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Design and Analysis for Melt Casting Metallic Fuel Pins Incorporating Volatile Actinides: Quarterly Progress Report 11/16/01- 2/15/02

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Phase I: Design and Analysis for Melt Casting Metallic Fuel Pins Incorporating Volatile Actinides

Quarterly Progress Report
11/16/01- 2/15/02

UNLV-AAA University Participation Program

Principle Investigator: Yitung Chen
Co-Principle Investigators: Randy Clarksean and Darrell Pepper

Purpose and Problem Statement

An important aspect of the Advanced Accelerator Applications (AAA) program is the development of a casting process by which volatile actinide element (i.e., americium) can be incorporated into metallic alloy fuel pins. The traditional metal fuel casting process uses an inductively heated crucible. The process involves evacuation of the furnace. The evacuation of the furnace also evacuates quartz rods used as fuel pin molds. Once evacuated the open ends of the molds are lowered into the melt; the casting furnace is then rapidly pressurized, forcing the molten metal up into the evacuated molds where solidification occurs.

This process works well for the fabrication of metal fuel pins traditionally composed of alloys of uranium and plutonium, but does not work well when highly volatile actinides are included in the melt. The problem occurs both during the extended time period required to superheat the alloy melt as well as when the chamber must be evacuated. The low vapor-pressure actinides, particularly americium, are susceptible to rapid vaporization and transport throughout the casting furnace, resulting in only a fraction of the charge being incorporated into the fuel pins as desired. This is undesirable both from a materials accountability standpoint as well as from the failure to achieve the objective of including these actinides in the fuel for transmutation.

Candidate design concepts are being evaluated for their potential to successfully cast alloys containing volatile actinides. The selection of design concepts has been conducted in close cooperation with ANL staff. The research centers on the development of advanced numerical models to assess conditions that significantly impact the transport of volatile actinides during the melt casting process. The work will include the collection and documentation of volatile actinide properties, development of several conceptual designs for melt casting furnaces, modeling and analysis of these concepts, development of sophisticated numerical models to assess furnace operations, and analysis of these operations to determine which furnace concept has the greatest potential of success. Research efforts will focus on the development of complex heat transfer, mass transfer, and inductive heating models.

Personnel

Principle Investigator:

- Dr. Yitung Chen (Mechanical Engineering)

Co-Principle Investigators:

- Dr. Randy Clarksean (Mechanical Engineering)
- Dr. Darrell Pepper (Mechanical Engineering)

Student:

- Mr. Xialong (Frank) Wu, M.S. Graduate Student, (Mechanical Engineering)

National Laboratory Collaborators:

- Dr. Mitch Meyer, Leader of Fabrication Development Group, ANL-West
- Dr. Steve Hayes, Manager of Fuels & Reactor Materials Section, Nuclear Technology Division, ANL-West

Management Progress

Budget Issues:

- The budget information is not shown correctly from the school accounting system in time because the employee documents and contracts have not correctly been done. The problem has been corrected in January, 2002.

Management Problems

We would like to make a request to carry over the first year budget to the second year. One undergraduate student will be recruited to work with us on this project in summer.

Technical Progress

The developmental work for the calculation of induction heating is nearing completion. The modeling efforts have centered around the development of the governing equations, developing a method to incorporate then into FIDAP, setting up a test problem, and making preliminary calculations for the geometry of interest. Complete details of the derivation and model development will be presented in the final report.

The resulting governing equations are shown below.

$$\left.\begin{aligned}\nabla\cdot(\tfrac{1}{r}\nabla C) &= -\mu J_o\\ \nabla\cdot(\tfrac{1}{r}\nabla S) &= 0\end{aligned}\right\} Coil \qquad (1)$$

$$\left.\begin{aligned} \nabla\cdot(\tfrac{1}{r}\nabla C) &= \frac{\mu\sigma\omega}{r}S \\ \nabla\cdot(\tfrac{1}{r}\nabla S) &= -\frac{\mu\sigma\omega}{r}C \end{aligned}\right\} Conductor \tag{2}$$

$$\left.\begin{aligned} \nabla\cdot(\tfrac{1}{r}\nabla C) &= 0 \\ \nabla\cdot(\tfrac{1}{r}\nabla S) &= 0 \end{aligned}\right\} Elsewhere \tag{3}$$

where

C, S = real and complex components of function substituted into governing equations to simplify solution process
r = radial coordinate
J_o = current density
μ = permeability
ω = frequency
σ = electrical conductivity

Using the appropriate relationships and integrating gives the heat deposition as a function of position.

$$Q(r,z) = \frac{\sigma\omega^2}{2r^2}\left[S^2 + C^2\right] \tag{4}$$

Surface plots of each of the functions, *C* and *S*, are shown in Figure 1 for a test problem. The test problem was taken from work previously reported in the literature. The domain consists of a crucible, a coil region, and a surrounding vessel. The regions of compressed mesh represent the crucible or coil regions. The left hand side image is the *C* variable and its greatest value occurs in the coil region. The right hand side image is the *S* variable and should be largest in the crucible region. Physically, each of these plots shows the proper trends and relationships for each of the variables in each of the regions of the mesh. Further work will be conducted to verify the solution and to calculate the power densities.

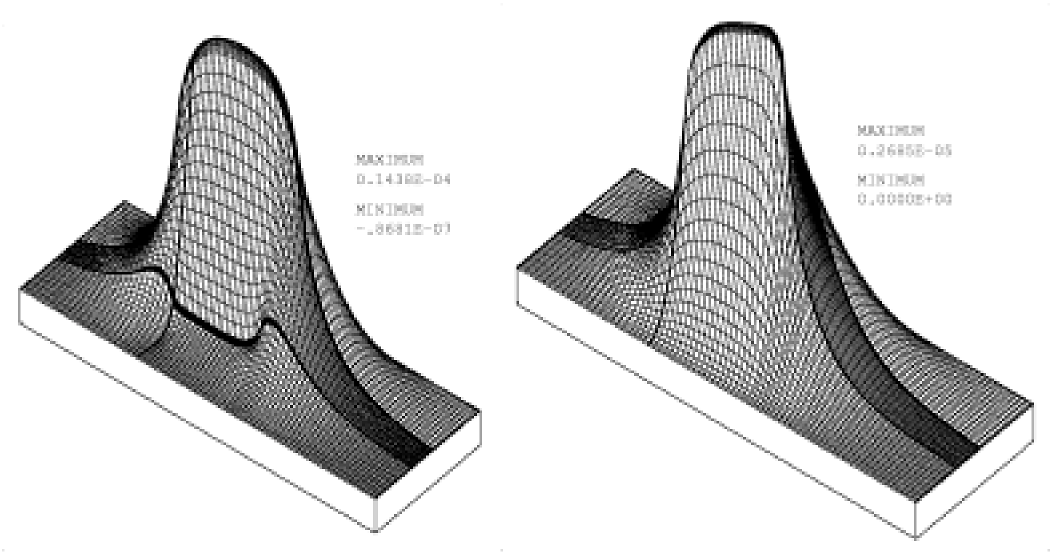

Figure 1 – Surface plots of the solution variables C and S for the analysis of the induction heating within an inductively heated furnace.

Modeling results for the injection into the mold have been completed and a parametric study is currently being undertaken. The general model geometry is shown below in Figure 2. The problem considers the flow of the melt into the mold and the heat transfer from the melt into the mold.

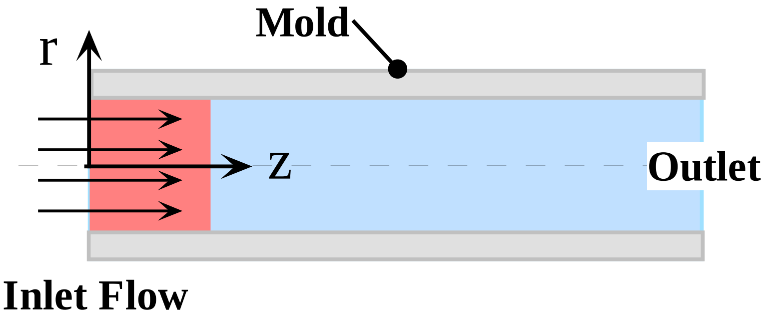

Figure 2 - Schematic of fuel rod casting model.

Figure 3 shows radial temperature profiles of the melt just behind the melt front as it advances into the mold. This region would be the melt region that would solidify most rapidly. The axial location for each of the temperature profiles is approximately located at the product of the velocity (1.6 m/sec) and the time.

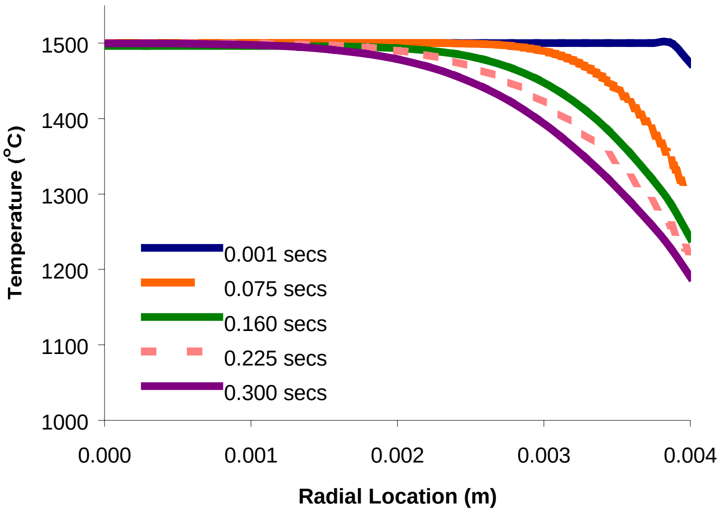

Figure 3 – Temperature profiles from the centerline projected radially outward for an initial mold temperature of 1000 ^{o}C. The axial location of each profile is slightly behind the front of the melt (location is the product of velocity times the time). Last profile is near the end of the mold.