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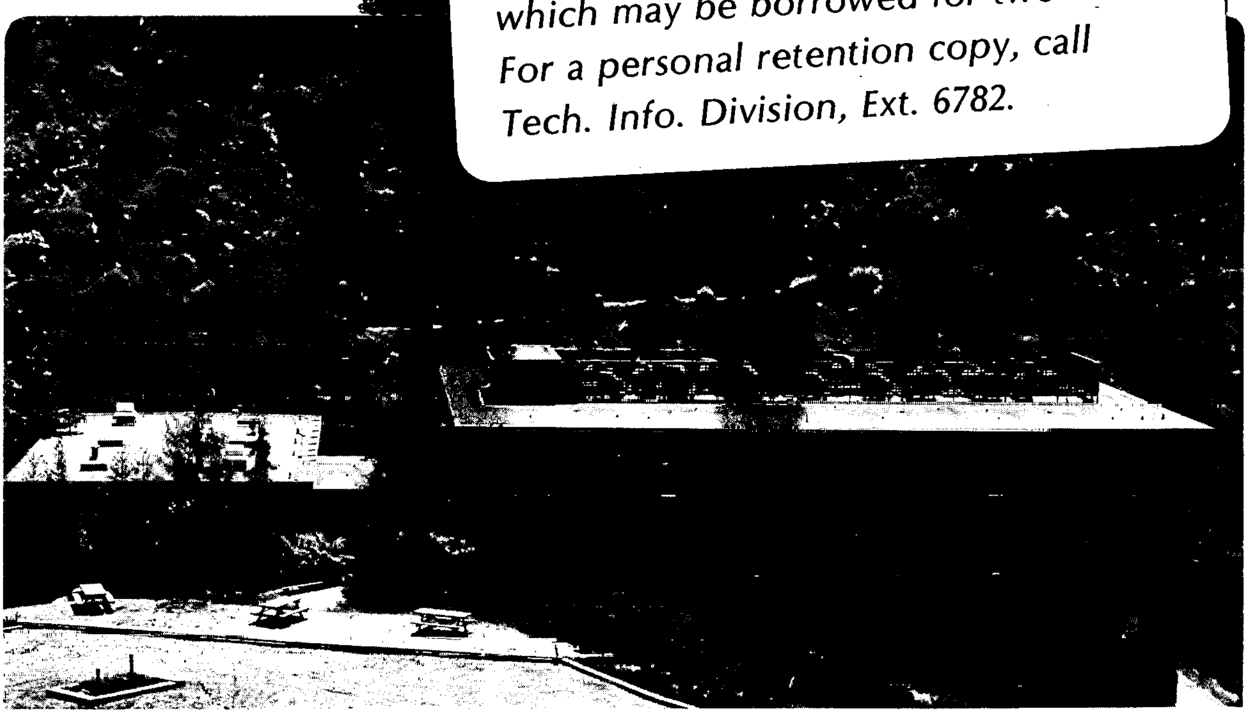

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AN IMPROVED MATHEMATICAL MODEL FOR MELT FLOW IN INDUCTION FURNACES AND COMPARISON WITH EXPERIMENTAL DATA

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There have been several recent studies (1-7) of electromagnetic stirring in induction furnaces or similar devices wherein currents are induced in a melt. These studies have entailed mathematical modeling, with the objective of predicting melt velocities, coupled with experimental measurements of velocity aimed at testing of the model's predictions. Velocity measurements in such melts are difficult and those presented in previous investigations are open to criticism. For example, Tarapore and Evans (2) measured surface velocities only in an investigation wherein pools of mercury up to 600 lb were inductively stirred using coils of various geometry. Agreement between prediction and measurement, in the case of surface velocities, may well be fortuitous since there is uncertainty in the mathematical modeling of turbulent flows at free surfaces. Similar criticisms can be made of the work of Tarapore et al. (3) and Szekely, Chang and Johnson (6) wherein surface velocites were measured for large scale steel melts. Tracer dispersion or radiotracer measurements reported by Szekely and Chang (4) are open to the criticism that the velocities obtained are averages over a considerable (and ill-defined) volume of melt and cannot therefore be directly compared with the velocities at a point obtained from mathematical modeling. The velocity measurements of Szekely, Chang and Ryan (5) are not subject to these criticisms. These investigators employed a reaction probe to measure velocites at a point within the body of an inductively stirred Woods metal melt. Unfortunately, the data are scant and the probe appears to have been capable of measuring only the vertical component of velocity while in induction furnaces substantial horizontal velocity components exist.

Recently a very thorough measurement of velocities throughout an inductively stirred mercury pool has been carried out by Moore and Hunt (7). These velocities were obtained using a reaction probe capable of measuring both horizontal and vertical velocity components. It is the purpose of this note to compare these experimental data with the predictions of a mathematical model. The mathematical model employed was an updated version of that of Tarapore and Evans (2). The model first solves Maxwell's equations to obtain the induced currents, magnetic fields and electromagnetic forces throughout the melt. The first part of the procedure consists of solving an integral equation for the current distribution within the melt. The solution is numerical and employs an unevenly spaced (Gaussian) grid. A subsequent numerical differentiation of this distribution yields the magnetic field. In the original version of the model such differentiation was facilitated by an intermediate interpolation from the Gaussian grid onto a second, evenly spaced, grid. In the updated version the differentiation is done directly from the Gaussian grid, with considerable improvement in precision.

From the electromagnetic force distribution the model carries out turbulent fluid flow calculations to obtain the velocities within the melt. The original computational procedure employed by Tarapore and Evans was replaced by one using the TEACH computer program developed at Imperial College, London, and nowadays widely available for fluid flow calculations. TEACH was modified to incorporate body forces and the free surface boundary conditions. In the language of turbulent flow modeling, TEACH employs primitive variables, wall functions and the k-ε representation of turbulence and is therefore significantly different from the prior flow modeling of Tarapore and Evans.

Fig. 1 provides a comparison between the velocity measurements of Moore and Hunt and the predictions of the mathematical modeling. The fit appears to be excellent (particularly since the model entails no adjustable parameters*). The location of the flow detachment point on the crucible wall (at about 15 cm height) and the location of the center of the upper vortex (at about 22 cm) are accurately predicted by the model. Less precise is the prediction of the location of the center of the lower vortex. The velocity predictions appear to match the experimental velocities with a precision better than previously achieved in such modeling. Hitherto it has been supposed that mathematical modeling of electromagnetically driven flows is accurate only to within a factor of two or three. The results presented here suggest that better experimental data and improvements in the model may result in a much greater degree of confidence in such predictions.

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*Strictly speaking the k-ε model for turbulence entails adjustable parameters. In this investigation the generally accepted values of these parameters (8) were used and no manipulation of the parameters was carried out to bring about the fit of Fig. 1.

ACKNOWLEDGEMENT

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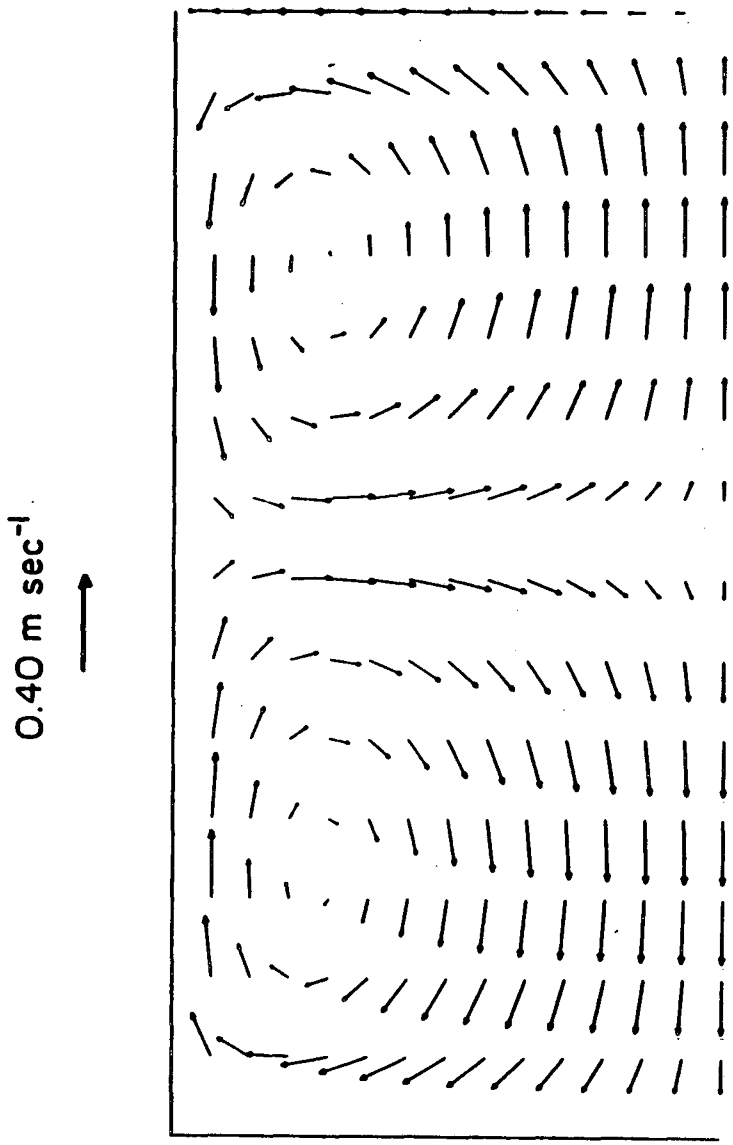
FIGURE CAPTION

1. A comparison of the computed velocity field (left of figure) and the measurements of Moore and Hunt (right of figure). The two velocity fields are shown as mirror images. Radius of melt = 0.15 m.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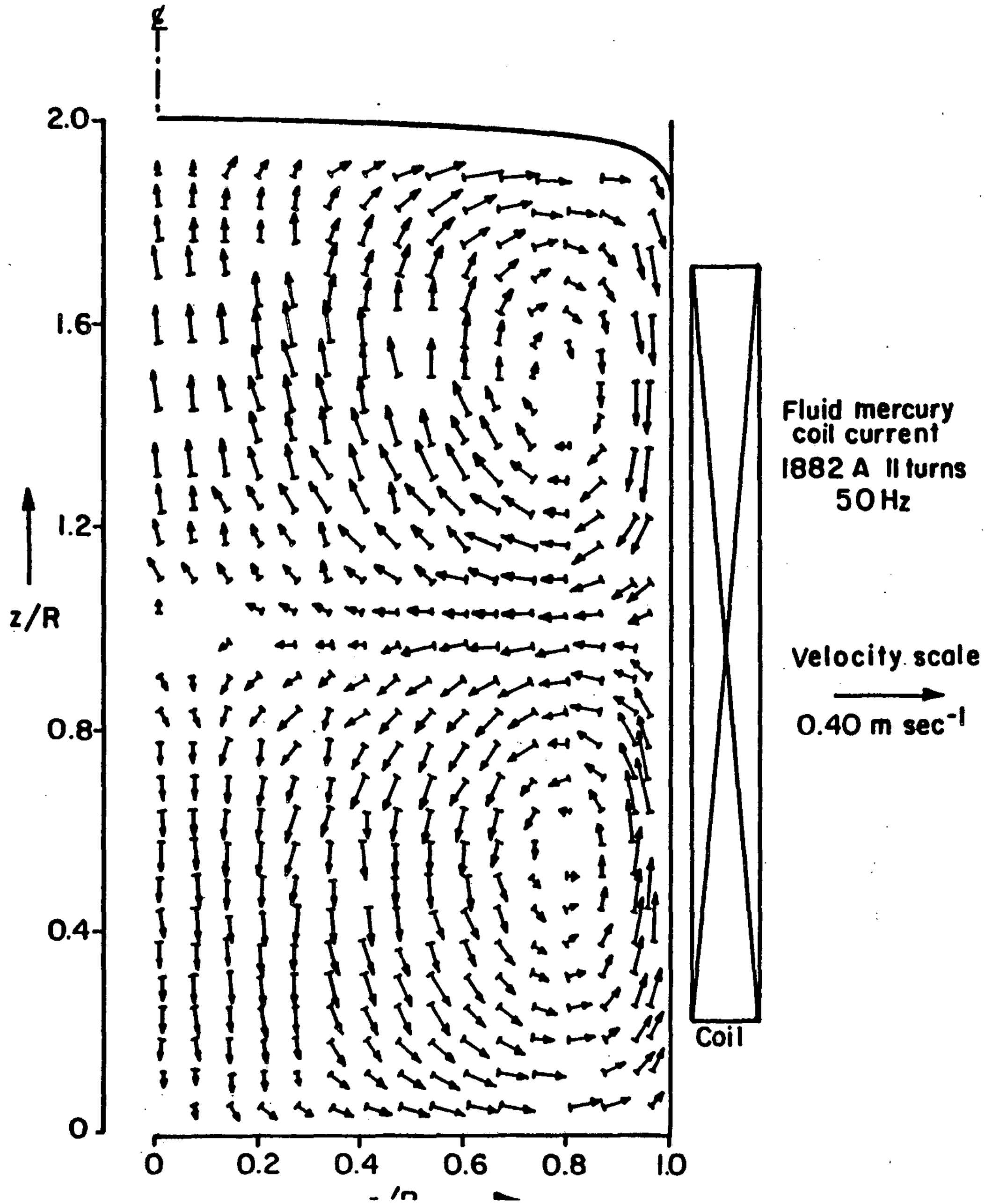
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0.6
0.8
1.0
Fluid mercury
coil current
1882 A 11 turns
50 Hz
Velocity scale
0.40 m sec^{-1}
Coil

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