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# Modeling of Electrofusion Coils for Performance Optimization

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**Abstract**

Modeling physical parameters provides a virtual design environment allowing the confirmation and optimization of electrofusion characteristics. Finite element incorporate physical parameters and their interactions along common boundaries defined within a model geometry. The electrofusion of polymeric piping is a widely accepted means of assembling piping systems with zero-leakage integrity. The key parameters in the fusion process are the coil resistance, the current passing through the coil and the time the current is applied. Modeling the coil and applying current to the model is accomplished using the MATLAB partial differential equations (PDE) toolbox. This paper presents the method of modeling and the results from changing the various fusion parameters such as time and current. Both the parameters and outputs are illustrated in various configurations.

## Introduction

Electrofusion is a widely accepted means of joining polymer piping into a containment system. Specifically, resistive heating is utilized to change the state of polymers thereby joining two separate pieces into a system. A conductive coil is molded into a socket and a mating pipe is inserted to create a piping system. A large current (60-90 amps) is driven through the conductive coil to generate resistive heating, melt the plastic near the coil and pipe, and join the two elements into a system. The heat transferred to the surrounding polymer changes the state of the polymer from a solid to a liquid and joins separate pieces into a common system.

Modeling the electrofusion process provides a virtual design and development environment where the parameters of material properties, current and time can be simulated for performance optimization.

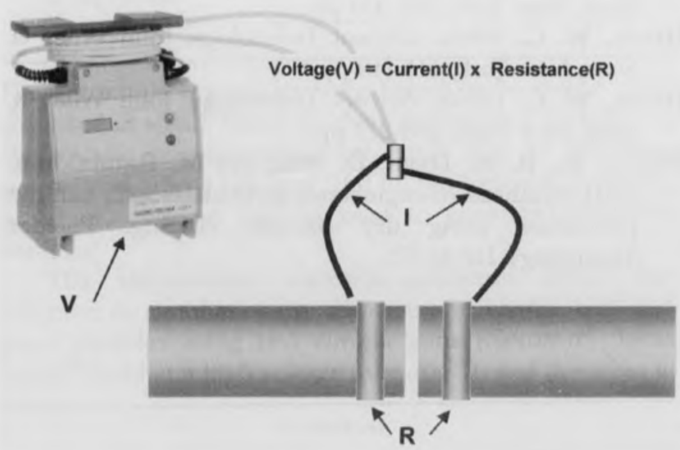


Fig. 1. Electrofusion process.

## Materials and Methods

The piping electrofusion process, shown in Fig. 1, is accomplished by first joining separate pieces of pipe and fittings, creating a current loop through the joining region and creating a voltage drop to drive the current. The voltage drop is created using a transformer-based fusion machine designed to provide a constant potential across the coil even as the resistive load changes with temperature.

Modeling the electrofusion process is begun by drawing, to scale, the geometry of the pipe joining components shown in Fig. 2. The platform for modeling is the Partial Differential Toolbox (PDE) with MATLAB, available from The Mathworks, Inc., Natick, Massachusetts. The PDE toolbox allows various analysis configurations such as electrostatic, stress and heat transfer. The heat transfer mode is used to model the electrofusion process since the heat flux between the copper and surrounding polymer is analyzed. (One note of caution in that the PDE toolbox does not automatically assign units to each value. It is recommended that the designer choose a system of units, such as metric or imperial, and maintain those units throughout the modeling process).

The next step, after drawing the geometry of the electrofusion process, is to enter the PDE specification for each material. A choice of elliptic or parabolic FEM is made

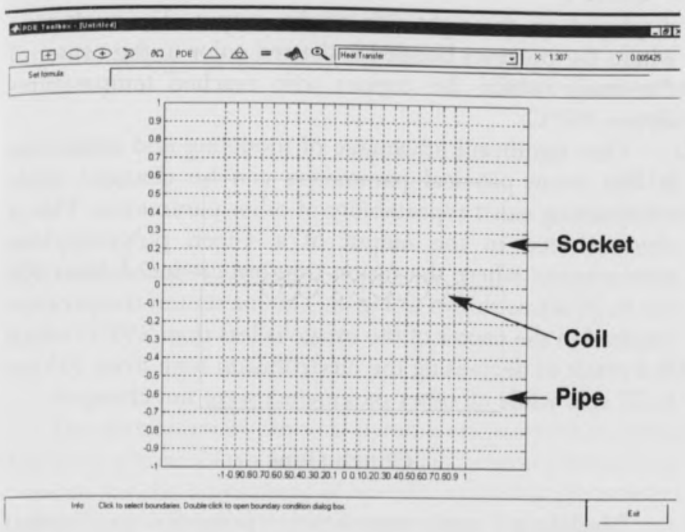


Fig. 2. Geometry in PDE toolbox draw-mode.

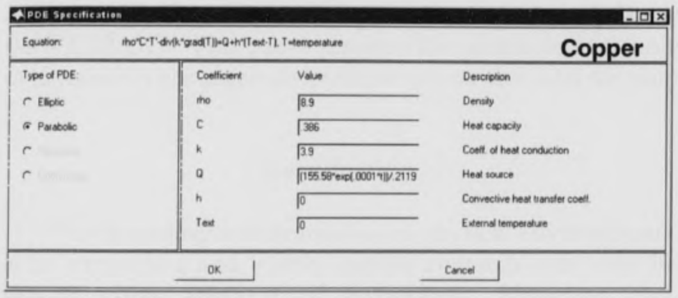


Figure 3. PDE specification parameters.

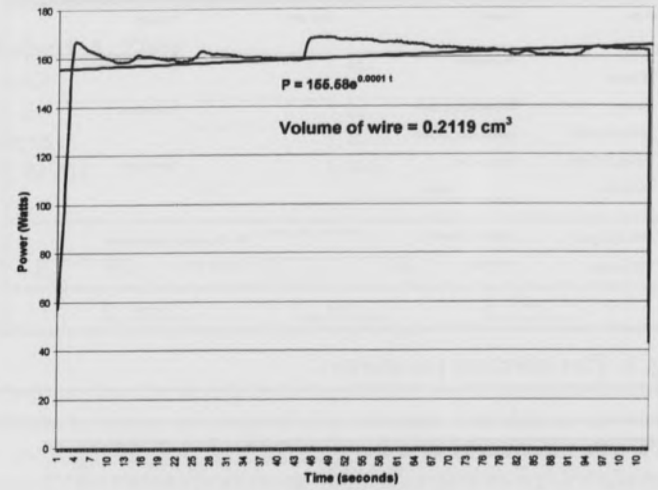


Fig. 4. Energy generated by fusion machine.

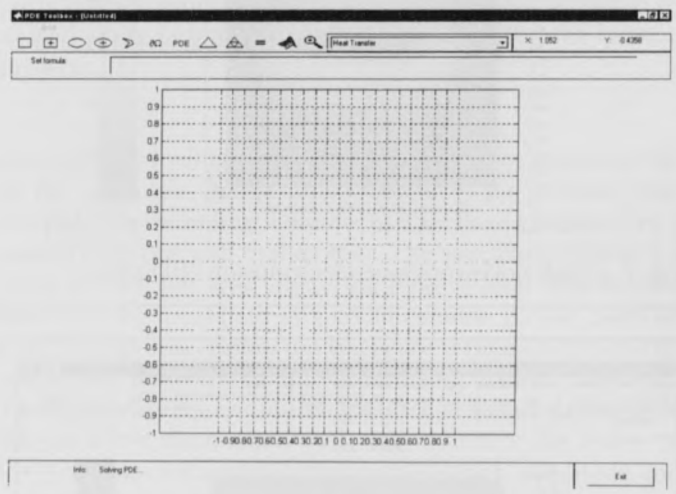

Fig. 5. Meshing during the FEM process.

depending upon the terms in the partial differential equation. In this case parabolic is selected to include material density (rho) and heat capacity (C) in the analysis. The remainder of parameters are entered as shown in Fig. 3 for the copper coils. The copper PDE specification is shown due to the unique heat source (Q) property that must be calculated.

The heat source is calculated via data acquisition by measuring the power output (Watts) of the fusion machine during a typical fusion process. The data is transferred to MS Excel and a trendline is assigned. The trendline represents the energy (joules/sec) that is produced by the fusion machine during the electrofusion process as shown in Fig. 4 for a 4-inch coil. The energy is then divided by the volume of the copper wire in each coil to calculate the volumetric heat flux generated by the copper.

The mesh is then initiated after the PDE specifications are complete as shown in Fig. 5. After the mesh is completed, the solve parameters of fusion time, initial temperature (u(t0)), relative tolerance and absolute tolerance are entered. The plot parameters are selected as shown in Fig. 6 and the simulation is executed. The results of the simulation are displayed and analyzed for dimensions of the polymer melt-zones and the maximum polymer temperature within each zone. As well, each of the fusion parameters are exactly repeatable and can be varied to demonstrate the affect of each polymer electrofusion process.

## Results

The results of simulation are shown in Fig. 7 for a 4-inch pipe, socket and coil. The pipe and socket are made of

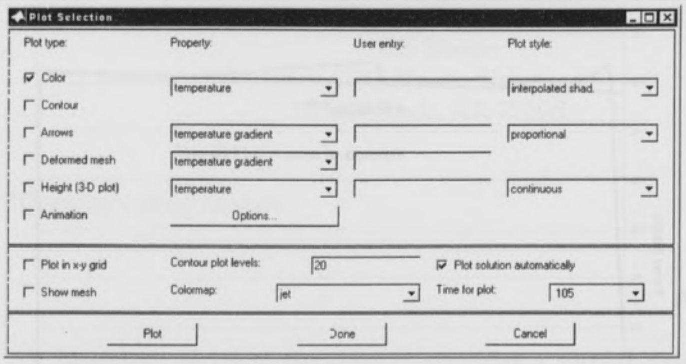


Fig. 6. Plot selection parameters.

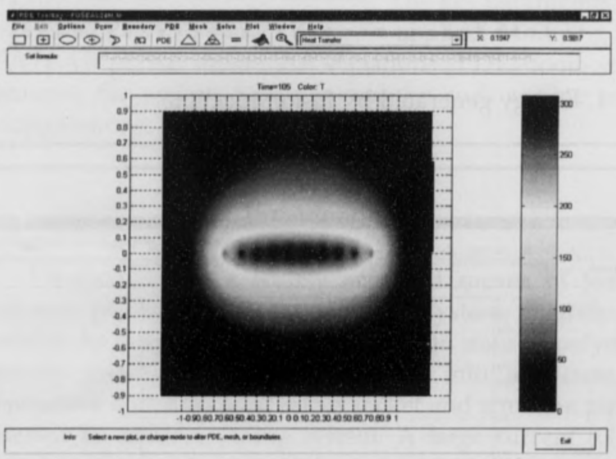


Fig. 7. 4-inch polypropylene electrofusion (105 sec).

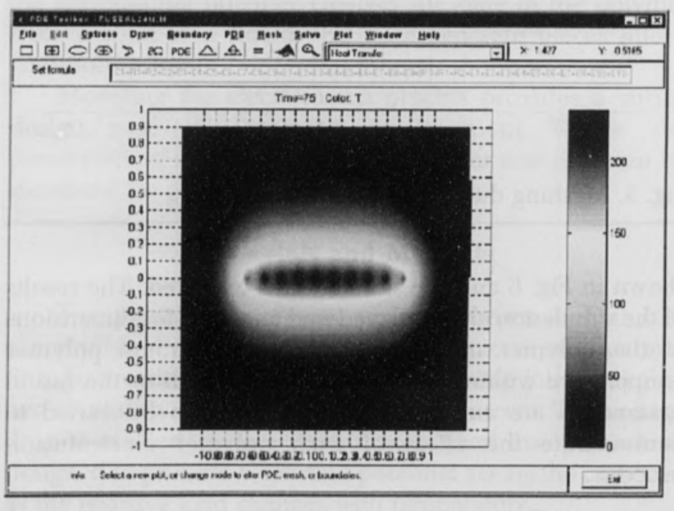


Fig. 8. 4-inch polypropylene electrofusion (75 sec).

polypropylene and the coil is copper with a polypropylene casing around each wire. The applied potential across the coil is 16.9 volts for 105 seconds. The final temperature is displayed on the right side of the output. The melt-zone where the polymer bonded is the red color in the center of the image where the copper wire reached temperatures above 300°C.

One significant advantage of modeling and simulation is that some physical parameters can be changed while maintaining exact repeatability of other parameters. This is demonstrated in the output of a 4-inch polypropylene electrofusion where the fusion time was reduced from 105 sec to 75 sec as shown in Fig. 8. The maximum temperature reached in the center of the image is less than 250°C which is a result of decreasing the electrofusion time from 105 sec to 75 secs while all other parameters were not changed.

## Conclusions

Modeling and simulation provides a virtual development environment free from requirements to change physical parameters in determining their affect. The flexibility of a virtual environment eliminates vast resources traditionally used to create new products and processes while shortening the development cycle.