1)))+T(
     +     i-1,1)
      T(i,2)=(fox*(T(i-1,1)+T(i-1,3)-(2*T(i-1,2))))+(2*foy*(T(i-1,13)-T(
     +     i-1,2)))+T(i-1,2)
      T(i,3)=(fox*(T(i-1,2)+T(i-1,4)-(2*T(i-1,3))))+(2*foy*(T(i-1,14)-T(
     +     i-1,3)))+T(i-1,3)
      T(i,4)=(fox*(T(i-1,3)+T(i-1,5)-(2*T(i-1,4))))+(2*foy*(T(i-1,15)-T(
     +     i-1,4)))+T(i-1,4)
      T(i,5)=(fox*(T(i-1,4)+T(i-1,6)-(2*T(i-1,5))))+(2*foy*(T(i-1,16)-T(
     +     i-1,5)))+T(i-1,5)
      T(i,6)=(fox*(T(i-1,5)+T(i-1,7)-(2*T(i-1,6))))+(2*foy*(T(i-1,17)-T(
     +     i-1,6)))+T(i-1,6)
      T(i,7)=(fox*(T(i-1,6)+T(i-1,8)-(2*T(i-1,7))))+(2*foy*(T(i-1,18)-T(
     +     i-1,7)))+T(i-1,7)
      T(i,8)=(fox*(T(i-1,7)+T(i-1,9)-(2*T(i-1,8))))+(2*foy*(T(i-1,19)-T(
     +     i-1,8)))+T(i-1,8)
      T(i,9)=(fox*(T(i-1,8)+T(i-1,10)-(2*T(i-1,9))))+(2*foy*(T(i-1,20)-T
     +     (i-1,9)))+T(i-1,9)
      T(i,10)=(fox*(T(i-1,9)+T(i-1,11)-(2*T(i-1,10))))+(2*foy*(T(i-1,21)
     +     -T(i-1,10)))+T(i-1,10)
      T(i,11)=2*bixl*fox*(Tinf-T(i-1,11))+2*fox*(T(i-1,10)-T(i-1,11))+2*
     +     foy*(T(i-1,10)-T(i-1,11))+T(i-1,11)
*     Row 2
      T(i,12)=(2*fox*(T(i-1,13)-T(i-1,12)))+foy*(T(i-1,1)+T(i-1,23)-2*T(
     +     i-1,12))+T(i-1,12)
      T(i,13)=(fox*(T(i-1,12)+T(i-1,14)-2*T(i-1,13)))+(foy*(T(i-1,2)+T(i
     +     -1,24)-2*T(i-1,13)))+T(i-1,13)
      T(i,14)=(fox*(T(i-1,13)+T(i-1,15)-2*T(i-1,14)))+(foy*(T(i-1,3)+T(i
     +     -1,25)-2*T(i-1,14)))+T(i-1,14)
      T(i,15)=(fox*(T(i-1,14)+T(i-1,16)-2*T(i-1,15)))+(foy*(T(i-1,4)+T(i
     +     -1,26)-2*T(i-1,15)))+T(i-1,15)
      T(i,16)=(fox*(T(i-1,15)+T(i-1,17)-2*T(i-1,16)))+(foy*(T(i-1,5)+T(i
     +     -1,27)-2*T(i-1,16)))+T(i-1,16)
      T(i,17)=(fox*(T(i-1,16)+T(i-1,18)-2*T(i-1,17)))+(foy*(T(i-1,6)+T(i
     +     -1,28)-2*T(i-1,17)))+T(i-1,17)
      T(i,18)=(fox*(T(i-1,17)+T(i-1,19)-2*T(i-1,18)))+(foy*(T(i-1,7)+T(i
     +     -1,29)-2*T(i-1,18)))+T(i-1,18)
      T(i,19)=(fox*(T(i-1,18)+T(i-1,20)-2*T(i-1,19)))+(foy*(T(i-1,8)+T(i
     +     -1,30)-2*T(i-1,19)))+T(i-1,19)
      T(i,20)=(fox*(T(i-1,19))+(fox*T(i-1,21))+(foy*T(i-1,9))+((1-2*fox
     +     -foy)*T(i-1,20))+(q/4))
      T(i,21)=(fox*(T(i-1,20)+T(i-1,22)-2*T(i-1,21)))+(foy*(T(i-1,10)+T(
     +     i-1,31)-2*T(i-1,21)))+T(i-1,21)
      T(i,22)=(2*fox*(T(i-1,21)-T(i-1,22)))+(2*bixl*fox*(Tinf-T(i-1,22))
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```
+     )+(foy*(T(i-1,32)+T(i-1,11)-2*T(i-1,22)))+T(i-1,22)
*     Row 3
      T(i,23)=(2*fox*(T(i-1,24)-T(i-1,23)))+foy*(T(i-1,12)+T(i-1,33)-2*T
+     (i-1,23))+T(i-1,23)
      T(i,24)=(fox*(T(i-1,23)+T(i-1,25)-2*T(i-1,24)))+(foy*(T(i-1,13)+T(
+     i-1,34)-2*T(i-1,24)))+T(i-1,24)
      T(i,25)=(fox*(T(i-1,24)+T(i-1,26)-2*T(i-1,25)))+(foy*(T(i-1,14)+T(
+     i-1,35)-2*T(i-1,25)))+T(i-1,25)
      T(i,26)=(fox*(T(i-1,25)+T(i-1,27)-2*T(i-1,26)))+(foy*(T(i-1,15)+T(
+     i-1,36)-2*T(i-1,26)))+T(i-1,26)
      T(i,27)=(fox*(T(i-1,26)+T(i-1,28)-2*T(i-1,27)))+(foy*(T(i-1,16)+T(
+     i-1,37)-2*T(i-1,27)))+T(i-1,27)
      T(i,28)=(fox*(T(i-1,27)+T(i-1,29)-2*T(i-1,28)))+(foy*(T(i-1,17)+T(
+     i-1,38)-2*T(i-1,28)))+T(i-1,28)
      T(i,29)=(fox*(T(i-1,28)+T(i-1,30)-2*T(i-1,29)))+(foy*(T(i-1,18)+T(
+     i-1,39)-2*T(i-1,29)))+T(i-1,29)
      T(i,30)=(foy*T(i-1,19)+foy*T(i-1,40)+fox*T(i-1,29)+((1-2*foy-fox)*
+     T(i-1,30))+(q/4))
      T(i,31)=(foy*T(i-1,21)+foy*T(i-1,42)+fox*T(i-1,32)+((1-2*foy-fox)*
+     T(i-1,31))+(q/4))
      T(i,32)=(2*fox*(T(i-1,31)-T(i-1,32)))+(2*bixl*fox*(Tinf-T(i-1,32))
+     )+(foy*(T(i-1,43)+T(i-1,22)-2*T(i-1,32)))+T(i-1,32)
*     Row 4
      T(i,33)=(2*fox*(T(i-1,34)-T(i-1,33)))+foy*(T(i-1,23)+T(i-1,44)-2*T
+     (i-1,33))+T(i-1,33)
      T(i,34)=(fox*(T(i-1,33)+T(i-1,35)-2*T(i-1,34)))+(foy*(T(i-1,24)+T(
+     i-1,45)-2*T(i-1,34)))+T(i-1,34)
      T(i,35)=(fox*(T(i-1,34)+T(i-1,36)-2*T(i-1,35)))+(foy*(T(i-1,25)+T(
+     i-1,46)-2*T(i-1,35)))+T(i-1,35)
      T(i,36)=(fox*(T(i-1,35)+T(i-1,37)-2*T(i-1,36)))+(foy*(T(i-1,26)+T(
+     i-1,47)-2*T(i-1,36)))+T(i-1,36)
      T(i,37)=(fox*(T(i-1,36)+T(i-1,38)-2*T(i-1,37)))+(foy*(T(i-1,27)+T(
+     i-1,48)-2*T(i-1,37)))+T(i-1,37)
      T(i,38)=(fox*(T(i-1,37)+T(i-1,39)-2*T(i-1,38)))+(foy*(T(i-1,28)+T(
+     i-1,49)-2*T(i-1,38)))+T(i-1,38)
      T(i,39)=(fox*(T(i-1,38)+T(i-1,40)-2*T(i-1,39)))+(foy*(T(i-1,29)+T(
+     i-1,50)-2*T(i-1,39)))+T(i-1,39)
      T(i,40)=(fox*(T(i-1,39)+T(i-1,41)-2*T(i-1,40)))+(foy*(T(i-1,30)+T(
+     i-1,51)-2*T(i-1,40)))+T(i-1,40)
      T(i,41)=(fox*(T(i-1,40)))+(fox*(T(i-1,42)))+(foy*(T(i-1,52)))+(1-2
+     *fox-foy)*T(i-1,41)+(q/4)
      T(i,42)=(fox*(T(i-1,41)+T(i-1,43)-2*T(i-1,42)))+(foy*(T(i-1,31)+T(
+     i-1,53)-2*T(i-1,42)))+T(i-1,42)
      T(i,43)=(2*fox*(T(i-1,42)-T(i-1,43)))+(2*bixl*fox*(Tinf-T(i-1,43))
+     )+(foy*(T(i-1,54)+T(i-1,32)-2*T(i-1,43)))+T(i-1,43)
*     Row 5
      T(i,44)=(2*fox*(T(i-1,45)-T(i-1,44)))+foy*(T(i-1,33)+T(i-1,55)-2*T
+     (i-1,44))+T(i-1,44)
      T(i,45)=(fox*(T(i-1,44)+T(i-1,46)-2*T(i-1,45)))+(foy*(T(i-1,34)+T(
+     i-1,56)-2*T(i-1,45)))+T(i-1,45)
      T(i,46)=(fox*(T(i-1,45)+T(i-1,47)-2*T(i-1,46)))+(foy*(T(i-1,35)+T(
+     i-1,57)-2*T(i-1,46)))+T(i-1,46)
      T(i,47)=(fox*(T(i-1,46))+(fox*T(i-1,48))+(foy*T(i-1,36))+((1-2*fox
+     -foy)*T(i-1,47))+(q/4))
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      T(i,48)=(fox*(T(i-1,47)+T(i-1,49)-2*T(i-1,48)))+(foy*(T(i-1,37)+T(
     +     i-1,58)-2*T(i-1,48)))+T(i-1,48)
      T(i,49)=(fox*(T(i-1,48)+T(i-1,50)-2*T(i-1,49)))+(foy*(T(i-1,38)+T(
     +     i-1,59)-2*T(i-1,49)))+T(i-1,49)
      T(i,50)=(fox*(T(i-1,49)+T(i-1,51)-2*T(i-1,50)))+(foy*(T(i-1,39)+T(
     +     i-1,60)-2*T(i-1,50)))+T(i-1,50)
      T(i,51)=(fox*(T(i-1,50)+T(i-1,52)-2*T(i-1,51)))+(foy*(T(i-1,40)+T(
     +     i-1,61)-2*T(i-1,51)))+T(i-1,51)
      T(i,52)=(fox*(T(i-1,51)+T(i-1,53)-2*T(i-1,52)))+(foy*(T(i-1,41)+T(
     +     i-1,62)-2*T(i-1,52)))+T(i-1,52)
      T(i,53)=(fox*(T(i-1,52)+T(i-1,54)-2*T(i-1,53)))+(foy*(T(i-1,42)+T(
     +     i-1,63)-2*T(i-1,53)))+T(i-1,53)
      T(i,54)=(2*fox*(T(i-1,53)-T(i-1,54)))+(2*bixl*fox*(Tinf-T(i-1,54))
     +     )+(foy*(T(i-1,64)+T(i-1,43)-2*T(i-1,54)))+T(i-1,54)
*     Row 6
      T(i,55)=(2*fox*(T(i-1,56)-T(i-1,55)))+foy*(T(i-1,44)+T(i-1,65)-2*T
     +     (i-1,55))+T(i-1,55)
      T(i,56)=(fox*(T(i-1,55)+T(i-1,57)-2*T(i-1,56)))+(foy*(T(i-1,45)+T(
     +     i-1,66)-2*T(i-1,56)))+T(i-1,56)
      T(i,57)=(fox*T(i-1,56))+(foy*T(i-1,67))+(foy*T(i-1,46))+((1-2*foy-
     +     fox)*T(i-1,57))+(q/4)
      T(i,58)=(fox*T(i-1,59))+(foy*T(i-1,69))+(foy*T(i-1,48))+((1-2*foy-
     +     fox)*T(i-1,58))+(q/4)
      T(i,59)=(fox*(T(i-1,58)+T(i-1,60)-2*T(i-1,59)))+(foy*(T(i-1,49)+T(
     +     i-1,70)-2*T(i-1,59)))+T(i-1,59)
      T(i,60)=(fox*(T(i-1,59)+T(i-1,61)-2*T(i-1,60)))+(foy*(T(i-1,50)+T(
     +     i-1,71)-2*T(i-1,60)))+T(i-1,60)
      T(i,61)=(fox*(T(i-1,60)+T(i-1,62)-2*T(i-1,61)))+(foy*(T(i-1,51)+T(
     +     i-1,72)-2*T(i-1,61)))+T(i-1,61)
      T(i,62)=(fox*(T(i-1,61)+T(i-1,63)-2*T(i-1,62)))+(foy*(T(i-1,52)+T(
     +     i-1,73)-2*T(i-1,62)))+T(i-1,62)
      T(i,63)=(fox*(T(i-1,62)+T(i-1,64)-2*T(i-1,62)))+(foy*(T(i-1,53)+T(
     +     i-1,74)-2*T(i-1,63)))+T(i-1,63)
      T(i,64)=(2*fox*(T(i-1,63)-T(i-1,64)))+(2*bixl*fox*(Tinf-T(i-1,64))
     +     )+(foy*(T(i-1,75)+T(i-1,54)-2*T(i-1,64)))+T(i-1,64)
*     Row 7
      T(i,65)=(2*fox*(T(i-1,66)-T(i-1,65)))+foy*(T(i-1,55)+T(i-1,76)-2*T
     +     (i-1,65))+T(i-1,65)
      T(i,66)=(fox*(T(i-1,65)+T(i-1,67)-2*T(i-1,66)))+(foy*(T(i-1,56)+T(
     +     i-1,77)-2*T(i-1,66)))+T(i-1,66)
      T(i,67)=(fox*(T(i-1,66)+T(i-1,68)-2*T(i-1,67)))+(foy*(T(i-1,57)+T(
     +     i-1,78)-2*T(i-1,67)))+T(i-1,67)
      T(i,68)=(fox*T(i-1,67))+(foy*T(i-1,79))+(fox*T(i-1,69))+((1-2*fox
     +     -foy)*T(i-1,68))+(q/4)
      T(i,69)=(fox*(T(i-1,68)+T(i-1,70)-2*T(i-1,69)))+(foy*(T(i-1,58)+T(
     +     i-1,80)-2*T(i-1,69)))+T(i-1,69)
      T(i,70)=(fox*(T(i-1,69)+T(i-1,71)-2*T(i-1,70)))+(foy*(T(i-1,59)+T(
     +     i-1,81)-2*T(i-1,70)))+T(i-1,70)
      T(i,71)=(fox*(T(i-1,70)+T(i-1,72)-2*T(i-1,71)))+(foy*(T(i-1,60)+T(
     +     i-1,82)-2*T(i-1,71)))+T(i-1,71)
      T(i,72)=(fox*(T(i-1,71)+T(i-1,73)-2*T(i-1,72)))+(foy*(T(i-1,61)+T(
     +     i-1,83)-2*T(i-1,72)))+T(i-1,72)
      T(i,73)=(fox*(T(i-1,72)+T(i-1,74)-2*T(i-1,73)))+(foy*(T(i-1,62)+T(
     +     i-1,84)-2*T(i-1,73)))+T(i-1,73)
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      T(i,74)=(fox*(T(i-1,73)+T(i-1,75)-2*T(i-1,74)))+(foy*(T(i-1,63)+T(
     +      i-1,85)-2*T(i-1,74)))+T(i-1,74)
      T(i,75)=(2*fox*(T(i-1,74)-T(i-1,75)))+(2*bixl*fox*(Tinf-T(i-1,75))
     +      )+(foy*(T(i-1,86)+T(i-1,64)-2*T(i-1,75)))+T(i-1,75)
*     Row 8
      T(i,76)=(2*fox*(T(i-1,77)-T(i-1,76)))+foy*(T(i-1,65)+T(i-1,87)-2*T
     +      (i-1,76))+T(i-1,76)
      T(i,77)=(fox*(T(i-1,76)+T(i-1,78)-2*T(i-1,77)))+(foy*(T(i-1,66)+T(
     +      i-1,88)-2*T(i-1,77)))+T(i-1,77)
      T(i,78)=(fox*(T(i-1,77)+T(i-1,79)-2*T(i-1,78)))+(foy*(T(i-1,67)+T(
     +      i-1,89)-2*T(i-1,78)))+T(i-1,78)
      T(i,79)=(fox*(T(i-1,78)+T(i-1,80)-2*T(i-1,79)))+(foy*(T(i-1,68)+T(
     +      i-1,90)-2*T(i-1,79)))+T(i-1,79)
      T(i,80)=(fox*(T(i-1,79)+T(i-1,81)-2*T(i-1,80)))+(foy*(T(i-1,69)+T(
     +      i-1,91)-2*T(i-1,80)))+T(i-1,80)
      T(i,81)=(fox*(T(i-1,80)+T(i-1,82)-2*T(i-1,81)))+(foy*(T(i-1,70)+T(
     +      i-1,92)-2*T(i-1,81)))+T(i-1,81)
      T(i,82)=(fox*(T(i-1,81)+T(i-1,83)-2*T(i-1,82)))+(foy*(T(i-1,71)+T(
     +      i-1,93)-2*T(i-1,82)))+T(i-1,82)
      T(i,83)=(fox*(T(i-1,82)+T(i-1,84)-2*T(i-1,83)))+(foy*(T(i-1,72)+T(
     +      i-1,94)-2*T(i-1,83)))+T(i-1,83)
      T(i,84)=(fox*(T(i-1,83)+T(i-1,85)-2*T(i-1,84)))+(foy*(T(i-1,73)+T(
     +      i-1,95)-2*T(i-1,84)))+T(i-1,84)
      T(i,85)=(fox*(T(i-1,84)+T(i-1,86)-2*T(i-1,85)))+(foy*(T(i-1,74)+T(
     +      i-1,96)-2*T(i-1,85)))+T(i-1,85)
      T(i,86)=(2*fox*(T(i-1,85)-T(i-1,86)))+(2*bixl*fox*(Tinf-T(i-1,86))
     +      )+(foy*(T(i-1,97)+T(i-1,75)-2*T(i-1,86)))+T(i-1,86)
*     Row 9
      T(i,87)=(2*fox*(T(i-1,88)))+(2*biyb*foy*Tinf)+(2*foy*T(i-1,76))+(1
     +      -2*foy-2*biyb*foy-2*fox)*T(i-1,87)
      T(i,88)=fox*T(i-1,87)+fox*T(i-1,89)+2*biyb*foy*Tinf+2*foy*T(i-1,77
     +      )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,88)
      T(i,89)=fox*T(i-1,88)+fox*T(i-1,90)+2*biyb*foy*Tinf+2*foy*T(i-1,78
     +      )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,89)
      T(i,90)=fox*T(i-1,89)+fox*T(i-1,91)+2*biyb*foy*Tinf+2*foy*T(i-1,79
     +      )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,90)
      T(i,91)=fox*T(i-1,90)+fox*T(i-1,92)+2*biyb*foy*Tinf+2*foy*T(i-1,80
     +      )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,91)
      T(i,92)=fox*T(i-1,91)+fox*T(i-1,93)+2*biyb*foy*Tinf+2*foy*T(i-1,81
     +      )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,92)
      T(i,93)=fox*T(i-1,92)+fox*T(i-1,94)+2*biyb*foy*Tinf+2*foy*T(i-1,82
     +      )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,93)
      T(i,94)=fox*T(i-1,93)+fox*T(i-1,95)+2*biyb*foy*Tinf+2*foy*T(i-1,83
     +      )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,94)
      T(i,95)=fox*T(i-1,94)+fox*T(i-1,96)+2*biyb*foy*Tinf+2*foy*T(i-1,84
     +      )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,95)
      T(i,96)=fox*T(i-1,95)+fox*T(i-1,97)+2*biyb*foy*Tinf+2*foy*T(i-1,85
     +      )+(1-2*foy-2*biy*bfoy-2*fox)*T(i-1,96)
      T(i,97)=2*fox*T(i-1,96)+2*bixl*fox*Tinf+2*biyb*foy*Tinf+2*foy*T(i-
     +      1,86)+(1-2*foy-2*biyb*foy-2*bixl*fox-2*fox)*T(i-1,97)

      l=l+1
      if(iprint.ne.kprint) then
         goto 15
```

```
           endif

        m=1
        print*,'iteration',l
*       row 1
        print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
        j=12
        m=2
*       row 2
        print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
        j=23
        m=3
*       row 3
        print 32,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9)
        j=33
        m=4
*       row 4
        print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
        j=44
        m=5
*       row 5
        print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
        j=55
        m=6
*       row 6
        print 33,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9)
        j=65
        m=7
*       row 7
        print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
        j=76
        m=8
*       row 8
        print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(i,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
        j=87
        m=9
*       row 9
        print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(i,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
        iprint=0
        if( l.lt.count) then
        goto 50
        else
        print*,'Calculation terminated in heating due to too many
     +       iterations!'
        goto 40
```

```
      endif
 50   if(((T(i,30)-T(i-1,30)).gt.setpoint).and.(T(i,1).lt.corner)) then
      goto 15
      else
      print*,'The corner temperature before cooling
     +      is.................'
      print*,T(i-1,1)
      goto 30
      endif
 30   Print*,'Die has reached Steady State.  Is the corner node at the
     +      desired temperature?'
      print*,'Enter 1 for Yes (Cooling Begins).  Enter 2 for No.'
      read*,n
      print*,n
      if(n.lt.2) then
         print*,'Cooling Is Now Initiated!!'
         goto 34
         else
            print*,'The Heating Cycle Has Been Repeated.'
            goto 15
            endif
 31         format (1x,i2,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0
     +           ,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0)
 32         format (1x,i2,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0
     +           ,1x,f6.0,1x,f6.0,1x,f6.0,8x,f6.0,1x,f6.0)
 33         format (1x,i2,1x,f6.0,1x,f6.0,1x,f6.0,8x,f6.0,1x,f6.0
     +           ,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0)
*     Turn off heaters begin cooling




 34   q=0
      j=1
      m=1
      print*,'iteration',1
*     row 1
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=12
      m=2
*     row 2
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=23
      m=3
*     row 3
      print 32,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9)
      j=33
      m=4
*     row 4
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
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     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=44
      m=5
*     row 5
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=55
      m=6
*     row 6
      print 33,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9)
      j=65
      m=7
*     row 7
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=76
      m=8
*     row 8
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(i,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=87
      m=9
*     row 9
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(i,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      iprint=0

 35   i=i+1
      iprint=iprint+1
      j=1
*     Row 1
      T(i,1)=(2*fox*(T(i-1,2)-T(i-1,1)))+(2*foy*(T(i-1,12)-T(i-1,1)))+T(
     +     i-1,1)
      T(i,2)=(fox*(T(i-1,1)+T(i-1,3)-(2*T(i-1,2))))+(2*foy*(T(i-1,13)-T(
     +     i-1,2)))+T(i-1,2)
      T(i,3)=(fox*(T(i-1,2)+T(i-1,4)-(2*T(i-1,3))))+(2*foy*(T(i-1,14)-T(
     +     i-1,3)))+T(i-1,3)
      T(i,4)=(fox*(T(i-1,3)+T(i-1,5)-(2*T(i-1,4))))+(2*foy*(T(i-1,15)-T(
     +     i-1,4)))+T(i-1,4)
      T(i,5)=(fox*(T(i-1,4)+T(i-1,6)-(2*T(i-1,5))))+(2*foy*(T(i-1,16)-T(
     +     i-1,5)))+T(i-1,5)
      T(i,6)=(fox*(T(i-1,5)+T(i-1,7)-(2*T(i-1,6))))+(2*foy*(T(i-1,17)-T(
     +     i-1,6)))+T(i-1,6)
      T(i,7)=(fox*(T(i-1,6)+T(i-1,8)-(2*T(i-1,7))))+(2*foy*(T(i-1,18)-T(
     +     i-1,7)))+T(i-1,7)
      T(i,8)=(fox*(T(i-1,7)+T(i-1,9)-(2*T(i-1,8))))+(2*foy*(T(i-1,19)-T(
     +     i-1,8)))+T(i-1,8)
      T(i,9)=(fox*(T(i-1,8)+T(i-1,10)-(2*T(i-1,9))))+(2*foy*(T(i-1,20)-T
     +     (i-1,9)))+T(i-1,9)
      T(i,10)=(fox*(T(i-1,9)+T(i-1,11)-(2*T(i-1,10))))+(2*foy*(T(i-1,21)
     +     -T(i-1,10)))+T(i-1,10)
      T(i,11)=2*bix1co*fox*(Tinf-T(i-1,11))+2*fox*(T(i-1,10)-T(i-1,11))+
     +     2*foy*(T(i-1,10)-T(i-1,11))+T(i-1,11)
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*       Row 2
        T(i,12)=(2*fox*(T(i-1,13)-T(i-1,12)))+foy*(T(i-1,1)+T(i-1,23)-2*T(
     +      i-1,12))+T(i-1,12)
        T(i,13)=(fox*(T(i-1,12)+T(i-1,14)-2*T(i-1,13)))+(foy*(T(i-1,2)+T(i
     +      -1,24)-2*T(i-1,13)))+T(i-1,13)
        T(i,14)=(fox*(T(i-1,13)+T(i-1,15)-2*T(i-1,14)))+(foy*(T(i-1,3)+T(i
     +      -1,25)-2*T(i-1,14)))+T(i-1,14)
        T(i,15)=(fox*(T(i-1,14)+T(i-1,16)-2*T(i-1,15)))+(foy*(T(i-1,4)+T(i
     +      -1,26)-2*T(i-1,15)))+T(i-1,15)
        T(i,16)=(fox*(T(i-1,15)+T(i-1,17)-2*T(i-1,16)))+(foy*(T(i-1,5)+T(i
     +      -1,27)-2*T(i-1,16)))+T(i-1,16)
        T(i,17)=(fox*(T(i-1,16)+T(i-1,18)-2*T(i-1,17)))+(foy*(T(i-1,6)+T(i
     +      -1,28)-2*T(i-1,17)))+T(i-1,17)
        T(i,18)=(fox*(T(i-1,17)+T(i-1,19)-2*T(i-1,18)))+(foy*(T(i-1,7)+T(i
     +      -1,29)-2*T(i-1,18)))+T(i-1,18)
        T(i,19)=(fox*(T(i-1,18)+T(i-1,20)-2*T(i-1,19)))+(foy*(T(i-1,8)+T(i
     +      -1,30)-2*T(i-1,19)))+T(i-1,19)
        T(i,20)=(fox*(T(i-1,19))+(fox*T(i-1,21))+(foy*T(i-1,9))+((1-2*fox-
     +      foy)*T(i-1,20))+(q/4))
        T(i,21)=(fox*(T(i-1,20)+T(i-1,22)-2*T(i-1,21)))+(foy*(T(i-1,10)+T(
     +      i-1,31)-2*T(i-1,21)))+T(i-1,21)
        T(i,22)=(2*fox*(T(i-1,21)-T(i-1,22)))+(2*bixlco*fox*(Tinf-T(i-1,22
     +      )))+(foy*(T(i-1,32)+T(i-1,11)-2*T(i-1,22)))+T(i-1,22)
*       Row 3
        T(i,23)=(2*fox*(T(i-1,24)-T(i-1,23)))+foy*(T(i-1,12)+T(i-1,33)-2*T
     +      (i-1,23))+T(i-1,23)
        T(i,24)=(fox*(T(i-1,23)+T(i-1,25)-2*T(i-1,24)))+(foy*(T(i-1,13)+T(
     +      i-1,34)-2*T(i-1,24)))+T(i-1,24)
        T(i,25)=(fox*(T(i-1,24)+T(i-1,26)-2*T(i-1,25)))+(foy*(T(i-1,14)+T(
     +      i-1,35)-2*T(i-1,25)))+T(i-1,25)
        T(i,26)=(fox*(T(i-1,25)+T(i-1,27)-2*T(i-1,26)))+(foy*(T(i-1,15)+T(
     +      i-1,36)-2*T(i-1,26)))+T(i-1,26)
        T(i,27)=(fox*(T(i-1,26)+T(i-1,28)-2*T(i-1,27)))+(foy*(T(i-1,16)+T(
     +      i-1,37)-2*T(i-1,27)))+T(i-1,27)
        T(i,28)=(fox*(T(i-1,27)+T(i-1,29)-2*T(i-1,28)))+(foy*(T(i-1,17)+T(
     +      i-1,38)-2*T(i-1,28)))+T(i-1,28)
        T(i,29)=(fox*(T(i-1,28)+T(i-1,30)-2*T(i-1,29)))+(foy*(T(i-1,18)+T(
     +      i-1,39)-2*T(i-1,29)))+T(i-1,29)
        T(i,30)=(foy*T(i-1,19)+foy*T(i-1,40)+fox*T(i-1,29)+((1-2*foy-fox)*
     +      T(i-1,30))+(q/4))
        T(i,31)=(foy*T(i-1,21)+foy*T(i-1,42)+fox*T(i-1,32)+((1-2*foy-fox)*
     +      T(i-1,31))+(q/4))
        T(i,32)=(2*fox*(T(i-1,31)-T(i-1,32)))+(2*bixlco*fox*(Tinf-T(i-1,32
     +      )))+(foy*(T(i-1,43)+T(i-1,22)-2*T(i-1,32)))+T(i-1,32)
*       Row 4
        T(i,33)=(2*fox*(T(i-1,34)-T(i-1,33)))+foy*(T(i-1,23)+T(i-1,44)-2*T
     +      (i-1,33))+T(i-1,33)
        T(i,34)=(fox*(T(i-1,33)+T(i-1,35)-2*T(i-1,34)))+(foy*(T(i-1,24)+T(
     +      i-1,45)-2*T(i-1,34)))+T(i-1,34)
        T(i,35)=(fox*(T(i-1,34)+T(i-1,36)-2*T(i-1,35)))+(foy*(T(i-1,25)+T(
     +      i-1,46)-2*T(i-1,35)))+T(i-1,35)
        T(i,36)=(fox*(T(i-1,35)+T(i-1,37)-2*T(i-1,36)))+(foy*(T(i-1,26)+T(
     +      i-1,47)-2*T(i-1,36)))+T(i-1,36)
        T(i,37)=(fox*(T(i-1,36)+T(i-1,38)-2*T(i-1,37)))+(foy*(T(i-1,27)+T(
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+     i-1,48)-2*T(i-1,37)))+T(i-1,37)
      T(i,38)=(fox*(T(i-1,37)+T(i-1,39)-2*T(i-1,38)))+(foy*(T(i-1,28)+T(
+     i-1,49)-2*T(i-1,38)))+T(i-1,38)
      T(i,39)=(fox*(T(i-1,38)+T(i-1,40)-2*T(i-1,39)))+(foy*(T(i-1,29)+T(
+     i-1,50)-2*T(i-1,39)))+T(i-1,39)
      T(i,40)=(fox*(T(i-1,39)+T(i-1,41)-2*T(i-1,40)))+(foy*(T(i-1,30)+T(
+     i-1,51)-2*T(i-1,40)))+T(i-1,40)
      T(i,41)=(fox*(T(i-1,40)))+(fox*(T(i-1,42)))+(foy*(T(i-1,52)))+(1-2
+     *fox-foy)*T(i-1,41)+(q/4)
      T(i,42)=(fox*(T(i-1,41)+T(i-1,43)-2*T(i-1,42)))+(foy*(T(i-1,31)+T(
+     i-1,53)-2*T(i-1,42)))+T(i-1,42)
      T(i,43)=(2*fox*(T(i-1,42)-T(i-1,43)))+(2*bixlco*fox*(Tinf-T(i-1,43
+     )))+(foy*(T(i-1,54)+T(i-1,32)-2*T(i-1,43)))+T(i-1,43)
*     Row 5
      T(i,44)=(2*fox*(T(i-1,45)-T(i-1,44)))+foy*(T(i-1,33)+T(i-1,55)-2*T
+     (i-1,44))+T(i-1,44)
      T(i,45)=(fox*(T(i-1,44)+T(i-1,46)-2*T(i-1,45)))+(foy*(T(i-1,34)+T(
+     i-1,56)-2*T(i-1,45)))+T(i-1,45)
      T(i,46)=(fox*(T(i-1,45)+T(i-1,47)-2*T(i-1,46)))+(foy*(T(i-1,35)+T(
+     i-1,57)-2*T(i-1,46)))+T(i-1,46)
      T(i,47)=(fox*(T(i-1,46))+(fox*T(i-1,48))+(foy*T(i-1,36))+((1-2*fox
+     -foy)*T(i-1,47))+(q/4))
      T(i,48)=(fox*(T(i-1,47)+T(i-1,49)-2*T(i-1,48)))+(foy*(T(i-1,37)+T(
+     i-1,58)-2*T(i-1,48)))+T(i-1,48)
      T(i,49)=(fox*(T(i-1,48)+T(i-1,50)-2*T(i-1,49)))+(foy*(T(i-1,38)+T(
+     i-1,59)-2*T(i-1,49)))+T(i-1,49)
      T(i,50)=(fox*(T(i-1,49)+T(i-1,51)-2*T(i-1,50)))+(foy*(T(i-1,39)+T(
+     i-1,60)-2*T(i-1,50)))+T(i-1,50)
      T(i,51)=(fox*(T(i-1,50)+T(i-1,52)-2*T(i-1,51)))+(foy*(T(i-1,40)+T(
+     i-1,61)-2*T(i-1,51)))+T(i-1,51)
      T(i,52)=(fox*(T(i-1,51)+T(i-1,53)-2*T(i-1,52)))+(foy*(T(i-1,41)+T(
+     i-1,62)-2*T(i-1,52)))+T(i-1,52)
      T(i,53)=(fox*(T(i-1,52)+T(i-1,54)-2*T(i-1,53)))+(foy*(T(i-1,42)+T(
+     i-1,63)-2*T(i-1,53)))+T(i-1,53)
      T(i,54)=(2*fox*(T(i-1,53)-T(i-1,54)))+(2*bixlco*fox*(Tinf-T(i-1,54
+     )))+(foy*(T(i-1,64)+T(i-1,43)-2*T(i-1,54)))+T(i-1,54)
*     Row 6
      T(i,55)=(2*fox*(T(i-1,56)-T(i-1,55)))+foy*(T(i-1,44)+T(i-1,65)-2*T
+     (i-1,55))+T(i-1,55)
      T(i,56)=(fox*(T(i-1,55)+T(i-1,57)-2*T(i-1,56)))+(foy*(T(i-1,45)+T(
+     i-1,66)-2*T(i-1,56)))+T(i-1,56)
      T(i,57)=(fox*T(i-1,56))+(foy*T(i-1,67))+(foy*T(i-1,46))+((1-2*foy-
+     fox)*T(i-1,57))+(q/4)
      T(i,58)=(fox*T(i-1,59))+(foy*T(i-1,48))+(foy*T(i-1,69))+((1-2*foy-
+     fox)*T(i-1,58))+(q/4)
      T(i,59)=(fox*(T(i-1,58)+T(i-1,60)-2*T(i-1,59)))+(foy*(T(i-1,49)+T(
+     i-1,70)-2*T(i-1,59)))+T(i-1,59)
      T(i,60)=(fox*(T(i-1,59)+T(i-1,61)-2*T(i-1,60)))+(foy*(T(i-1,50)+T(
+     i-1,71)-2*T(i-1,60)))+T(i-1,60)
      T(i,61)=(fox*(T(i-1,60)+T(i-1,62)-2*T(i-1,61)))+(foy*(T(i-1,51)+T(
+     i-1,72)-2*T(i-1,61)))+T(i-1,61)
      T(i,62)=(fox*(T(i-1,61)+T(i-1,63)-2*T(i-1,62)))+(foy*(T(i-1,52)+T(
+     i-1,73)-2*T(i-1,62)))+T(i-1,62)
      T(i,63)=(fox*(T(i-1,62)+T(i-1,64)-2*T(i-1,63)))+(foy*(T(i-1,53)+T(
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+      i-1,74)-2*T(i-1,63)))+T(i-1,63)
       T(i,64)=(2*fox*(T(i-1,63)-T(i-1,64)))+(2*bixlco*fox*(Tinf-T(i-1,64
+      )))+(foy*(T(i-1,75)+T(i-1,54)-2*T(i-1,64)))+T(i-1,64)
*      Row 7
       T(i,65)=(2*fox*(T(i-1,66)-T(i-1,65)))+foy*(T(i-1,55)+T(i-1,76)-2*T
+      (i-1,65))+T(i-1,65)
       T(i,66)=(fox*(T(i-1,65)+T(i-1,67)-2*T(i-1,66)))+(foy*(T(i-1,56)+T(
+      i-1,77)-2*T(i-1,66)))+T(i-1,66)
       T(i,67)=(fox*(T(i-1,66)+T(i-1,68)-2*T(i-1,67)))+(foy*(T(i-1,57)+T(
+      i-1,78)-2*T(i-1,67)))+T(i-1,67)
       T(i,68)=fox*T(i-1,67)+foy*T(i-1,79)+fox*T(i-1,69)+((1-2*fox-foy)*T
+      (i-1,68))+q/4
       T(i,69)=(fox*(T(i-1,68)+T(i-1,70)-2*T(i-1,69)))+(foy*(T(i-1,58)+T(
+      i-1,80)-2*T(i-1,69)))+T(i-1,69)
       T(i,70)=(fox*(T(i-1,69)+T(i-1,71)-2*T(i-1,70)))+(foy*(T(i-1,59)+T(
+      i-1,81)-2*T(i-1,70)))+T(i-1,70)
       T(i,71)=(fox*(T(i-1,70)+T(i-1,72)-2*T(i-1,71)))+(foy*(T(i-1,60)+T(
+      i-1,82)-2*T(i-1,71)))+T(i-1,71)
       T(i,72)=(fox*(T(i-1,71)+T(i-1,73)-2*T(i-1,72)))+(foy*(T(i-1,61)+T(
+      i-1,83)-2*T(i-1,72)))+T(i-1,72)
       T(i,73)=(fox*(T(i-1,72)+T(i-1,74)-2*T(i-1,73)))+(foy*(T(i-1,62)+T(
+      i-1,84)-2*T(i-1,73)))+T(i-1,73)
       T(i,74)=(fox*(T(i-1,73)+T(i-1,75)-2*T(i-1,74)))+(foy*(T(i-1,63)+T(
+      i-1,85)-2*T(i-1,74)))+T(i-1,74)
       T(i,75)=(2*fox*(T(i-1,74)-T(i-1,75)))+(2*bixlco*fox*(Tinf-T(i-1,75
+      )))+(foy*(T(i-1,86)+T(i-1,64)-2*T(i-1,75)))+T(i-1,75)
*      Row 8
       T(i,76)=(2*fox*(T(i-1,77)-T(i-1,76)))+foy*(T(i-1,65)+T(i-1,87)-2*T
+      (i-1,76))+T(i-1,76)
       T(i,77)=(fox*(T(i-1,76)+T(i-1,78)-2*T(i-1,77)))+(foy*(T(i-1,66)+T(
+      i-1,88)-2*T(i-1,77)))+T(i-1,77)
       T(i,78)=(fox*(T(i-1,77)+T(i-1,79)-2*T(i-1,78)))+(foy*(T(i-1,67)+T(
+      i-1,89)-2*T(i-1,78)))+T(i-1,78)
       T(i,79)=(fox*(T(i-1,78)+T(i-1,80)-2*T(i-1,79)))+(foy*(T(i-1,68)+T(
+      i-1,90)-2*T(i-1,79)))+T(i-1,79)
       T(i,80)=(fox*(T(i-1,79)+T(i-1,81)-2*T(i-1,80)))+(foy*(T(i-1,69)+T(
+      i-1,91)-2*T(i-1,80)))+T(i-1,80)
       T(i,81)=(fox*(T(i-1,80)+T(i-1,82)-2*T(i-1,81)))+(foy*(T(i-1,70)+T(
+      i-1,92)-2*T(i-1,81)))+T(i-1,81)
       T(i,82)=(fox*(T(i-1,81)+T(i-1,83)-2*T(i-1,82)))+(foy*(T(i-1,71)+T(
+      i-1,93)-2*T(i-1,82)))+T(i-1,82)
       T(i,83)=(fox*(T(i-1,82)+T(i-1,84)-2*T(i-1,83)))+(foy*(T(i-1,72)+T(
+      i-1,94)-2*T(i-1,83)))+T(i-1,83)
       T(i,84)=(fox*(T(i-1,83)+T(i-1,85)-2*T(i-1,84)))+(foy*(T(i-1,73)+T(
+      i-1,95)-2*T(i-1,84)))+T(i-1,84)
       T(i,85)=(fox*(T(i-1,84)+T(i-1,86)-2*T(i-1,85)))+(foy*(T(i-1,74)+T(
+      i-1,96)-2*T(i-1,85)))+T(i-1,85)
       T(i,86)=(2*fox*(T(i-1,85)-T(i-1,86)))+(2*bixlco*fox*(Tinf-T(i-1,86
+      )))+(foy*(T(i-1,97)+T(i-1,75)-2*T(i-1,86)))+T(i-1,86)
*      Row 9
       T(i,87)=(2*fox*(T(i-1,88)))+(2*biybco*foy*Tinf)+(2*foy*T(i-1,76))+
+      (1-2*foy-2*biybco*foy-2*fox)*T(i-1,87)
       T(i,88)=fox*T(i-1,87)+fox*T(i-1,89)+2*biybco*foy*Tinf+2*foy*T(i-1,
+      77)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,88)
```

```
      T(i,89)=fox*T(i-1,88)+fox*T(i-1,90)+2*biybco*foy*Tinf+2*foy*T(i-1,
     +     78)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,89)
      T(i,90)=fox*T(i-1,89)+fox*T(i-1,91)+2*biybco*foy*Tinf+2*foy*T(i-1,
     +     79)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,90)
      T(i,91)=fox*T(i-1,90)+fox*T(i-1,92)+2*biybco*foy*Tinf+2*foy*T(i-1,
     +     80)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,91)
      T(i,92)=fox*T(i-1,91)+fox*T(i-1,93)+2*biybco*foy*Tinf+2*foy*T(i-1,
     +     81)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,92)
      T(i,93)=fox*T(i-1,92)+fox*T(i-1,94)+2*biybco*foy*Tinf+2*foy*T(i-1,
     +     82)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,93)
      T(i,94)=fox*T(i-1,93)+fox*T(i-1,95)+2*biybco*foy*Tinf+2*foy*T(i-1,
     +     83)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,94)
      T(i,95)=fox*T(i-1,94)+fox*T(i-1,96)+2*biybco*foy*Tinf+2*foy*T(i-1,
     +     84)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,95)
      T(i,96)=fox*T(i-1,95)+fox*T(i-1,97)+2*biybco*foy*Tinf+2*foy*T(i-1,
     +     85)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,96)
      T(i,97)=2*fox*T(i-1,96)+2*bixlco*fox*Tinf+2*biybco*foy*Tinf+2*foy*
     +     T(i-1,86)+(1-2*foy-2*biybco*foy-2*bixlco*fox-2*fox)*T(i-1,97)

      l=l+1
      if(iprint.ne.jprint) goto 35
      iprint=0
      m=1
      print*,'iteration',l
*     row 1
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=12
      m=2
*     row 2
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=23
      m=3
*     row 3
      print 32,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9)
      j=33
      m=4
*     row 4
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=44
      m=5
*     row 5
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=55
      m=6
*     row 6
      print 33,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9)
      j=65
      m=7
```

```
*     row 7
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=76
      m=8
      Tinf=300
*     row 8
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(i,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=87
      m=9
*     row 9
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(i,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
        if(l.lt.countt)then
      goto 60
      else
      print*,'Calculation terminated in cooling due to too many
     +      iterations!'
      goto 40
      endif

 60   if (T(i,1).gt.cornert)then
         goto 35
         else
         print*,'The Process Has Ended'
         goto 40
         endif
 40   end
```

```
*         *     Program Explicit Method

*     cooling passage location #1
*
      real T(1:20000,1:100),dx,dy,fox,foy,k,bixc,biyc,hc,rho,cp,
     +     alpha,hl,bixl,biyb,bixlco,biybco,hbco,hlco,
     +     dt,Ta,q,Tinf,setpoint,ssetpoint,corner,cornert
      integer i,j,l,m,n,count,countt
      print*,'Enter the node spacing in the x direction in meters'
      read*, dx
      print*,'Enter the node spacing in the y direction in meters'
      read*, dy
      print*,'Enter the ambient temperature in kelvin'
      read*, Ta
      print*,'Enter the value for temperature at measured at infinity.'
      read*, Tinf
      print*,'Enter the time step in seconds'
      read*,dt
      print*,'Enter the corner temperature desired before cooling is
     +     initiated in the pultrusion simulator block.'
      read*, corner
      print*,'Enter the desired corner temperature after cooling is
     +      initiated in the pultrusion simulator block.'
      read*,cornert
      print*,'Enter the external heat transfer coefficient on the
     +     right side of the pultrusion simulator block when the block
     +     is heating.'
      read*, hl
      print*,'Enter the external heat transfer coefficient on the
     +     bottom of the pultrusion simulator block when the block
     +     is heating.'
      read*, hb
      print*,'Enter the external heat transfer coefficient on the
     +     right side of the pultrusion simulator block when the block
     +     is cooling.'
      read*, hlco
      print*,'Enter the external heat transfer coefficient on the
     +     bottom of the pultrusion simulator block when the block
     +     is heating.'
      read*, hbco
      print*,'Enter the external heat transfer coefficient of the
     +     fluid used within the cooling passage.'
      read*, hc
      print*,'Enter the amount of heat input into the numerically
     +     represented portion of the pultrusion simulator block.'
      read*, q

      count=15900
      setpoint=0.10
      kprint=100
      jprint=1000
```

```
      k= 43
      rho=7833
      cp=400
      bixc=(hc*dx)/k
      biyc=(hc*dy)/k
      bixl=(hl*dx)/k
      biyb=(hb*dy)/k
      bixlco=(hlco*dx)/k
      biybco=(hbco*dy)/k
      alpha=k/(rho*cp)
      fox=(k*dt)/(rho*cp*dx**2)
      foy=(k*dt)/(rho*cp*dy**2)
      ssetpoint=0.1
      countt=59000
      i=1
      j=1

 10   if(j.lt.98) then
      T(1,j)=Ta
      j=j+1
      goto 10
      else
      j=1
      endif
*     Initiate Initial temperature throuout the matrix
      print*,'Iteration 1'
*     row 1
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=12
*     row 2
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=23
*     row 3
      print 32,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9)
      j=33
*     row 4
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=44
*     row 5
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=55
*     row 6
      print 33,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9)
      j=65
*     row 7
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=76
```

```
*     row 8
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=87
*     row 9
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      iprint=0
      l=1
*     Calculating the Temperature to establish Steady State
 15   i=i+1
      iprint=iprint+1
      j=1
*     Row 1
      T(i,1)=(2*fox*(T(i-1,2)-T(i-1,1)))+(2*foy*(T(i-1,12)-T(i-1,1)))+T(
     +     i-1,1)
      T(i,2)=(fox*(T(i-1,1)+T(i-1,3)-(2*T(i-1,2))))+(2*foy*(T(i-1,13)-T(
     +     i-1,2)))+T(i-1,2)
      T(i,3)=(fox*(T(i-1,2)+T(i-1,4)-(2*T(i-1,3))))+(2*foy*(T(i-1,14)-T(
     +     i-1,3)))+T(i-1,3)
      T(i,4)=(fox*(T(i-1,3)+T(i-1,5)-(2*T(i-1,4))))+(2*foy*(T(i-1,15)-T(
     +     i-1,4)))+T(i-1,4)
      T(i,5)=(fox*(T(i-1,4)+T(i-1,6)-(2*T(i-1,5))))+(2*foy*(T(i-1,16)-T(
     +     i-1,5)))+T(i-1,5)
      T(i,6)=(fox*(T(i-1,5)+T(i-1,7)-(2*T(i-1,6))))+(2*foy*(T(i-1,17)-T(
     +     i-1,6)))+T(i-1,6)
      T(i,7)=(fox*(T(i-1,6)+T(i-1,8)-(2*T(i-1,7))))+(2*foy*(T(i-1,18)-T(
     +     i-1,7)))+T(i-1,7)
      T(i,8)=(fox*(T(i-1,7)+T(i-1,9)-(2*T(i-1,8))))+(2*foy*(T(i-1,19)-T(
     +     i-1,8)))+T(i-1,8)
      T(i,9)=(fox*(T(i-1,8)+T(i-1,10)-(2*T(i-1,9))))+(2*foy*(T(i-1,20)-T
     +     (i-1,9)))+T(i-1,9)
      T(i,10)=(fox*(T(i-1,9)+T(i-1,11)-(2*T(i-1,10))))+(2*foy*(T(i-1,21)
     +     -T(i-1,10)))+T(i-1,10)
      T(i,11)=2*bixl*fox*(Tinf-T(i-1,11))+2*fox*(T(i-1,10)-T(i-1,11))+2*
     +     foy*(T(i-1,10)-T(i-1,11))+T(i-1,11)
*     Row 2
      T(i,12)=(2*fox*(T(i-1,13)-T(i-1,12)))+foy*(T(i-1,1)+T(i-1,23)-2*T(
     +     i-1,12))+T(i-1,12)
      T(i,13)=(fox*(T(i-1,12)+T(i-1,14)-2*T(i-1,13)))+(foy*(T(i-1,2)+T(i
     +     -1,24)-2*T(i-1,13)))+T(i-1,13)
      T(i,14)=(fox*(T(i-1,13)+T(i-1,15)-2*T(i-1,14)))+(foy*(T(i-1,3)+T(i
     +     -1,25)-2*T(i-1,14)))+T(i-1,14)
      T(i,15)=(fox*(T(i-1,14)+T(i-1,16)-2*T(i-1,15)))+(foy*(T(i-1,4)+T(i
     +     -1,26)-2*T(i-1,15)))+T(i-1,15)
      T(i,16)=(fox*(T(i-1,15)+T(i-1,17)-2*T(i-1,16)))+(foy*(T(i-1,5)+T(i
     +     -1,27)-2*T(i-1,16)))+T(i-1,16)
      T(i,17)=(fox*(T(i-1,16)+T(i-1,18)-2*T(i-1,17)))+(foy*(T(i-1,6)+T(i
     +     -1,28)-2*T(i-1,17)))+T(i-1,17)
      T(i,18)=(fox*(T(i-1,17)+T(i-1,19)-2*T(i-1,18)))+(foy*(T(i-1,7)+T(i
     +     -1,29)-2*T(i-1,18)))+T(i-1,18)
      T(i,19)=(fox*(T(i-1,18)+T(i-1,20)-2*T(i-1,19)))+(foy*(T(i-1,8)+T(i
     +     -1,30)-2*T(i-1,19)))+T(i-1,19)
      T(i,20)=(fox*T(i-1,19))+(fox*T(i-1,21))+(foy*T(i-1,9))+((1-2*fox-
```

```
+       foy)*T(i-1,20))+(q/4)
        T(i,21)=(fox*(T(i-1,20)+T(i-1,22)-2*T(i-1,21)))+(foy*(T(i-1,10)+T(
+       i-1,31)-2*T(i-1,21)))+T(i-1,21)
        T(i,22)=(2*fox*(T(i-1,21)-T(i-1,22)))+(2*bixl*fox*(Tinf-T(i-1,22))
+       )+(foy*(T(i-1,32)+T(i-1,11)-2*T(i-1,22)))+T(i-1,22)
*       Row 3
        T(i,23)=(2*fox*(T(i-1,24)-T(i-1,23)))+foy*(T(i-1,12)+T(i-1,33)-2*T
+       (i-1,23))+T(i-1,23)
        T(i,24)=(fox*(T(i-1,23)+T(i-1,25)-2*T(i-1,24)))+(foy*(T(i-1,13)+T(
+       i-1,34)-2*T(i-1,24)))+T(i-1,24)
        T(i,25)=(4*fox*T(i-1,24)/3)+(2*fox*T(i-1,26)/3)+(2*foy*T(i-1,35)/3
+       )+(4*foy*T(i-1,14)/3)+(1-(2*fox)-(2*foy))*T(i-1,25)
        T(i,26)=(2*fox*T(i-1,25)/3)+(2*foy*T(i-1,36)/3)+(4*foy*T(i-1,15)/3
+       )+(4*fox*T(i-1,27)/3)+(1-(2*fox)-(2*foy))* T(i-1,26)
        T(i,27)=(fox*(T(i-1,26)+T(i-1,28)-2*T(i-1,27)))+(foy*(T(i-1,16)+T(
+       i-1,37)-2*T(i-1,27)))+T(i-1,27)
        T(i,28)=(fox*(T(i-1,27)+T(i-1,29)-2*T(i-1,28)))+(foy*(T(i-1,17)+T(
+       i-1,38)-2*T(i-1,28)))+T(i-1,28)
        T(i,29)=(fox*(T(i-1,28)+T(i-1,30)-2*T(i-1,29)))+(foy*(T(i-1,18)+T(
+       i-1,39)-2*T(i-1,29)))+T(i-1,29)
        T(i,30)=(fox*T(i-1,29))+(foy*T(i-1,19))+(foy*T(i-1,40))+((1-2*foy-
+       fox)*T(i-1,30))+(q/4)
        T(i,31)=(fox*T(i-1,32))+(foy*T(i-1,21))+(foy*T(i-1,42))+(1-2*foy-
+       fox)*T(i-1,31)+(q/4)
        T(i,32)=(2*fox*(T(i-1,31)-T(i-1,32)))+(2*bixl*fox*(Tinf-T(i-1,32))
+       )+(foy*(T(i-1,43)+T(i-1,22)-2*T(i-1,32)))+T(i-1,32)
*       Row 4
        T(i,33)=(2*fox*(T(i-1,34)-T(i-1,33)))+(foy*(T(i-1,23)+T(i-1,44)
+       -2*T(i-1,33)))+T(i-1,33)
        T(i,34)=(fox*(T(i-1,33)+T(i-1,35)-2*T(i-1,34)))+(foy*(T(i-1,24)+T(
+       i-1,45)-2*T(i-1,34)))+T(i-1,34)
        T(i,35)=(4*fox*T(i-1,34)/3)+(2*fox*T(i-1,36)/3)+(2*foy*T(i-1,25)/3
+       )+(4*foy*T(i-1,46)/3)+(1-(2*fox)-(2*foy))*T(i-1,35)
        T(i,36)=(2*fox*T(i-1,35)/3)+(4*fox*T(i-1,37)/3)+(2*foy*T(i-1,26)/3
+       )+(4*foy*T(i-1,47)/3)+(1-(2*fox)-(2*foy))*T(i-1,36)
        T(i,37)=(fox*(T(i-1,36)+T(i-1,38)-2*T(i-1,37)))+(foy*(T(i-1,27)+T(
+       i-1,48)-2*T(i-1,37)))+T(i-1,37)
        T(i,38)=(fox*(T(i-1,37)+T(i-1,39)-2*T(i-1,38)))+(foy*(T(i-1,28)+T(
+       i-1,49)-2*T(i-1,38)))+T(i-1,38)
        T(i,39)=(fox*(T(i-1,38)+T(i-1,40)-2*T(i-1,39)))+(foy*(T(i-1,29)+T(
+       i-1,50)-2*T(i-1,39)))+T(i-1,39)
        T(i,40)=(fox*(T(i-1,39)+T(i-1,41)-2*T(i-1,40)))+(foy*(T(i-1,30)+T(
+       i-1,51)-2*T(i-1,40)))+T(i-1,40)
        T(i,41)=(fox*T(i-1,40))+(fox*T(i-1,42))+(foy*T(i-1,52))+((1-2*fox
+       -foy)*T(i-1,41))+(q/4)
        T(i,42)=(fox*(T(i-1,41)+T(i-1,43)-2*T(i-1,42)))+(foy*(T(i-1,31)+T(
+       i-1,53)-2*T(i-1,42)))+T(i-1,42)
        T(i,43)=(2*fox*(T(i-1,42)-T(i-1,43)))+(2*bixl*fox*(Tinf-T(i-1,43))
+       )+(foy*(T(i-1,54)+T(i-1,32)-2*T(i-1,43)))+T(i-1,43)
*       Row 5
        T(i,44)=(2*fox*(T(i-1,45)-T(i-1,44)))+foy*(T(i-1,33)+T(i-1,55)-2*T
+       (i-1,44))+T(i-1,44)
        T(i,45)=(fox*(T(i-1,44)+T(i-1,46)-2*T(i-1,45)))+(foy*(T(i-1,34)+T(
+       i-1,56)-2*T(i-1,45)))+T(i-1,45)
```

```
      T(i,46)=(fox*(T(i-1,45)+T(i-1,47)-2*T(i-1,46)))+(foy*(T(i-1,35)+T(
     +      i-1,57)-2*T(i-1,46)))+T(i-1,46)
      T(i,47)=fox*T(i-1,46)+fox*T(i-1,48)+foy*T(i-1,36)+((1-2*fox-foy)*T
     +      (i-1,47))+(q/4)
      T(i,48)=(fox*(T(i-1,47)+T(i-1,49)-2*T(i-1,48)))+(foy*(T(i-1,37)+T(
     +      i-1,58)-2*T(i-1,48)))+T(i-1,48)
      T(i,49)=(fox*(T(i-1,48)+T(i-1,50)-2*T(i-1,49)))+(foy*(T(i-1,38)+T(
     +      i-1,59)-2*T(i-1,49)))+T(i-1,49)
      T(i,50)=(fox*(T(i-1,49)+T(i-1,51)-2*T(i-1,50)))+(foy*(T(i-1,39)+T(
     +      i-1,60)-2*T(i-1,50)))+T(i-1,50)
      T(i,51)=(fox*(T(i-1,50)+T(i-1,52)-2*T(i-1,51)))+(foy*(T(i-1,40)+T(
     +      i-1,61)-2*T(i-1,51)))+T(i-1,51)
      T(i,52)=(fox*(T(i-1,51)+T(i-1,53)-2*T(i-1,52)))+(foy*(T(i-1,41)+T(
     +      i-1,62)-2*T(i-1,52)))+T(i-1,52)
      T(i,53)=(fox*(T(i-1,52)+T(i-1,54)-2*T(i-1,53)))+(foy*(T(i-1,42)+T(
     +      i-1,63)-2*T(i-1,53)))+T(i-1,53)
      T(i,54)=(2*fox*(T(i-1,53)-T(i-1,54)))+(2*bixl*fox*(Tinf-T(i-1,54))
     +      )+(foy*(T(i-1,64)+T(i-1,43)-2*T(i-1,54)))+T(i-1,54)
*     Row 6
      T(i,55)=(2*fox*(T(i-1,56)-T(i-1,55)))+foy*(T(i-1,44)+T(i-1,65)-2*T
     +      (i-1,55))+T(i-1,55)
      T(i,56)=(fox*(T(i-1,55)+T(i-1,57)-2*T(i-1,56)))+(foy*(T(i-1,45)+T(
     +      i-1,66)-2*T(i-1,56)))+T(i-1,56)
      T(i,57)=(fox*T(i-1,56))+(foy*T(i-1,46))+(foy*T(i-1,67))+((1-2*foy
     +      -fox)*T(i-1,57))+(q/4)
      T(i,58)=(fox*T(i-1,59))+(foy*T(i-1,48))+(foy*T(i-1,69))+((1-2*foy
     +      -fox)*T(i-1,58))+(q/4)
      T(i,59)=(fox*(T(i-1,58)+T(i-1,60)-2*T(i-1,59)))+(foy*(T(i-1,49)+T(
     +      i-1,70)-2*T(i-1,59)))+T(i-1,59)
      T(i,60)=(fox*(T(i-1,59)+T(i-1,61)-2*T(i-1,60)))+(foy*(T(i-1,50)+T(
     +      i-1,71)-2*T(i-1,60)))+T(i-1,60)
      T(i,61)=(fox*(T(i-1,60)+T(i-1,62)-2*T(i-1,61)))+(foy*(T(i-1,51)+T(
     +      i-1,72)-2*T(i-1,61)))+T(i-1,61)
      T(i,62)=(fox*(T(i-1,61)+T(i-1,63)-2*T(i-1,62)))+(foy*(T(i-1,52)+T(
     +      i-1,73)-2*T(i-1,62)))+T(i-1,62)
      T(i,63)=(fox*(T(i-1,62)+T(i-1,64)-2*T(i-1,63)))+(foy*(T(i-1,53)+T(
     +      i-1,74)-2*T(i-1,63)))+T(i-1,63)
      T(i,64)=(2*fox*(T(i-1,63)-T(i-1,64)))+(2*bixl*fox*(Tinf-T(i-1,64))
     +      )+(foy*(T(i-1,75)+T(i-1,54)-2*T(i-1,64)))+T(i-1,64)
*     Row 7
      T(i,65)=(2*fox*(T(i-1,66)-T(i-1,65)))+foy*(T(i-1,55)+T(i-1,76)-2*T
     +      (i-1,65))+T(i-1,65)
      T(i,66)=(fox*(T(i-1,65)+T(i-1,67)-2*T(i-1,66)))+(foy*(T(i-1,56)+T(
     +      i-1,77)-2*T(i-1,66)))+T(i-1,66)
      T(i,67)=(fox*(T(i-1,66)+T(i-1,68)-2*T(i-1,67)))+(foy*(T(i-1,57)+T(
     +      i-1,78)-2*T(i-1,67)))+T(i-1,67)
      T(i,68)=foy*T(i-1,79)+fox*T(i-1,67)+fox*T(i-1,69)+((1-2*fox-foy)*T
     +      (i-1,68))+q/4
      T(i,69)=(fox*(T(i-1,68)+T(i-1,70)-2*T(i-1,69)))+(foy*(T(i-1,58)+T(
     +      i-1,80)-2*T(i-1,69)))+T(i-1,69)
      T(i,70)=(fox*(T(i-1,69)+T(i-1,71)-2*T(i-1,70)))+(foy*(T(i-1,59)+T(
     +      i-1,81)-2*T(i-1,70)))+T(i-1,70)
      T(i,71)=(fox*(T(i-1,70)+T(i-1,72)-2*T(i-1,71)))+(foy*(T(i-1,60)+T(
     +      i-1,82)-2*T(i-1,71)))+T(i-1,71)
```

```
      T(i,72)=(fox*(T(i-1,71)+T(i-1,73)-2*T(i-1,72)))+(foy*(T(i-1,61)+T(
     +       i-1,83)-2*T(i-1,72)))+T(i-1,72)
      T(i,73)=(fox*(T(i-1,72)+T(i-1,74)-2*T(i-1,73)))+(foy*(T(i-1,62)+T(
     +       i-1,84)-2*T(i-1,73)))+T(i-1,73)
      T(i,74)=(fox*(T(i-1,73)+T(i-1,75)-2*T(i-1,74)))+(foy*(T(i-1,63)+T(
     +       i-1,85)-2*T(i-1,74)))+T(i-1,74)
      T(i,75)=(2*fox*(T(i-1,74)-T(i-1,75)))+(2*bixl*fox*(Tinf-T(i-1,75))
     +       )+(foy*(T(i-1,86)+T(i-1,64)-2*T(i-1,75)))+T(i-1,75)
*     Row 8
      T(i,76)=(2*fox*(T(i-1,77)-T(i-1,76)))+foy*(T(i-1,65)+T(i-1,87)-2*T
     +       (i-1,76))+T(i-1,76)
      T(i,77)=(fox*(T(i-1,76)+T(i-1,78)-2*T(i-1,77)))+(foy*(T(i-1,66)+T(
     +       i-1,88)-2*T(i-1,77)))+T(i-1,77)
      T(i,78)=(fox*(T(i-1,77)+T(i-1,79)-2*T(i-1,78)))+(foy*(T(i-1,67)+T(
     +       i-1,89)-2*T(i-1,78)))+T(i-1,78)
      T(i,79)=(fox*(T(i-1,78)+T(i-1,80)-2*T(i-1,79)))+(foy*(T(i-1,68)+T(
     +       i-1,90)-2*T(i-1,79)))+T(i-1,79)
      T(i,80)=(fox*(T(i-1,79)+T(i-1,81)-2*T(i-1,80)))+(foy*(T(i-1,69)+T(
     +       i-1,91)-2*T(i-1,80)))+T(i-1,80)
      T(i,81)=(fox*(T(i-1,80)+T(i-1,82)-2*T(i-1,81)))+(foy*(T(i-1,70)+T(
     +       i-1,92)-2*T(i-1,81)))+T(i-1,81)
      T(i,82)=(fox*(T(i-1,81)+T(i-1,83)-2*T(i-1,82)))+(foy*(T(i-1,71)+T(
     +       i-1,93)-2*T(i-1,82)))+T(i-1,82)
      T(i,83)=(fox*(T(i-1,82)+T(i-1,84)-2*T(i-1,83)))+(foy*(T(i-1,72)+T(
     +       i-1,94)-2*T(i-1,83)))+T(i-1,83)
      T(i,84)=(fox*(T(i-1,83)+T(i-1,85)-2*T(i-1,84)))+(foy*(T(i-1,73)+T(
     +       i-1,95)-2*T(i-1,84)))+T(i-1,84)
      T(i,85)=(fox*(T(i-1,84)+T(i-1,86)-2*T(i-1,85)))+(foy*(T(i-1,74)+T(
     +       i-1,96)-2*T(i-1,85)))+T(i-1,85)
      T(i,86)=(2*fox*(T(i-1,85)-T(i-1,86)))+(2*bixl*fox*(Tinf-T(i-1,86))
     +       )+(foy*(T(i-1,97)+T(i-1,75)-2*T(i-1,86)))+T(i-1,86)
*     Row 9
      T(i,87)=(2*fox*(T(i-1,88)))+(2*biyb*foy*Tinf)+(2*foy*T(i-
     +       1,76))+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,87)
      T(i,88)=fox*T(i-1,87)+fox*T(i-1,89)+2*biyb*foy*Tinf+2*foy*T(i-1,77
     +       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,88)
      T(i,89)=fox*T(i-1,88)+fox*T(i-1,90)+2*biyb*foy*Tinf+2*foy*T(i-1,78
     +       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,89)
      T(i,90)=fox*T(i-1,89)+fox*T(i-1,91)+2*biyb*foy*Tinf+2*foy*T(i-1,79
     +       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,90)
      T(i,91)=fox*T(i-1,90)+fox*T(i-1,92)+2*biyb*foy*Tinf+2*foy*T(i-1,80
     +       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,91)
      T(i,92)=fox*T(i-1,91)+fox*T(i-1,93)+2*biyb*foy*Tinf+2*foy*T(i-1,81
     +       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,92)
      T(i,93)=fox*T(i-1,92)+fox*T(i-1,94)+2*biyb*foy*Tinf+2*foy*T(i-1,82
     +       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,93)
      T(i,94)=fox*T(i-1,93)+fox*T(i-1,95)+2*biyb*foy*Tinf+2*foy*T(i-1,83
     +       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,94)
      T(i,95)=fox*T(i-1,94)+fox*T(i-1,96)+2*biyb*foy*Tinf+2*foy*T(i-1,84
     +       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,95)
      T(i,96)=fox*T(i-1,95)+fox*T(i-1,97)+2*biyb*foy*Tinf+2*foy*T(i-1,85
     +       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,96)
      T(i,97)=2*fox*T(i-1,96)+2*bixl*fox*Tinf+2*biyb*foy*Tinf+2*foy*T(i-
     +       1,86)+(1-2*foy-2*biyb*foy-2*bixl*fox-2*fox)*T(i-1,97)
```

```
      l=l+1
      if(iprint.ne.kprint) then
         goto 15
         endif

      m=1
      print*,'iteration',l
*     row 1
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=12
      m=2
*     row 2
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=23
      m=3
*     row 3
      print 32,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9)
      j=33
      m=4
*     row 4
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=44
      m=5
*     row 5
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=55
      m=6
*     row 6
      print 33,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9)
      j=65
      m=7
*     row 7
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=76
      m=8
*     row 8
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(i,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=87
      m=9
*     row 9
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(i,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      iprint=0
      if( l.lt.count) then
      goto 50
```

```
      else
      print*,'Calculation terminated in heating due to too many
     +      iterations!'
      goto 40
      endif
 50   if(((T(i,30)-T(i-1,30)).gt.setpoint).and.(T(i,1).lt.corner)) then
      goto 15
      else
      print*,'The corner temperature before cooling
     +      is...................'
      print*,T(i-1,1)
      goto 30
      endif
 30   Print*,'Die has reached Steady State. Is the corner node at the
     +      desired temperature?'
      Print*,'Enter 1 for Yes (Cooling Begins).  Enter 2 for No.'
      read*,n
      print*,n
      if(n.lt.2) then
         print*,'Cooling Is Now Initiated!!'
         goto 34
         else
            print*,'The Heating Cycle Has Been Repeated.'
            goto 15
            endif
 31         format (1x,i2,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0
     +           ,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0)
 32         format (1x,i2,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0
     +           ,1x,f6.0,1x,f6.0,1x,f6.0,8x,f6.0,1x,f6.0)
 33         format (1x,i2,1x,f6.0,1x,f6.0,1x,f6.0,8x,f6.0,1x,f6.0
     +           ,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0)
*     Turn off heaters begin cooling




 34   q=0
      j=1
      m=1
      print*,'iteration',1
*     row 1
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=12
      m=2
*     row 2
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=23
      m=3
*     row 3
      print 32,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9)
```

```
      j=33
      m=4
*     row 4
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +      ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=44
      m=5
*     row 5
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +      ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=55
      m=6
*     row 6
      print 33,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +      ,j+6),T(1,j+7),T(1,j+8),T(1,j+9)
      j=65
      m=7
*     row 7
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +      ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=76
      m=8
*     row 8
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(i,j+5),T(1
     +      ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=87
      m=9
*     row 9
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(i,j+5),T(1
     +      ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      iprint=0

 35   i=i+1
      iprint=iprint+1
      j=1
*     Row 1
      T(i,1)=(2*fox*(T(i-1,2)-T(i-1,1)))+(2*foy*(T(i-1,12)-T(i-1,1)))+T(
     +      i-1,1)
      T(i,2)=(fox*(T(i-1,1)+T(i-1,3)-(2*T(i-1,2))))+(2*foy*(T(i-1,13)-T(
     +      i-1,2)
     +      ))+T(i-1,2)
      T(i,3)=(fox*(T(i-1,2)+T(i-1,4)-(2*T(i-1,3))))+(2*foy*(T(i-1,14)-T(
     +      i-1,3)
     +      ))+T(i-1,3)
      T(i,4)=(fox*(T(i-1,3)+T(i-1,5)-(2*T(i-1,4))))+(2*foy*(T(i-1,15)-T(
     +      i-1,4)
     +      ))+T(i-1,4)
      T(i,5)=(fox*(T(i-1,4)+T(i-1,6)-(2*T(i-1,5))))+(2*foy*(T(i-1,16)-T(
     +      i-1,5)))+T(i-1,5)
      T(i,6)=(fox*(T(i-1,5)+T(i-1,7)-(2*T(i-1,6))))+(2*foy*(T(i-1,17)-T(
     +      i-1,6)))+T(i-1,6)
      T(i,7)=(fox*(T(i-1,6)+T(i-1,8)-(2*T(i-1,7))))+(2*foy*(T(i-1,18)-T(
     +      i-1,7)))+T(i-1,7)
      T(i,8)=(fox*(T(i-1,7)+T(i-1,9)-(2*T(i-1,8))))+(2*foy*(T(i-1,19)-T(
```

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+      i-1,8)))+T(i-1,8)
      T(i,9)=(fox*(T(i-1,8)+T(i-1,10)-(2*T(i-1,9))))+(2*foy*(T(i-1,20)-T
+      (i-1,9)))+T(i-1,9)
      T(i,10)=(fox*(T(i-1,9)+T(i-1,11)-(2*T(i-1,10))))+(2*foy*(T(i-1,21)
+      -T(i-1,10)))+T(i-1,10)
      T(i,11)=2*bixlco*fox*(Tinf-T(i-1,11))+2*fox*(T(i-1,10)-T(i-1,11))+
+      2*foy*(T(i-1,10)-T(i-1,11))+T(i-1,11)
*     Row 2
      T(i,12)=(2*fox*(T(i-1,13)-T(i-1,12)))+foy*(T(i-1,1)+T(i-1,23)-2*T(
+      i-1,12))+T(i-1,12)
      T(i,13)=(fox*(T(i-1,12)+T(i-1,14)-2*T(i-1,13)))+(foy*(T(i-
+      1,24)-2*T(i-1,13)))+T(i-1,13)
      T(i,14)=(fox*(T(i-1,13)+T(i-1,15)-2*T(i-1,14)))+(foy*(T(i-
+      1,3)+T(i-1,25)-2*T(i-1,14)))+T(i-1,14)
      T(i,15)=(fox*(T(i-1,14)+T(i-1,16)-2*T(i-1,15)))+(foy*(T(i-
+      1,4)+T(i-1,26)-2*T(i-1,15)))+T(i-1,15)
      T(i,16)=(fox*(T(i-1,15)+T(i-1,17)-2*T(i-1,16)))+(foy*(T(i-
+      1,5)+T(i-1,27)-2*T(i-1,16)))+T(i-1,16)
      T(i,17)=(fox*(T(i-1,16)+T(i-1,18)-2*T(i-1,17)))+(foy*(T(i-
+      1,6)+T(i-1,28)-2*T(i-1,17)))+T(i-1,17)
      T(i,18)=(fox*(T(i-1,17)+T(i-1,19)-2*T(i-1,18)))+(foy*(T(i-
+      1,7)+T(i-1,29)-2*T(i-1,18)))+T(i-1,18)
      T(i,19)=(fox*(T(i-1,18)+T(i-1,20)-2*T(i-1,19)))+(foy*(T(i-
+      1,8)+T(i-1,30)-2*T(i-1,19)))+T(i-1,19)
      T(i,20)=(fox*T(i-1,19))+(fox*T(i-1,21))+(foy*T(i-1,9))+((1-2*fox
+      -foy)*T(i-1,20))+(q/4)
      T(i,21)=(fox*(T(i-1,20)+T(i-1,22)-2*T(i-1,21)))+(foy*(T(i-1,10)+T(
+      i-1,31)-2*T(i-1,21)))+T(i-1,21)
      T(i,22)=(2*fox*(T(i-1,21)-T(i-1,22)))+(2*bixlco*fox*(Tinf-T(i-1,22
+      )))+(foy*(T(i-1,32)+T(i-1,11)-2*T(i-1,22)))+T(i-1,22)
*     Row 3
      T(i,23)=(2*fox*(T(i-1,24)-T(i-1,23)))+foy*(T(i-1,12)+T(i-1,33)-2*T
+      (i-1,23))+T(i-1,23)
      T(i,24)=(fox*(T(i-1,23)+T(i-1,25)-2*T(i-1,24)))+(foy*(T(i-1,13)+T(
+      i-1,34)-2*T(i-1,24)))+T(i-1,24)
      T(i,25)=(4*fox*(T(i-1,24)-T(i-1,25))/3)+(2*fox*(T(i-1,26)-T(i-1,25
+      ))/3)+(2*foy*(T(i-1,35)-T(i-1,25))/3)+(4*foy*(T(i-1,14)-T(i-1
+      ,25))/3)+(((2*biyc*foy/3)+(2*bixc*fox/3))*Tinf)+((1-(2*biyc*
+      foy/3)-(2*bixc*fox/3))*T(i-1,25))
      T(i,26)=(2*fox*(T(i-1,25)-T(i-1,26))/3)+(2*foy*(T(i-1,36)-T(i-1,26
+      ))/3)+(4*foy*(T(i-1,15)-T(i-1,26))/3)+(4*fox*(T(i-1,27)-T(i-
+      1,26))/3)+(((2*biyc*foy/3)+(2*bixc*fox/3))*Tinf)+((1-
+      (2*biyc*foy/3)-(2*bixc*fox/3))*T(i-1,26))
      T(i,27)=(fox*(T(i-1,26)+T(i-1,28)-2*T(i-1,27)))+(foy*(T(i-1,16)+T(
+      i-1,37)-2*T(i-1,27)))+T(i-1,27)
      T(i,28)=(fox*(T(i-1,27)+T(i-1,29)-2*T(i-1,28)))+(foy*(T(i-1,17)+T(
+      i-1,38)-2*T(i-1,28)))+T(i-1,28)
      T(i,29)=(fox*(T(i-1,28)+T(i-1,30)-2*T(i-1,29)))+(foy*(T(i-1,18)+T(
+      i-1,39)-2*T(i-1,29)))+T(i-1,29)
      T(i,30)=(fox*T(i-1,29))+(foy*T(i-1,19))+(foy*T(i-1,40))+((1-2*foy
+      -fox)*T(i-1,30))+(q/4)
      T(i,31)=(foy*T(i-1,21))+(foy*T(i-1,42))+(fox*T(i-1,32))+((1-2*foy
+      -fox)*T(i-1,31))+(q/4)
      T(i,32)=(2*fox*(T(i-1,31)-T(i-1,32)))+(2*bixlco*fox*(Tinf-T(i-1,32
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     +     )))+(foy*(T(i-1,43)+T(i-1,22)-2*T(i-1,32)))+T(i-1,32)
*     Row 4
      T(i,33)=(2*fox*(T(i-1,34)-T(i-1,33)))+foy*(T(i-1,23)+T(i-1,44)-2*
     +     T(i-1,33))+T(i-1,33)
      T(i,34)=(fox*(T(i-1,33)+T(i-1,35)-2*T(i-1,34)))+(foy*(T(i-1,24)+T(
     +     i-1,45)-2*T(i-1,34)))+T(i-1,34)
      T(i,35)=(4*fox*(T(i-1,34)-T(i-1,35))/3)+(2*fox*(T(i-1,36)-T(i-1,35
     +     ))/3)+(2*foy*(T(i-1,25)-T(i-1,35))/3)+(4*foy*(T(i-1,46)-T(i-1
     +     ,35))/3)+(((2*biyc*foy/3)+(2*bixc*fox/3))*Tinf)+((1-(2*biyc*
     +     foy/3)-(2*bixc*fox/3))*T(i-1,35))
      T(i,36)=(2*fox*(T(i-1,35)-T(i-1,36))/3)+(4*fox*(T(i-1,37)-T(i-1,36
     +     ))/3)+(2*foy*(T(i-1,26)-T(i-1,36))/3)+(4*foy*(T(i-1,47)-T(i-1
     +     ,36))/3)+(((2*biyc*foy/3)+(2*bixc*fox/3))*Tinf)+((1-(2*biyc*
     +     foy/3)-(2*bixc*fox/3))*T(i-1,36))
      T(i,37)=(fox*(T(i-1,36)+T(i-1,38)-2*T(i-1,37)))+(foy*(T(i-1,27)+T(
     +     i-1,48)-2*T(i-1,37)))+T(i-1,37)
      T(i,38)=(fox*(T(i-1,37)+T(i-1,39)-2*T(i-1,38)))+(foy*(T(i-1,28)+T(
     +     i-1,49)-2*T(i-1,38)))+T(i-1,38)
      T(i,39)=(fox*(T(i-1,38)+T(i-1,40)-2*T(i-1,39)))+(foy*(T(i-1,29)+T(
     +     i-1,50)-2*T(i-1,39)))+T(i-1,39)
      T(i,40)=(fox*(T(i-1,39)+T(i-1,41)-2*T(i-1,40)))+(foy*(T(i-1,30)+T(
     +     i-1,51)-2*T(i-1,40)))+T(i-1,40)
      T(i,41)=(fox*T(i-1,40))+(fox*T(i-1,42))+(foy*T(i-1,52))+((1-2*fox-
     +     foy)*T(i-1,41))+(q/4)
      T(i,42)=(fox*(T(i-1,41)+T(i-1,43)-2*T(i-1,42)))+(foy*(T(i-1,31)+T(
     +     i-1,53)-2*T(i-1,42)))+T(i-1,42)
      T(i,43)=(2*fox*(T(i-1,42)-T(i-1,43)))+(2*bixlco*fox*(Tinf-T(i-1,43
     +     )))+(foy*(T(i-1,54)+T(i-1,32)-2*T(i-1,43)))+T(i-1,43)
*     Row 5
      T(i,44)=(2*fox*(T(i-1,45)-T(i-1,44)))+foy*(T(i-1,33)+T(i-1,55)-2*T
     +     (i-1,44))+T(i-1,44)
      T(i,45)=(fox*(T(i-1,44)+T(i-1,46)-2*T(i-1,45)))+(foy*(T(i-1,34)+T(
     +     i-1,56)-2*T(i-1,45)))+T(i-1,45)
      T(i,46)=(fox*(T(i-1,45)+T(i-1,47)-2*T(i-1,46)))+(foy*(T(i-1,35)+T(
     +     i-1,57)-2*T(i-1,46)))+T(i-1,46)
      T(i,47)=(fox*T(i-1,46))+(fox*T(i-1,48))+(foy*T(i-1,36))+((1-2*fox-
     +     foy)*T(i-1,47))+(q/4)
      T(i,48)=(fox*(T(i-1,47)+T(i-1,49)-2*T(i-1,48)))+(foy*(T(i-1,37)+T(
     +     i-1,58)-2*T(i-1,48)))+T(i-1,48)
      T(i,49)=(fox*(T(i-1,48)+T(i-1,50)-2*T(i-1,49)))+(foy*(T(i-1,38)+T(
     +     i-1,59)-2*T(i-1,49)))+T(i-1,49)
      T(i,50)=(fox*(T(i-1,49)+T(i-1,51)-2*T(i-1,50)))+(foy*(T(i-1,39)+T(
     +     i-1,60)-2*T(i-1,50)))+T(i-1,50)
      T(i,51)=(fox*(T(i-1,50)+T(i-1,52)-2*T(i-1,51)))+(foy*(T(i-1,40)+T(
     +     i-1,61)-2*T(i-1,51)))+T(i-1,51)
      T(i,52)=(fox*(T(i-1,51)+T(i-1,53)-2*T(i-1,52)))+(foy*(T(i-1,41)+T(
     +     i-1,62)-2*T(i-1,52)))+T(i-1,52)
      T(i,53)=(fox*(T(i-1,52)+T(i-1,54)-2*T(i-1,53)))+(foy*(T(i-1,42)+T(
     +     i-1,63)-2*T(i-1,53)))+T(i-1,53)
      T(i,54)=(2*fox*(T(i-1,53)-T(i-1,54)))+(2*bixlco*fox*(Tinf-T(i-1,54
     +     )))+(foy*(T(i-1,64)+T(i-1,43)-2*T(i-1,54)))+T(i-1,54)
*     Row 6
      T(i,55)=(2*fox*(T(i-1,56)-T(i-1,55)))+foy*(T(i-1,44)+T(i-1,65)-2*T
     +     (i-1,55))+T(i-1,55)
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      T(i,56)=(fox*(T(i-1,55)+T(i-1,57)-2*T(i-1,56)))+(foy*(T(i-1,45)+T(
     +      i-1,66)-2*T(i-1,56)))+T(i-1,56)
      T(i,57)=(fox*T(i-1,56))+(foy*T(i-1,67))+(foy*T(i-1,46))+((1-2*foy
     +      -fox)*T(i-1,57))+(q/4)
      T(i,58)=(fox*T(i-1,59))+(foy*T(i-1,69))+(foy*T(i-1,48))+((1-2*foy
     +      -fox)*T(i-1,58))+(q/4)
      T(i,59)=(fox*(T(i-1,58)+T(i-1,60)-2*T(i-1,59)))+(foy*(T(i-1,49)+T(
     +      i-1,70)-2*T(i-1,59)))+T(i-1,59)
      T(i,60)=(fox*(T(i-1,59)+T(i-1,61)-2*T(i-1,60)))+(foy*(T(i-1,50)+T(
     +      i-1,71)-2*T(i-1,60)))+T(i-1,60)
      T(i,61)=(fox*(T(i-1,60)+T(i-1,62)-2*T(i-1,61)))+(foy*(T(i-1,51)+T(
     +      i-1,72)-2*T(i-1,61)))+T(i-1,61)
      T(i,62)=(fox*(T(i-1,61)+T(i-1,63)-2*T(i-1,62)))+(foy*(T(i-1,52)+T(
     +      i-1,73)-2*T(i-1,62)))+T(i-1,62)
      T(i,63)=(fox*(T(i-1,62)+T(i-1,64)-2*T(i-1,63)))+(foy*(T(i-1,53)+T(
     +      i-1,74)-2*T(i-1,63)))+T(i-1,63)
      T(i,64)=(2*fox*(T(i-1,63)-T(i-1,64)))+(2*bixlco*fox*(Tinf-T(i-1,64
     +      )))+(foy*(T(i-1,75)+T(i-1,54)-2*T(i-1,64)))+T(i-1,64)
*     Row 7
      T(i,65)=(2*fox*(T(i-1,66)-T(i-1,65)))+foy*(T(i-1,55)+T(i-1,76)-2*T
     +      (i-1,65))+T(i-1,65)
      T(i,66)=(fox*(T(i-1,65)+T(i-1,67)-2*T(i-1,66)))+(foy*(T(i-1,56)+T(
     +      i-1,77)-2*T(i-1,66)))+T(i-1,66)
      T(i,67)=(fox*(T(i-1,66)+T(i-1,68)-2*T(i-1,67)))+(foy*(T(i-1,57)+T(
     +      i-1,78)-2*T(i-1,67)))+T(i-1,67)
      T(i,68)=foy*T(i-1,79)+fox*T(i-1,67)+fox*T(i-1,69)+((1-2*fox-foy)*T
     +      (i-1,68))+q/4
      T(i,69)=(fox*(T(i-1,68)+T(i-1,70)-2*T(i-1,69)))+(foy*(T(i-1,58)+T(
     +      i-1,80)-2*T(i-1,69)))+T(i-1,69)
      T(i,70)=(fox*(T(i-1,69)+T(i-1,71)-2*T(i-1,70)))+(foy*(T(i-1,59)+T(
     +      i-1,81)-2*T(i-1,70)))+T(i-1,70)
      T(i,71)=(fox*(T(i-1,70)+T(i-1,72)-2*T(i-1,71)))+(foy*(T(i-1,60)+T(
     +      i-1,82)-2*T(i-1,71)))+T(i-1,71)
      T(i,72)=(fox*(T(i-1,71)+T(i-1,73)-2*T(i-1,72)))+(foy*(T(i-1,61)+T(
     +      i-1,83)-2*T(i-1,72)))+T(i-1,72)
      T(i,73)=(fox*(T(i-1,72)+T(i-1,74)-2*T(i-1,73)))+(foy*(T(i-1,62)+T(
     +      i-1,84)-2*T(i-1,73)))+T(i-1,73)
      T(i,74)=(fox*(T(i-1,73)+T(i-1,75)-2*T(i-1,74)))+(foy*(T(i-1,63)+T(
     +      i-1,85)-2*T(i-1,74)))+T(i-1,74)
      T(i,75)=(2*fox*(T(i-1,74)-T(i-1,75)))+(2*bixlco*fox*(Tinf-T(i-1,75
     +      )))+(foy*(T(i-1,86)+T(i-1,64)-2*T(i-1,75)))+T(i-1,75)
*     Row 8
      T(i,76)=(2*fox*(T(i-1,77)-T(i-1,76)))+foy*(T(i-1,65)+T(i-1,87)-2*T
     +      (i-1,76))+T(i-1,76)
      T(i,77)=(fox*(T(i-1,76)+T(i-1,78)-2*T(i-1,77)))+(foy*(T(i-1,66)+T(
     +      i-1,88)-2*T(i-1,77)))+T(i-1,77)
      T(i,78)=(fox*(T(i-1,77)+T(i-1,79)-2*T(i-1,78)))+(foy*(T(i-1,67)+T(
     +      i-1,89)-2*T(i-1,78)))+T(i-1,78)
      T(i,79)=(fox*(T(i-1,78)+T(i-1,80)-2*T(i-1,79)))+(foy*(T(i-1,68)+T(
     +      i-1,90)-2*T(i-1,79)))+T(i-1,79)
      T(i,80)=(fox*(T(i-1,79)+T(i-1,81)-2*T(i-1,80)))+(foy*(T(i-1,69)+T(
     +      i-1,91)-2*T(i-1,80)))+T(i-1,80)
      T(i,81)=(fox*(T(i-1,80)+T(i-1,82)-2*T(i-1,81)))+(foy*(T(i-1,70)+T(
     +      i-1,92)-2*T(i-1,81)))+T(i-1,81)
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      T(i,82)=(fox*(T(i-1,81)+T(i-1,83)-2*T(i-1,82)))+(foy*(T(i-1,71)+T(
     +     i-1,93)-2*T(i-1,82)))+T(i-1,82)
      T(i,83)=(fox*(T(i-1,82)+T(i-1,84)-2*T(i-1,83)))+(foy*(T(i-1,72)+T(
     +     i-1,94)-2*T(i-1,83)))+T(i-1,83)
      T(i,84)=(fox*(T(i-1,83)+T(i-1,85)-2*T(i-1,84)))+(foy*(T(i-1,73)+T(
     +     i-1,95)-2*T(i-1,84)))+T(i-1,84)
      T(i,85)=(fox*(T(i-1,84)+T(i-1,86)-2*T(i-1,85)))+(foy*(T(i-1,74)+T(
     +     i-1,96)-2*T(i-1,85)))+T(i-1,85)
      T(i,86)=(2*fox*(T(i-1,85)-T(i-1,86)))+(2*bixlco*fox*(Tinf-T(i-1,86
     +     )))+(foy*(T(i-1,97)+T(i-1,75)-2*T(i-1,86)))+T(i-1,86)
*     Row 9
      T(i,87)=(2*fox*(T(i-1,88)))+(2*biybco*foy*Tinf)+(2*foy*T(i-1,76))+
     +     (1-2*foy-2*biybco*foy-2*fox)*T(i-1,87)
      T(i,88)=fox*T(i-1,87)+fox*T(i-1,89)+2*biybco*foy*Tinf+2*foy*T(i-1
     +     ,77)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,88)
      T(i,89)=fox*T(i-1,88)+fox*T(i-1,90)+2*biybco*foy*Tinf+2*foy*T(i-1
     +     ,78)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,89)
      T(i,90)=fox*T(i-1,89)+fox*T(i-1,91)+2*biybco*foy*Tinf+2*foy*T(i-1
     +     ,79)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,90)
      T(i,91)=fox*T(i-1,90)+fox*T(i-1,92)+2*biybco*foy*Tinf+2*foy*T(i-1
     +     ,80)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,91)
      T(i,92)=fox*T(i-1,91)+fox*T(i-1,93)+2*biybco*foy*Tinf+2*foy*T(i-1
     +     ,81)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,92)
      T(i,93)=fox*T(i-1,92)+fox*T(i-1,94)+2*biybco*foy*Tinf+2*foy*T(i-1
     +     ,82)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,93)
      T(i,94)=fox*T(i-1,93)+fox*T(i-1,95)+2*biybco*foy*Tinf+2*foy*T(i-1
     +     ,83)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,94)
      T(i,95)=fox*T(i-1,94)+fox*T(i-1,96)+2*biybco*foy*Tinf+2*foy*T(i-1
     +     ,84)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,95)
      T(i,96)=fox*T(i-1,95)+fox*T(i-1,97)+2*biybco*foy*Tinf+2*foy*T(i-1
     +     ,85)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,96)
      T(i,97)=2*fox*T(i-1,96)+2*bixlco*fox*Tinf+2*biybco*foy*Tinf+2*foy*
     +     T(i-1,86)+(1-2*foy-2*biybco*foy-2*bixlco*fox-2*fox)*T(i-1,97)

      l=l+1
      if(iprint.ne.jprint) goto 35
      iprint=0
      m=1
      print*,'iteration',l
*     row 1
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=12
      m=2
*     row 2
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=23
      m=3
*     row 3
      print 32,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9)
      j=33
      m=4
```

```
*     row 4
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=44
      m=5
*     row 5
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=55
      m=6
*     row 6
      print 33,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9)
      j=65
      m=7
*     row 7
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=76
      m=8
      Tinf=300
*     row 8
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(i,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=87
      m=9
*     row 9
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(i,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
        if(l.lt.countt)then
      goto 60
      else
      print*,'Calculation terminated in cooling due to too many
     +       iterations!'
      goto 40
      endif

 60   if (T(i,1).gt.cornert)then
         goto 35
         else
         print*,'The Process Has Ended'
         goto 40

         endif
40    end
```

```
*       Program Explicit Method

*       cooling passage location #2

        real T(1:20000,1:100),dx,dy,fox,foy,k,bixc,biyc,hc,rho,cp,
     +     alpha,hl,
     +     dt,Ta,q,Tinf,setpoint,ssetpoint,corner,cornert
        integer i,j,l,m,n,count,countt
        Print*,'Enter the node spacing in the x direction in meters'
        read*, dx
        Print*,'Enter the node spacing in the y direction in meters'
        read*, dy
        Print*,'Enter the ambient temperature in kelvin'
        read*, Ta
        Print*,'Enter the time step in seconds'
        read*, dt
        print*,'Enter the value for temperature at measured at infinity.'
        read*, Tinf
        print*,'Enter the corner temperature desired before cooling is
     +     initiated in the pultrusion simulator block.'
       read*, corner
       print*,'Enter the desired corner temperature after cooling is
     +     initiated in the pultrusion simulator block.'
       read*,cornert
       print*,'Enter the external heat transfer coefficient on the
     +     right side of the pultrusion simulator block when the block
     +     is heating.'
       read*, hl
       print*,'Enter the external heat transfer coefficient on the
     +     bottom of the pultrusion simulator block when the block
     +     is heating.'
       read*, hb
       print*,'Enter the external heat transfer coefficient on the
     +     right side of the pultrusion simulator block when the block
     +     is cooling.'
       read*, hlco
       print*,'Enter the external heat transfer coefficient on the
     +     bottom of the pultrusion simulator block when the block
     +     is heating.'
       read*, hbco
       print*,'Enter the external heat transfer coefficient of the
     +     fluid used within the cooling passage.'
       read*, hc
       print*'Enter the amount of heat input into the numerically
     +     modeled portion of the pultrusion simulator block.'
       read*, q
       count=15900
       setpoint=0.10
       kprint=100
       jprint=1000
       k= 43
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      rho=7833
      cp=400
      bixlco=(hlco*dx)/k
      bixc=(hc*dx)/k
      biybco=(hbco*dy)/k
      biyc=(hc*dy)/k
      bixl=(hl*dx)/k
      biyb=(hb*dy)/k
      alpha=k/(rho*cp)
      fox=(k*dt)/(rho*cp*dx**2)
      foy=(k*dt)/(rho*cp*dy**2)
      ssetpoint=0.1
      countt=59000
      i=1
      j=1

 10   if(j.lt.98) then
      T(1,j)=Ta
      j=j+1
      goto 10
      else
      j=1
      endif
*     Initiate Initial temperature throuout the matrix
      print*,'Iteration 1'
*     row 1
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=12
*     row 2
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=23
*     row 3
      print 32,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9)
      j=33
*     row 4
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=44
*     row 5
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=55
*     row 6
      print 33,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9)
      j=65
*     row 7
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=76
*     row 8
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      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      j=87
*     row 9
      print 31,j,T(i,j),T(i,j+1),T(i,j+2),T(i,j+3),T(i,j+4),T(i,j+5),T(i
     +     ,j+6),T(i,j+7),T(i,j+8),T(i,j+9),T(i,j+10)
      iprint=0
      l=1
*     Calculating the Temperature to establish Steady State
 15   i=i+1
      iprint=iprint+1
      j=1
*     Row 1
      T(i,1)=(2*fox*(T(i-1,2)-T(i-1,1)))+(2*foy*(T(i-1,12)-T(i-1,1)))+T(
     +     i-1,1)
      T(i,2)=(fox*(T(i-1,1)+T(i-1,3)-(2*T(i-1,2))))+(2*foy*(T(i-1,13)-T(
     +     i-1,2)
     +     ))+T(i-1,2)
      T(i,3)=(fox*(T(i-1,2)+T(i-1,4)-(2*T(i-1,3))))+(2*foy*(T(i-1,14)-T(
     +     i-1,3)))+T(i-1,3)
      T(i,4)=(fox*(T(i-1,3)+T(i-1,5)-(2*T(i-1,4))))+(2*foy*(T(i-1,15)-T(
     +     i-1,4)))+T(i-1,4)
      T(i,5)=(fox*(T(i-1,4)+T(i-1,6)-(2*T(i-1,5))))+(2*foy*(T(i-1,16)-T(
     +     i-1,5)))+T(i-1,5)
      T(i,6)=(fox*(T(i-1,5)+T(i-1,7)-(2*T(i-1,6))))+(2*foy*(T(i-1,17)-T(
     +     i-1,6)))+T(i-1,6)
      T(i,7)=(fox*(T(i-1,6)+T(i-1,8)-(2*T(i-1,7))))+(2*foy*(T(i-1,18)-T(
     +     i-1,7)))+T(i-1,7)
      T(i,8)=(fox*(T(i-1,7)+T(i-1,9)-(2*T(i-1,8))))+(2*foy*(T(i-1,19)-T(
     +     i-1,8)))+T(i-1,8)
      T(i,9)=(fox*(T(i-1,8)+T(i-1,10)-(2*T(i-1,9))))+(2*foy*(T(i-1,20)-T
     +     (i-1,9)))+T(i-1,9)
      T(i,10)=(fox*(T(i-1,9)+T(i-1,11)-(2*T(i-1,10))))+(2*foy*(T(i-1,21)
     +     -T(i-1,10)))+T(i-1,10)
      T(i,11)=2*bixl*fox*(Tinf-T(i-1,11))+2*fox*(T(i-1,10)-T(i-1,11))+2*
     +     foy*(T(i-1,10)-T(i-1,11))+T(i-1,11)
*     Row 2
      T(i,12)=(2*fox*(T(i-1,13)-T(i-1,12)))+foy*(T(i-1,1)+T(i-1,23)-2*T(
     +     i-1,12))+T(i-1,12)
      T(i,13)=(4*fox*T(i-1,12)/3)+(2*fox*T(i-1,14)/3)+(2*foy*T(i-1,24)/3
     +     )+(4*foy*T(i-1,2)/3)+(1-(2*fox)-(2*foy))*T(i-1,13)
      T(i,14)=(2*fox*T(i-1,13)/3)+(2*foy*T(i-1,25)/3)+(4*foy*T(i-1,3)/3)
     +     +(4*fox*T(i-1,15)/3)+(1-(2*fox)-(2*foy))*T(i-1,14)
      T(i,15)=(fox*(T(i-1,14)+T(i-1,16)-2*T(i-1,15)))+(foy*(T(i-1,4)+T(i
     +     -1,26)-2*T(i-1,15)))+T(i-1,15)
      T(i,16)=(fox*(T(i-1,15)+T(i-1,17)-2*T(i-1,16)))+(foy*(T(i-1,5)+T(i
     +     -1,27)-2*T(i-1,16)))+T(i-1,16)
      T(i,17)=(fox*(T(i-1,16)+T(i-1,18)-2*T(i-1,17)))+(foy*(T(i-1,6)+T(i
     +     -1,28)-2*T(i-1,17)))+T(i-1,17)
      T(i,18)=(fox*(T(i-1,17)+T(i-1,19)-2*T(i-1,18)))+(foy*(T(i-1,7)+T(i
     +     -1,29)-2*T(i-1,18)))+T(i-1,18)
      T(i,19)=(fox*(T(i-1,18)+T(i-1,20)-2*T(i-1,19)))+(foy*(T(i-1,8)+T(i
     +     -1,30)-2*T(i-1,19)))+T(i-1,19)
      T(i,20)=(fox*T(i-1,19))+(fox*T(i-1,21))+(foy*T(i-1,9))+((1-2*fox
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+      -foy)*T(i-1,20))+(q/4)
       T(i,21)=(fox*(T(i-1,20)+T(i-1,22)-2*T(i-1,21)))+(foy*(T(i-1,10)+T(
+      i-1,31)-2*T(i-1,21)))+T(i-1,21)
       T(i,22)=(2*fox*(T(i-1,21)-T(i-1,22)))+(2*bixl*fox*(Tinf-T(i-1,22))
+      )+(foy*(T(i-1,32)+T(i-1,11)-2*T(i-1,22)))+T(i-1,22)
*      Row 3
       T(i,23)=(2*fox*(T(i-1,24)-T(i-1,23)))+foy*(T(i-1,12)+T(i-1,33)-2*T
+      (i-1,23))+T(i-1,23)
       T(i,24)=(4*fox*T(i-1,23)/3)+(2*fox*T(i-1,25)/3)+(2*foy*T(i-1,13)/3
+      )+(4*foy*T(i-1,34)/3)+(1-(2*fox)-(2*foy))*T(i-1,24)
       T(i,25)=(2*fox*T(i-1,24)/3)+(4*fox*T(i-1,26)/3)+(2*foy*T(i-1,14)/3
+      )+(4*foy*T(i-1,35)/3)+(1-(2*fox)-(2*foy))*T(i-1,25)
       T(i,26)=(fox*(T(i-1,25)+T(i-1,27)-2*T(i-1,26)))+(foy*(T(i-1,15)+T(
+      i-1,36)-2*T(i-1,26)))+T(i-1,26)
       T(i,27)=(fox*(T(i-1,26)+T(i-1,28)-2*T(i-1,27)))+(foy*(T(i-1,16)+T(
+      i-1,37)-2*T(i-1,27)))+T(i-1,27)
       T(i,28)=(fox*(T(i-1,27)+T(i-1,29)-2*T(i-1,28)))+(foy*(T(i-1,17)+T(
+      i-1,38)-2*T(i-1,28)))+T(i-1,28)
       T(i,29)=(fox*(T(i-1,28)+T(i-1,30)-2*T(i-1,29)))+(foy*(T(i-1,18)+T(
+      i-1,39)-2*T(i-1,29)))+T(i-1,29)
       T(i,30)=(foy*T(i-1,19))+(foy*T(i-1,40))+(fox*T(i-1,29))+((1-2*foy
+      -fox)*T(i-1,30))+(q/4)
       T(i,31)=(foy*T(i-1,21))+(foy*T(i-1,42))+(fox*T(i-1,32))+((1-2*foy
+      -fox)*T(i-1,31))+(q/4)
       T(i,32)=(2*fox*(T(i-1,31)-T(i-1,32)))+(2*bixl*fox*(Tinf-T(i-1,32))
+      )+(foy*(T(i-1,43)+T(i-1,22)-2*T(i-1,32)))+T(i-1,32)

*      Row 4
       T(i,33)=(2*fox*(T(i-1,34)-T(i-1,33)))+foy*(T(i-1,23)+T(i-1,44)-2*T
+      (i-1,34))+T(i-1,34)
       T(i,34)=(fox*(T(i-1,33)+T(i-1,35)-2*T(i-1,34)))+(foy*(T(i-1,24)+T(
+      i-1,45)-2*T(i-1,34)))+T(i-1,34)
       T(i,35)=(fox*(T(i-1,34)+T(i-1,36)-2*T(i-1,35)))+(foy*(T(i-1,25)+T(
+      i-1,46)-2*T(i-1,35)))+T(i-1,35)
       T(i,36)=(fox*(T(i-1,35)+T(i-1,37)-2*T(i-1,36)))+(foy*(T(i-1,26)+T(
+      i-1,47)-2*T(i-1,36)))+T(i-1,36)
       T(i,37)=(fox*(T(i-1,36)+T(i-1,38)-2*T(i-1,37)))+(foy*(T(i-1,27)+T(
+      i-1,48)-2*T(i-1,37)))+T(i-1,37)
       T(i,38)=(fox*(T(i-1,37)+T(i-1,39)-2*T(i-1,38)))+(foy*(T(i-1,28)+T(
+      i-1,49)-2*T(i-1,38)))+T(i-1,38)
       T(i,39)=(fox*(T(i-1,38)+T(i-1,40)-2*T(i-1,39)))+(foy*(T(i-1,29)+T(
+      i-1,50)-2*T(i-1,39)))+T(i-1,39)
       T(i,40)=(fox*(T(i-1,39)+T(i-1,41)-2*T(i-1,40)))+(foy*(T(i-1,30)+T(
+      i-1,51)-2*T(i-1,40)))+T(i-1,40)
       T(i,41)=(foy*T(i-1,52))+(fox*T(i-1,40))+(fox*T(i-1,42))+((1-2*fox
+      -foy)*T(i-1,41))+(q/4)
       T(i,42)=(fox*(T(i-1,41)+T(i-1,43)-2*T(i-1,42)))+(foy*(T(i-1,31)+T(
+      i-1,53)-2*T(i-1,42)))+T(i-1,42)
       T(i,43)=(2*fox*(T(i-1,42)-T(i-1,43)))+(2*bixl*fox*(Tinf-T(i-1,43))
+      )+(foy*(T(i-1,54)+T(i-1,32)-2*T(i-1,43)))+T(i-1,43)
*      Row 5
       T(i,44)=(2*fox*(T(i-1,45)-T(i-1,44)))+foy*(T(i-1,33)+T(i-1,55)-2*T
+      (i-1,44))+T(i-1,44)
       T(i,45)=(fox*(T(i-1,44)+T(i-1,46)-2*T(i-1,45)))+(foy*(T(i-1,34)+T(
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+     i-1,56)-2*T(i-1,45)))+T(i-1,45)
      T(i,46)=(fox*(T(i-1,45)+T(i-1,47)-2*T(i-1,46)))+(foy*(T(i-1,35)+T(
+     i-1,57)-2*T(i-1,46)))+T(i-1,46)
      T(i,47)=(foy*T(i-1,36))+(fox*T(i-1,46))+(fox*T(i-1,48))+((1-2*fox
+     -foy)*T(i-1,47))+(q/4)
      T(i,48)=(fox*(T(i-1,47)+T(i-1,49)-2*T(i-1,48)))+(foy*(T(i-1,37)+T(
+     i-1,58)-2*T(i-1,48)))+T(i-1,48)
      T(i,49)=(fox*(T(i-1,48)+T(i-1,50)-2*T(i-1,49)))+(foy*(T(i-1,38)+T(
+     i-1,59)-2*T(i-1,49)))+T(i-1,49)
      T(i,50)=(fox*(T(i-1,49)+T(i-1,51)-2*T(i-1,50)))+(foy*(T(i-1,39)+T(
+     i-1,60)-2*T(i-1,50)))+T(i-1,50)
      T(i,51)=(fox*(T(i-1,50)+T(i-1,52)-2*T(i-1,51)))+(foy*(T(i-1,40)+T(
+     i-1,61)-2*T(i-1,51)))+T(i-1,51)
      T(i,52)=(fox*(T(i-1,51)+T(i-1,53)-2*T(i-1,52)))+(foy*(T(i-1,41)+T(
+     i-1,62)-2*T(i-1,52)))+T(i-1,52)
      T(i,53)=(fox*(T(i-1,52)+T(i-1,54)-2*T(i-1,53)))+(foy*(T(i-1,42)+T(
+     i-1,63)-2*T(i-1,53)))+T(i-1,53)
      T(i,54)=(2*fox*(T(i-1,53)-T(i-1,54)))+(2*bixl*fox*(Tinf-T(i-1,54))
+     )+(foy*(T(i-1,64)+T(i-1,43)-2*T(i-1,54)))+T(i-1,54)
*     Row 6
      T(i,55)=(2*fox*(T(i-1,56)-T(i-1,55)))+foy*(T(i-1,44)+T(i-1,65)-2*T
+     (i-1,55))+T(i-1,55)
      T(i,56)=(fox*(T(i-1,55)+T(i-1,57)-2*T(i-1,56)))+(foy*(T(i-1,45)+T(
+     i-1,66)-2*T(i-1,56)))+T(i-1,56)
      T(i,57)=(fox*T(i-1,56))+(foy*T(i-1,46))+(foy*T(i-1,67))+((1-2*foy
+     -fox)*T(i-1,57))+(q/4)
      T(i,58)=(fox*T(i-1,59))+(foy*T(i-1,48))+(foy*T(i-1,69))+((1-2*foy
+     -fox)*T(i-1,58))+(q/4)
      T(i,59)=(fox*(T(i-1,58)+T(i-1,60)-2*T(i-1,59)))+(foy*(T(i-1,49)+T(
+     i-1,70)-2*T(i-1,59)))+T(i-1,59)
      T(i,60)=(fox*(T(i-1,59)+T(i-1,61)-2*T(i-1,60)))+(foy*(T(i-1,50)+T(
+     i-1,71)-2*T(i-1,60)))+T(i-1,60)
      T(i,61)=(fox*(T(i-1,60)+T(i-1,62)-2*T(i-1,61)))+(foy*(T(i-1,51)+T(
+     i-1,72)-2*T(i-1,61)))+T(i-1,61)
      T(i,62)=(fox*(T(i-1,61)+T(i-1,63)-2*T(i-1,62)))+(foy*(T(i-1,52)+T(
+     i-1,73)-2*T(i-1,62)))+T(i-1,62)
      T(i,63)=(fox*(T(i-1,62)+T(i-1,64)-2*T(i-1,63)))+(foy*(T(i-1,53)+T(
+     i-1,74)-2*T(i-1,63)))+T(i-1,63)
      T(i,64)=(2*fox*(T(i-1,63)-T(i-1,64)))+(2*bixl*fox*(Tinf-T(i-1,64))
+     )+(foy*(T(i-1,75)+T(i-1,54)-2*T(i-1,64)))+T(i-1,64)
*     Row 7
      T(i,65)=(2*fox*(T(i-1,66)-T(i-1,65)))+foy*(T(i-1,55)+T(i-1,76)-2*T
+     (i-1,65))+T(i-1,65)
      T(i,66)=(fox*(T(i-1,65)+T(i-1,67)-2*T(i-1,66)))+(foy*(T(i-1,56)+T(
+     i-1,77)-2*T(i-1,66)))+T(i-1,66)
      T(i,67)=(fox*(T(i-1,66)+T(i-1,68)-2*T(i-1,67)))+(foy*(T(i-1,57)+T(
+     i-1,78)-2*T(i-1,67)))+T(i-1,67)
      T(i,68)=fox*T(i-1,67)+foy*T(i-1,79)+fox*T(i-1,69)+((1-2*fox-foy)*T
+     (i-1,68))+q/4
      T(i,69)=(fox*(T(i-1,68)+T(i-1,70)-2*T(i-1,69)))+(foy*(T(i-1,58)+T(
+     i-1,80)-2*T(i-1,69)))+T(i-1,69)
      T(i,70)=(fox*(T(i-1,69)+T(i-1,71)-2*T(i-1,70)))+(foy*(T(i-1,59)+T(
+     i-1,81)-2*T(i-1,70)))+T(i-1,70)
      T(i,71)=(fox*(T(i-1,70)+T(i-1,72)-2*T(i-1,71)))+(foy*(T(i-1,60)+T(
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+       i-1,82)-2*T(i-1,71)))+T(i-1,71)
      T(i,72)=(fox*(T(i-1,71)+T(i-1,73)-2*T(i-1,72)))+(foy*(T(i-1,61)+T(
+       i-1,83)-2*T(i-1,72)))+T(i-1,72)
      T(i,73)=(fox*(T(i-1,72)+T(i-1,74)-2*T(i-1,73)))+(foy*(T(i-1,62)+T(
+       i-1,84)-2*T(i-1,73)))+T(i-1,73)
      T(i,74)=(fox*(T(i-1,73)+T(i-1,75)-2*T(i-1,74)))+(foy*(T(i-1,63)+T(
+       i-1,85)-2*T(i-1,74)))+T(i-1,74)
      T(i,75)=(2*fox*(T(i-1,74)-T(i-1,75)))+(2*bixl*fox*(Tinf-T(i-1,75))
+       )+(foy*(T(i-1,86)+T(i-1,64)-2*T(i-1,75)))+T(i-1,75)
*     Row 8
      T(i,76)=(2*fox*(T(i-1,77)-T(i-1,76)))+foy*(T(i-1,65)+T(i-1,87)-2*T
+       (i-1,76))+T(i-1,76)
      T(i,77)=(fox*(T(i-1,76)+T(i-1,78)-2*T(i-1,77)))+(foy*(T(i-1,66)+T(
+       i-1,88)-2*T(i-1,77)))+T(i-1,77)
      T(i,78)=(fox*(T(i-1,77)+T(i-1,79)-2*T(i-1,78)))+(foy*(T(i-1,67)+T(
+       i-1,89)-2*T(i-1,78)))+T(i-1,78)
      T(i,79)=(fox*(T(i-1,78)+T(i-1,80)-2*T(i-1,79)))+(foy*(T(i-1,68)+T(
+       i-1,90)-2*T(i-1,79)))+T(i-1,79)
      T(i,80)=(fox*(T(i-1,79)+T(i-1,81)-2*T(i-1,80)))+(foy*(T(i-1,69)+T(
+       i-1,91)-2*T(i-1,80)))+T(i-1,80)
      T(i,81)=(fox*(T(i-1,80)+T(i-1,82)-2*T(i-1,81)))+(foy*(T(i-1,70)+T(
+       i-1,92)-2*T(i-1,81)))+T(i-1,81)
      T(i,82)=(fox*(T(i-1,81)+T(i-1,83)-2*T(i-1,82)))+(foy*(T(i-1,71)+T(
+       i-1,93)-2*T(i-1,82)))+T(i-1,82)
      T(i,83)=(fox*(T(i-1,82)+T(i-1,84)-2*T(i-1,83)))+(foy*(T(i-1,72)+T(
+       i-1,94)-2*T(i-1,83)))+T(i-1,83)
      T(i,84)=(fox*(T(i-1,83)+T(i-1,85)-2*T(i-1,84)))+(foy*(T(i-1,73)+T(
+       i-1,95)-2*T(i-1,84)))+T(i-1,84)
      T(i,85)=(fox*(T(i-1,84)+T(i-1,86)-2*T(i-1,85)))+(foy*(T(i-1,74)+T(
+       i-1,96)-2*T(i-1,85)))+T(i-1,85)
      T(i,86)=(2*fox*(T(i-1,85)-T(i-1,86)))+(2*bixl*fox*(Tinf-T(i-1,86))
+       )+(foy*(T(i-1,97)+T(i-1,75)-2*T(i-1,86)))+T(i-1,86)
*     Row 9
      T(i,87)=(2*fox*(T(i-1,88)))+(2*biyb*foy*Tinf)+(2*foy*T(i-1,76))+(1
+       -2*foy-2*biyb*foy-2*fox)*T(i-1,87)
      T(i,88)=fox*T(i-1,87)+fox*T(i-1,89)+2*biyb*foy*Tinf+2*foy*T(i-1,77
+       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,88)
      T(i,89)=fox*T(i-1,88)+fox*T(i-1,90)+2*biyb*foy*Tinf+2*foy*T(i-1,78
+       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,89)
      T(i,90)=fox*T(i-1,89)+fox*T(i-1,91)+2*biyb*foy*Tinf+2*foy*T(i-1,79
+       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,90)
      T(i,91)=fox*T(i-1,90)+fox*T(i-1,92)+2*biyb*foy*Tinf+2*foy*T(i-1,80
+       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,91)
      T(i,92)=fox*T(i-1,91)+fox*T(i-1,93)+2*biyb*foy*Tinf+2*foy*T(i-1,81
+       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,92)
      T(i,93)=fox*T(i-1,92)+fox*T(i-1,94)+2*biyb*foy*Tinf+2*foy*T(i-1,82
+       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,93)
      T(i,94)=fox*T(i-1,93)+fox*T(i-1,95)+2*biyb*foy*Tinf+2*foy*T(i-1,83
+       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,94)
      T(i,95)=fox*T(i-1,94)+fox*T(i-1,96)+2*biyb*foy*Tinf+2*foy*T(i-1,84
+       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,95)
      T(i,96)=fox*T(i-1,95)+fox*T(i-1,97)+2*biyb*foy*Tinf+2*foy*T(i-1,85
+       )+(1-2*foy-2*biyb*foy-2*fox)*T(i-1,96)
      T(i,97)=2*fox*T(i-1,96)+2*bixl*fox*Tinf+2*biyb*foy*Tinf+2*foy*T(i-
```

```
     +      1,86)+(1-2*foy-2*biyb*foy-2*bixl*fox-2*fox)*T(i-1,97)

       l=l+1
       if(iprint.ne.kprint) then
          goto 15
          endif

       m=1
       print*,'iteration',l
*      row 1
       print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
       j=12
       m=2
*      row 2
       print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
       j=23
       m=3
*      row 3
       print 32,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9)
       j=33
       m=4
*      row 4
       print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
       j=44
       m=5
*      row 5
       print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
       j=55
       m=6
*      row 6
       print 33,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9)
       j=65
       m=7
*      row 7
       print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
       j=76
       m=8
*      row 8
       print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(i,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
       j=87
       m=9
*      row 9
       print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(i,j+5),T(l
     +      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
       iprint=0
       if( l.lt.count) then
```

```
      goto 50
      else
      print*,'Calculation terminated in heating due to too many
     +      iterations!'
      goto 40
      endif
 50   if(((T(i,30)-T(i-1,30)).gt.setpoint).and.(T(i,1).lt.corner)) then
      goto 15
      else
      print*,'The corner temperature before cooling
     +      is...................'
      print*,T(i,1)
      goto 30
      endif
 30   Print*,'Die has reached Steady State. Is the corner node at the
     +      desired temperature?'
      Print*,'Enter 1 for Yes (Cooling Begins).  Enter 2 for No.'
      read*,n
      print*,n
      if(n.lt.2) then
         print*,'Cooling Is Now Initiated!!'
         goto 34
         else
            print*,'The Heating Cycle Has Been Repeated.'
            goto 15
            endif
 31         format (1x,i2,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0
     +           ,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0)
 32         format (1x,i2,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0
     +           ,1x,f6.0,1x,f6.0,1x,f6.0,8x,f6.0,1x,f6.0)
 33         format (1x,i2,1x,f6.0,1x,f6.0,1x,f6.0,8x,f6.0,1x,f6.0
     +           ,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0,1x,f6.0)
 41         format (1x,i2,1x,f6.2,1x,f6.2,1x,f6.2,1x,f6.2,1x,f6.2
     +           ,1x,f6.2,1x,f6.2,1x,f6.2,1x,f6.2,1x,f6.2,1x,f6.2)
 42         format (1x,i2,1x,f6.2,1x,f6.2,1x,f6.2,1x,f6.2,1x,f6.2
     +           ,1x,f6.2,1x,f6.2,1x,f6.2,8x,f6.2,1x,f6.2)
 43         format (1x,i2,1x,f6.2,1x,f6.2,1x,f6.2,8x,f6.2,1x,f6.2,
     +           1x,f6.2,1x,f6.2,1x,f6.2,1x,f6.2,1x,f6.2)
*     Turn off heaters begin cooling



 34   q=0
      j=1
      m=1
      print*,'iteration',1
*     row 1
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=12
      m=2
*     row 2
```

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      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=23
      m=3
*     row 3
      print 32,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9)
      j=33
      m=4
*     row 4
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=44
      m=5
*     row 5
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=55
      m=6
*     row 6
      print 33,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9)
      j=65
      m=7
*     row 7
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=76
      m=8
*     row 8
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(i,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      j=87
      m=9
*     row 9
      print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(i,j+5),T(l
     +     ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
      iprint=0

 35   i=i+1
      iprint=iprint+1
      j=1
      q=0
*     Row 1
      T(i,1)=(2*fox*(T(i-1,2)-T(i-1,1)))+(2*foy*(T(i-1,12)-T(i-1,1)))+T(
     +     i-1,1)
      T(i,2)=(fox*(T(i-1,1)+T(i-1,3)-(2*T(i-1,2))))+(2*foy*(T(i-1,13)-T(
     +     i-1,2)))+T(i-1,2)
      T(i,3)=(fox*(T(i-1,2)+T(i-1,4)-(2*T(i-1,3))))+(2*foy*(T(i-1,14)-T(
     +     i-1,3)))+T(i-1,3)
      T(i,4)=(fox*(T(i-1,3)+T(i-1,5)-(2*T(i-1,4))))+(2*foy*(T(i-1,15)-T(
     +     i-1,4)))+T(i-1,4)
      T(i,5)=(fox*(T(i-1,4)+T(i-1,6)-(2*T(i-1,5))))+(2*foy*(T(i-1,16)-T(
     +     i-1,5)))+T(i-1,5)
```

```
      T(i,6)=(fox*(T(i-1,5)+T(i-1,7)-(2*T(i-1,6))))+(2*foy*(T(i-1,17)-T(
     +     i-1,6)))+T(i-1,6)
      T(i,7)=(fox*(T(i-1,6)+T(i-1,8)-(2*T(i-1,7))))+(2*foy*(T(i-1,18)-T(
     +     i-1,7)))+T(i-1,7)
      T(i,8)=(fox*(T(i-1,7)+T(i-1,9)-(2*T(i-1,8))))+(2*foy*(T(i-1,19)-T(
     +     i-1,8)))+T(i-1,8)
      T(i,9)=(fox*(T(i-1,8)+T(i-1,10)-(2*T(i-1,9))))+(2*foy*(T(i-1,20)-T
     +     (i-1,9)))+T(i-1,9)
      T(i,10)=(fox*(T(i-1,9)+T(i-1,11)-(2*T(i-1,10))))+(2*foy*(T(i-1,21)
     +     -T(i-1,10)))+T(i-1,10)
      T(i,11)=2*bixlco*fox*(Tinf-T(i-1,11))+2*fox*(T(i-1,10)-T(i-1,11))+
     +     2*foy*(T(i-1,10)-T(i-1,11))+T(i-1,11)
*     Row 2
      T(i,12)=(2*fox*(T(i-1,13)-T(i-1,12)))+foy*(T(i-1,1)+T(i-1,23)-2*T(
     +     i-1,12))+T(i-1,12)
      T(i,13)=(4*fox*(T(i-1,12)-T(i-1,13))/3)+(2*fox*(T(i-1,14)-T(i-1,13
     +     ))/3)+(2*foy*(T(i-1,24)-T(i-1,13))/3)+(4*foy*(T(i-1,2)-T(i-1,
     +     13))/3)+(((2*biyc*foy/3)+(2*bixc*fox/3))*Tinf)+((1-(2*biyc*
     +     foy/3)-(2*bixc*fox/3))*T(i-1,13))
      T(i,14)=(2*fox*(T(i-1,13)-T(i-1,14))/3)+(2*foy*(T(i-1,25)-T(i-1,14
     +     ))/3)+(4*foy*(T(i-1,3)-T(i-1,14))/3)+(4*fox*(T(i-1,15)-T(i-1,
     +     14))/3)+(((2*biyc*foy/3)+(2*bixc*fox/3))*Tinf)+((1-(2*biyc*
     +     foy/3)-(2*bixc*fox/3))*T(i-1,14))
      T(i,15)=(fox*(T(i-1,14)+T(i-1,16)-2*T(i-1,15)))+(foy*(T(i-1,4)+T(i
     +     -1,26)-2*T(i-1,15)))+T(i-1,15)
      T(i,16)=(fox*(T(i-1,15)+T(i-1,17)-2*T(i-1,16)))+(foy*(T(i-1,5)+T(i
     +     -1,27)-2*T(i-1,16)))+T(i-1,16)
      T(i,17)=(fox*(T(i-1,16)+T(i-1,18)-2*T(i-1,17)))+(foy*(T(i-1,6)+T(i
     +     -1,28)-2*T(i-1,17)))+T(i-1,17)
      T(i,18)=(fox*(T(i-1,17)+T(i-1,19)-2*T(i-1,18)))+(foy*(T(i-1,7)+T(i
     +     -1,29)-2*T(i-1,18)))+T(i-1,18)
      T(i,19)=(fox*(T(i-1,18)+T(i-1,20)-2*T(i-1,19)))+(foy*(T(i-1,8)+T(i
     +     -1,30)-2*T(i-1,19)))+T(i-1,19)
      T(i,20)=(fox*T(i-1,19))+(fox*T(i-1,21))+(foy*T(i-1,9))+((1-2*fox
     +     -foy)*T(i-1,20))+(q/4)
      T(i,21)=(fox*(T(i-1,20)+T(i-1,22)-2*T(i-1,21)))+(foy*(T(i-1,10)+T(
     +     i-1,31)-2*T(i-1,21)))+T(i-1,21)
      T(i,22)=(2*fox*(T(i-1,21)-T(i-1,22)))+(2*bixlco*fox*(Tinf-T(i-1,22
     +     )))+(foy*(T(i-1,32)+T(i-1,11)-2*T(i-1,22)))+T(i-1,22)
*     Row 3
      T(i,23)=(2*fox*(T(i-1,24)-T(i-1,23)))+foy*(T(i-1,12)+T(i-1,33)-2*T
     +     (i-1,23))+T(i-1,23)
      T(i,24)=(4*fox*(T(i-1,23)-T(i-1,24))/3)+(2*fox*(T(i-1,25)-T(i-1,24
     +     ))/3)+(2*foy*(T(i-1,13)-T(i-1,24))/3)+(4*foy*(T(i-1,34)-T(i-1
     +     ,24))/3)+(((2*biyc*foy/3)+(2*bixc*fox/3))*Tinf)+((1-(2*biyc*
     +     foy/3)-(2*bixc*fox/3))*T(i-1,24))
      T(i,25)=(2*fox*(T(i-1,24)-T(i-1,25))/3)+(4*fox*(T(i-1,26)-T(i-1,25
     +     ))/3)+(4*foy*(T(i-1,35)-T(i-1,25))/3)+(2*foy*(T(i-1,14)-T(i-1
     +     ,25))/3)+(((2*biyc*foy/3)+(2*bixc*fox/3))*Tinf)+((1-(2*biyc*
     +     foy/3)-(2*bixc*fox/3))*T(i-1,25))
      T(i,26)=(fox*(T(i-1,25)+T(i-1,27)-2*T(i-1,26)))+(foy*(T(i-1,15)+T(
     +     i-1,36)-2*T(i-1,26)))+T(i-1,26)
      T(i,27)=(fox*(T(i-1,26)+T(i-1,28)-2*T(i-1,27)))+(foy*(T(i-1,16)+T(
     +     i-1,37)-2*T(i-1,27)))+T(i-1,27)
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      T(i,28)=(fox*(T(i-1,27)+T(i-1,29)-2*T(i-1,28)))+(foy*(T(i-1,17)+T(
     +       i-1,38)-2*T(i-1,28)))+T(i-1,28)
      T(i,29)=(fox*(T(i-1,28)+T(i-1,30)-2*T(i-1,29)))+(foy*(T(i-1,18)+T(
     +       i-1,39)-2*T(i-1,29)))+T(i-1,29)
      T(i,30)=(foy*T(i-1,19))+(foy*T(i-1,40))+(fox*T(i-1,29))+((1-2*foy
     +      -fox)*T(i-1,30))+(q/4)
      T(i,31)=(foy*T(i-1,21))+(foy*T(i-1,42))+(fox*T(i-1,32))+((1-2*foy
     +      -fox)*T(i-1,31))+(q/4)
      T(i,32)=(2*fox*(T(i-1,31)-T(i-1,32)))+(2*bixlco*fox*(Tinf-T(i-1,32
     +       )))+(foy*(T(i-1,43)+T(i-1,22)-2*T(i-1,32)))+T(i-1,32)
*     Row 4
      T(i,33)=(2*fox*(T(i-1,34)-T(i-1,33)))+foy*(T(i-1,23)+T(i-1,44)-2*T
     +       (i-1,33))+T(i-1,33)
      T(i,34)=(fox*(T(i-1,33)+T(i-1,35)-2*T(i-1,34)))+(foy*(T(i-1,24)+T(
     +       i-1,45)-2*T(i-1,34)))+T(i-1,34)
      T(i,35)=(fox*(T(i-1,34)+T(i-1,36)-2*T(i-1,35)))+(foy*(T(i-1,25)+T(
     +       i-1,46)-2*T(i-1,35)))+T(i-1,35)
      T(i,36)=(fox*(T(i-1,35)+T(i-1,37)-2*T(i-1,36)))+(foy*(T(i-1,26)+T(
     +       i-1,47)-2*T(i-1,36)))+T(i-1,36)
      T(i,37)=(fox*(T(i-1,36)+T(i-1,38)-2*T(i-1,37)))+(foy*(T(i-1,27)+T(
     +       i-1,48)-2*T(i-1,37)))+T(i-1,37)
      T(i,38)=(fox*(T(i-1,37)+T(i-1,39)-2*T(i-1,38)))+(foy*(T(i-1,28)+T(
     +       i-1,49)-2*T(i-1,38)))+T(i-1,38)
      T(i,39)=(fox*(T(i-1,38)+T(i-1,40)-2*T(i-1,39)))+(foy*(T(i-1,29)+T(
     +       i-1,50)-2*T(i-1,39)))+T(i-1,39)
      T(i,40)=(fox*(T(i-1,39)+T(i-1,41)-2*T(i-1,40)))+(foy*(T(i-1,30)+T(
     +       i-1,51)-2*T(i-1,40)))+T(i-1,40)
      T(i,41)=(foy*T(i-1,52))+(fox*T(i-1,40))+(fox*T(i-1,42))+((1-2*fox
     +       -foy)*T(i-1,41))+(q/4)
      T(i,42)=(fox*(T(i-1,41)+T(i-1,43)-2*T(i-1,42)))+(foy*(T(i-1,31)+T(
     +       i-1,53)-2*T(i-1,42)))+T(i-1,42)
      T(i,43)=(2*fox*(T(i-1,42)-T(i-1,43)))+(2*bixlco*fox*(Tinf-T(i-1,43
     +       )))+(foy*(T(i-1,54)+T(i-1,32)-2*T(i-1,43)))+T(i-1,43)
*     Row 5
      T(i,44)=(2*fox*(T(i-1,45)-T(i-1,44)))+foy*(T(i-1,33)+T(i-1,55)-2*T
     +       (i-1,44))+T(i-1,44)
      T(i,45)=(fox*(T(i-1,44)+T(i-1,46)-2*T(i-1,45)))+(foy*(T(i-1,34)+T(
     +       i-1,56)-2*T(i-1,45)))+T(i-1,45)
      T(i,46)=(fox*(T(i-1,45)+T(i-1,47)-2*T(i-1,46)))+(foy*(T(i-1,35)+T(
     +       i-1,57)-2*T(i-1,46)))+T(i-1,46)
      T(i,47)=(foy*T(i-1,36))+(fox*T(i-1,46))+(fox*T(i-1,48))+((1-2*fox
     +       -foy)*T(i-1,47))+(q/4)
      T(i,48)=(fox*(T(i-1,47)+T(i-1,49)-2*T(i-1,48)))+(foy*(T(i-1,37)+T(
     +       i-1,58)-2*T(i-1,48)))+T(i-1,48)
      T(i,49)=(fox*(T(i-1,48)+T(i-1,50)-2*T(i-1,49)))+(foy*(T(i-1,38)+T(
     +       i-1,59)-2*T(i-1,49)))+T(i-1,49)
      T(i,50)=(fox*(T(i-1,49)+T(i-1,51)-2*T(i-1,50)))+(foy*(T(i-1,39)+T(
     +       i-1,60)-2*T(i-1,50)))+T(i-1,50)
      T(i,51)=(fox*(T(i-1,50)+T(i-1,52)-2*T(i-1,51)))+(foy*(T(i-1,40)+T(
     +       i-1,61)-2*T(i-1,51)))+T(i-1,51)
      T(i,52)=(fox*(T(i-1,51)+T(i-1,53)-2*T(i-1,52)))+(foy*(T(i-1,41)+T(
     +       i-1,62)-2*T(i-1,52)))+T(i-1,52)
      T(i,53)=(fox*(T(i-1,52)+T(i-1,54)-2*T(i-1,53)))+(foy*(T(i-1,42)+T(
     +       i-1,63)-2*T(i-1,53)))+T(i-1,53)
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      T(i,54)=(2*fox*(T(i-1,53)-T(i-1,54)))+(2*bixlco*fox*(Tinf-T(i-1,54
     +      )))+(foy*(T(i-1,64)+T(i-1,43)-2*T(i-1,54)))+T(i-1,54)
*     Row 6
      T(i,55)=(2*fox*(T(i-1,56)-T(i-1,55)))+foy*(T(i-1,44)+T(i-1,65)-2*T
     +      (i-1,55))+T(i-1,55)
      T(i,56)=(fox*(T(i-1,55)+T(i-1,57)-2*T(i-1,56)))+(foy*(T(i-1,45)+T
     +      (i-1,66)-2*T(i-1,56)))+T(i-1,56)
      T(i,57)=(fox*T(i-1,56))+(foy*T(i-1,46))+(foy*T(i-1,67))+((1-2*foy
     +      -fox)*T(i-1,57))+(q/4)
      T(i,58)=(fox*T(i-1,59))+(foy*T(i-1,48))+(foy*T(i-1,69))+((1-2*foy
     +      -fox)*T(i-1,58))+(q/4)
      T(i,59)=(fox*(T(i-1,58)+T(i-1,60)-2*T(i-1,59)))+(foy*(T(i-1,49)+T(
     +      i-1,70)-2*T(i-1,59)))+T(i-1,59)
      T(i,60)=(fox*(T(i-1,59)+T(i-1,61)-2*T(i-1,60)))+(foy*(T(i-1,50)+T(
     +      i-1,71)-2*T(i-1,60)))+T(i-1,60)
      T(i,61)=(fox*(T(i-1,60)+T(i-1,62)-2*T(i-1,61)))+(foy*(T(i-1,51)+T(
     +      i-1,72)-2*T(i-1,61)))+T(i-1,61)
      T(i,62)=(fox*(T(i-1,61)+T(i-1,63)-2*T(i-1,62)))+(foy*(T(i-1,52)+T(
     +      i-1,73)-2*T(i-1,62)))+T(i-1,62)
      T(i,63)=(fox*(T(i-1,62)+T(i-1,64)-2*T(i-1,63)))+(foy*(T(i-1,53)+T(
     +      i-1,74)-2*T(i-1,63)))+T(i-1,63)
      T(i,64)=(2*fox*(T(i-1,63)-T(i-1,64)))+(2*bixlco*fox*(Tinf-T(i-1,64
     +      )))+(foy*(T(i-1,75)+T(i-1,54)-2*T(i-1,64)))+T(i-1,64)
*     Row 7
      T(i,65)=(2*fox*(T(i-1,66)-T(i-1,65)))+foy*(T(i-1,55)+T(i-1,76)-2*T
     +      (i-1,65))+T(i-1,65)
      T(i,66)=(fox*(T(i-1,65)+T(i-1,67)-2*T(i-1,66)))+(foy*(T(i-1,56)+T(
     +      i-1,77)-2*T(i-1,66)))+T(i-1,66)
      T(i,67)=(fox*(T(i-1,66)+T(i-1,68)-2*T(i-1,67)))+(foy*(T(i-1,57)+T(
     +      i-1,78)-2*T(i-1,67)))+T(i-1,67)
      T(i,68)=foy*T(i-1,79)+fox*T(i-1,67)+fox*T(i-1,69)+((1-2*fox-foy)*T
     +      (i-1,68))+(q/4)
      T(i,69)=(fox*(T(i-1,68)+T(i-1,70)-2*T(i-1,69)))+(foy*(T(i-1,58)+T(
     +      i-1,80)-2*T(i-1,69)))+T(i-1,69)
      T(i,70)=(fox*(T(i-1,69)+T(i-1,71)-2*T(i-1,70)))+(foy*(T(i-1,59)+T(
     +      i-1,81)-2*T(i-1,70)))+T(i-1,70)
      T(i,71)=(fox*(T(i-1,70)+T(i-1,72)-2*T(i-1,71)))+(foy*(T(i-1,60)+T(
     +      i-1,82)-2*T(i-1,71)))+T(i-1,71)
      T(i,72)=(fox*(T(i-1,71)+T(i-1,73)-2*T(i-1,72)))+(foy*(T(i-1,61)+T(
     +      i-1,83)-2*T(i-1,72)))+T(i-1,72)
      T(i,73)=(fox*(T(i-1,72)+T(i-1,74)-2*T(i-1,73)))+(foy*(T(i-1,62)+T(
     +      i-1,84)-2*T(i-1,73)))+T(i-1,73)
      T(i,74)=(fox*(T(i-1,73)+T(i-1,75)-2*T(i-1,74)))+(foy*(T(i-1,63)+T(
     +      i-1,85)-2*T(i-1,74)))+T(i-1,74)
      T(i,75)=(2*fox*(T(i-1,74)-T(i-1,75)))+(2*bixlco*fox*(Tinf-T(i-1,75
     +      )))+(foy*(T(i-1,86)+T(i-1,64)-2*T(i-1,75)))+T(i-1,75)
*     Row 8
      T(i,76)=(2*fox*(T(i-1,77)-T(i-1,76)))+foy*(T(i-1,65)+T(i-1,87)-2*T
     +      (i-1,76))+T(i-1,76)
      T(i,77)=(fox*(T(i-1,76)+T(i-1,78)-2*T(i-1,77)))+(foy*(T(i-1,66)+T(
     +      i-1,88)-2*T(i-1,77)))+T(i-1,77)
      T(i,78)=(fox*(T(i-1,77)+T(i-1,79)-2*T(i-1,78)))+(foy*(T(i-1,67)+T(
     +      i-1,89)-2*T(i-1,78)))+T(i-1,78)
      T(i,79)=(fox*(T(i-1,78)+T(i-1,80)-2*T(i-1,79)))+(foy*(T(i-1,68)+T(
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+      i-1,90)-2*T(i-1,79)))+T(i-1,79)
       T(i,80)=(fox*(T(i-1,79)+T(i-1,81)-2*T(i-1,80)))+(foy*(T(i-1,69)+T(
+      i-1,91)-2*T(i-1,80)))+T(i-1,80)
       T(i,81)=(fox*(T(i-1,80)+T(i-1,82)-2*T(i-1,81)))+(foy*(T(i-1,70)+T(
+      i-1,92)-2*T(i-1,81)))+T(i-1,81)
       T(i,82)=(fox*(T(i-1,81)+T(i-1,83)-2*T(i-1,82)))+(foy*(T(i-1,71)+T(
+      i-1,93)-2*T(i-1,82)))+T(i-1,82)
       T(i,83)=(fox*(T(i-1,82)+T(i-1,84)-2*T(i-1,83)))+(foy*(T(i-1,72)+T(
+      i-1,94)-2*T(i-1,83)))+T(i-1,83)
       T(i,84)=(fox*(T(i-1,83)+T(i-1,85)-2*T(i-1,84)))+(foy*(T(i-1,73)+T(
+      i-1,95)-2*T(i-1,84)))+T(i-1,84)
       T(i,85)=(fox*(T(i-1,84)+T(i-1,86)-2*T(i-1,85)))+(foy*(T(i-1,74)+T(
+      i-1,96)-2*T(i-1,85)))+T(i-1,85)
       T(i,86)=(2*fox*(T(i-1,85)-T(i-1,86)))+(2*bixlco*fox*(Tinf-T(i-1,86
+      )))+(foy*(T(i-1,97)+T(i-1,75)-2*T(i-1,86)))+T(i-1,86)
*      Row 9
       T(i,87)=(2*fox*(T(i-1,88)))+(2*biybco*foy*Tinf)+(2*foy*T(i-1,76))+
+      (1-2*foy-2*biybco*foy-2*fox)*T(i-1,87)
       T(i,88)=fox*T(i-1,87)+fox*T(i-1,89)+2*biybco*foy*Tinf+2*foy*T(i-1,
+      77)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,88)
       T(i,89)=fox*T(i-1,88)+fox*T(i-1,90)+2*biybco*foy*Tinf+2*foy*T(i-1,
+      78)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,89)
       T(i,90)=fox*T(i-1,89)+fox*T(i-1,91)+2*biybco*foy*Tinf+2*foy*T(i-1,
+      79)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,90)
       T(i,91)=fox*T(i-1,90)+fox*T(i-1,92)+2*biybco*foy*Tinf+2*foy*T(i-1,
+      80)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,91)
       T(i,92)=fox*T(i-1,91)+fox*T(i-1,93)+2*biybco*foy*Tinf+2*foy*T(i-1,
+      81)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,92)
       T(i,93)=fox*T(i-1,92)+fox*T(i-1,94)+2*biybco*foy*Tinf+2*foy*T(i-1,
+      82)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,93)
       T(i,94)=fox*T(i-1,93)+fox*T(i-1,95)+2*biybco*foy*Tinf+2*foy*T(i-1,
+      83)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,94)
       T(i,95)=fox*T(i-1,94)+fox*T(i-1,96)+2*biybco*foy*Tinf+2*foy*T(i-1,
+      84)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,95)
       T(i,96)=fox*T(i-1,95)+fox*T(i-1,97)+2*biybco*foy*Tinf+2*foy*T(i-1,
+      85)+(1-2*foy-2*biybco*foy-2*fox)*T(i-1,96)
       T(i,97)=2*fox*T(i-1,96)+2*bixlco*fox*Tinf+2*biybco*foy*Tinf+2*foy*
+      T(i-1,86)+(1-2*foy-2*biybco*foy-2*bixlco*fox-2*fox)*T(i-1,97)

       l=l+1
       if(iprint.ne.jprint) goto 35
       iprint=0
       m=1
       print*,'iteration',l
*      row 1
       print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
+      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
       j=12
       m=2
*      row 2
       print 31,m,T(l,j),T(l,j+1),T(l,j+2),T(l,j+3),T(l,j+4),T(l,j+5),T(l
+      ,j+6),T(l,j+7),T(l,j+8),T(l,j+9),T(l,j+10)
       j=23
       m=3
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*     row 3
      print 32,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9)
      j=33
      m=4
*     row 4
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=44
      m=5
*     row 5
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=55
      m=6
*     row 6
      print 33,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9)
      j=65
      m=7
*     row 7
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(1,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=76
      m=8
      Tinf=300
*     row 8
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(i,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
      j=87
      m=9
*     row 9
      print 31,m,T(1,j),T(1,j+1),T(1,j+2),T(1,j+3),T(1,j+4),T(i,j+5),T(1
     +     ,j+6),T(1,j+7),T(1,j+8),T(1,j+9),T(1,j+10)
        if(l.lt.countt)then
      goto 60
      else
      print*,'Calculation terminated in cooling due to too many
     +      iterations!'
      goto 40
      endif

 60   if (T(i,1).gt.cornert)then
         goto 35
         else
         print*,'The Process Has Ended'
         goto 40
         endif
 40   end
```

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