

The Weisman-Pei correlation<sup>1</sup> did not fully account for the effect of flux distribution. It was found that  $\mu(R)$  decreased slightly as the axial offset (AO) was increased. By defining  $q_{DNB}^{design}$  as

$$q_{DNB}^{design} = q_{pred}^{*}(1.0 + 0.12 \text{ AO}) \quad (8)$$

where  $q_{pred}^{*}$  is the DNB heat flux predicted by the Weisman-Pei approach, we eliminate the axial offset effect. It was found that  $\mu(R) = 0.98$  and  $\sigma(R) = 0.09$  for the corrected predictions.

The analysis carried out shows that the proposed theoretically based DNB predictive procedure can be applied to rod bundles with simple grids. The fact that AO effects were small confirms the supposition that DNB at low qualities is primarily a local phenomenon.

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## 2. Turbulence Modeling in Buoyancy-Affected Liquid-Metal Pipe Flow, Marcelo J. S. de Lemos\* (PUC/RJ-Brazil), Alexander Sesonske (Purdue Univ)

Significant attention<sup>1</sup> has been devoted lately to the investigation of the role of body forces in convective heat

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transfer in liquid-metal fast breeder reactors (LMFBRs). The present research consisted of an investigation of the effect of buoyancy on the profiles of mean and turbulent quantities for the flow of mercury in a vertical heated pipe. To accomplish this goal, this work was divided into three parts: an algebraic stress model of turbulence was extended to liquid-metal flow; the model—in a simplified form—was applied to the geometry in question; and experimental work was performed to obtain a wall boundary condition specification for the equation for one-half of the variance of temperature fluctuations,  $g = \theta^2/2$ . The modeled equation for the turbulent kinetic energy,  $k$ , the rate of turbulent energy dissipation,  $\epsilon$ , and the Reynolds stresses,  $\bar{u}_i \bar{u}_j$ , were taken from the literature.<sup>2</sup> The modeling of the thermal field was extended to account for

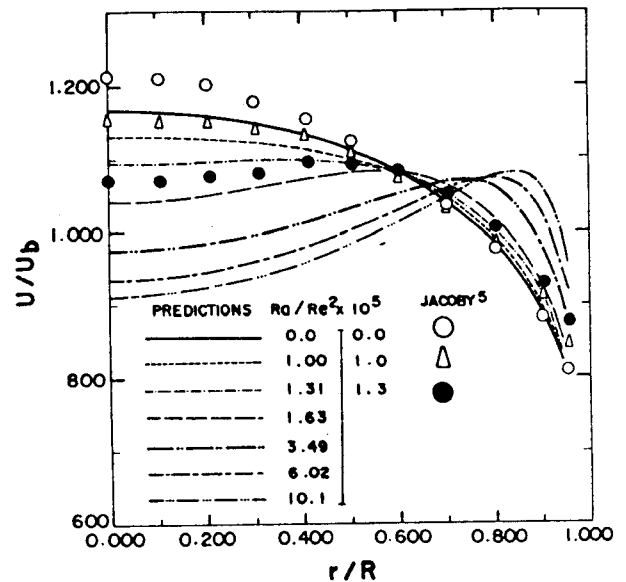


Fig. 1. Nondimensional mean velocity profile,  $Re = 30,000$ .

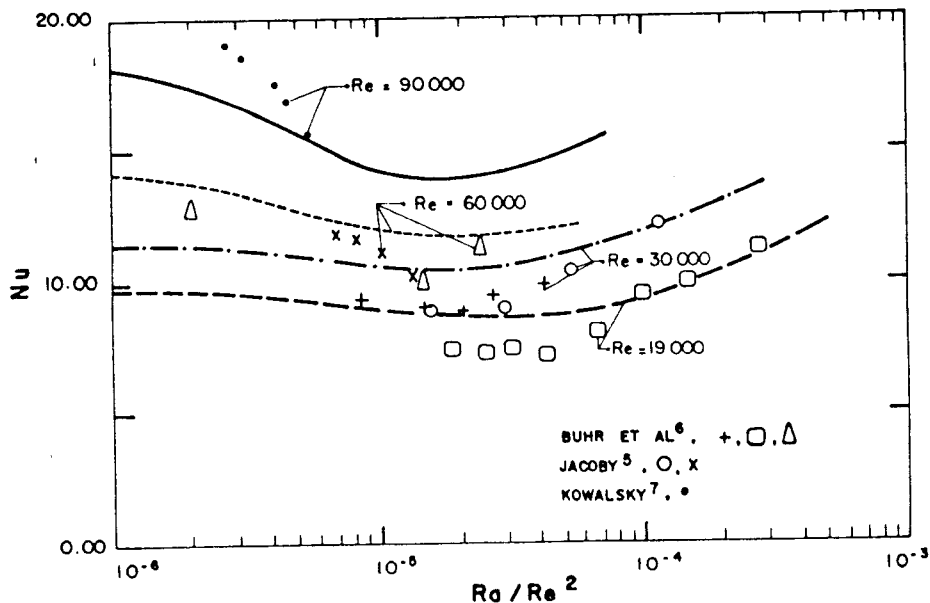


Fig. 2. Calculated Nusselt number as a function of  $Ra/Re^2$ .

$Pr \ll 1$  by making use of suggested forms<sup>5</sup> for the dissipative correlation in the  $u, \theta$  equation, and for the dissipative and turbulent diffusive terms in the  $g$  equation.<sup>3</sup> The model, written in its thin shear layer form, was embodied in the STAN5 computer code.<sup>4</sup> The required reprogramming consisted of a new treatment of the source terms for all turbulent quantities, implying a new set of coefficients for the finite difference equation. To provide a data base for wall boundary condition specification for the  $g$  equation, data for the temperature fluctuations were obtained for the near wall region ( $y^+ < 100$ ) for  $30,000 < Re < 60,000$  and  $1.0 \times 10^{-6} < Ra < 1.0 \times 10^{-3}$ , where  $Re$  is the Reynolds number, and  $Ra$  is the Rayleigh number.

The reduced data read:

$$\frac{\sqrt{2g}}{T^*} = y^+ Re^{0.0258} + 0.87 \times 10^{-5} Re,$$

where  $T^* = q_w / \rho c_p U^*$ , and  $U^*$  is the friction velocity.

The numerical results for isothermal mean and turbulent flow were found to be in agreement with experimental data for mercury and air. Nonisothermal calculations for the time-averaged flow were qualitatively in agreement with existing data.

Figure 1 shows the mean velocity,  $U$ , as a function of  $Ra/Re^2$ , compared with data of Jacoby.<sup>5</sup> Results for the turbulent parameters for heated flows are more difficult to evaluate due to lack of measurements under these conditions. Nevertheless, the initial damping and posterior enhancement of turbulent transfer as the  $Ra/Re^2$  increases is well calculated. These trends are shown in Fig. 2, where the predicted dependence of the Nusselt number with increasing  $Ra/Re^2$  is in agreement with measurements in liquid metals.<sup>5-7</sup>

The model also predicted the behavior of various turbulent structure quantities, including the effect of heating on turbulence energy and momentum transfer. Gravity was found to have an influence on the turbulent structure in the directions perpendicular to the gravity field as suggested by Launder.<sup>8</sup> Also of interest is a modeling confirmation of previously puzzling measured reversal of the turbulent axial heat flux.<sup>9</sup>

Although the research described was primarily concerned with the development of a predictive technique able to calculate the influence of buoyancy in a vertical heated turbulent flow of mercury in a pipe, the approach represents a first step toward the desired modeling of practical LMFBR systems.

However, particularly needed are additional experimental programs for measuring the turbulent correlations,  $u\theta$  and  $u\theta$ , to provide a better data base for modeling assumptions. In the case of the so-called "g equation," measurements of the contributing processes of turbulence diffusion, production, and dissipation would provide valuable insight for more reliable modeling.

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### 3. Turbulent Heat and Momentum Transport in an Infinite Rod Array, An-Shik Yang, Ching-Chang Chieng (Nat'l Tsing-Hua Univ-Taiwan)

In many cases, the surface temperature of fuel rods limits the thermal power of nuclear reactors, which is usually obtained after subchannel analysis. Subchannel analysis employs the average mass flow rate in each subchannel and the corresponding heat transfer coefficient from proper correlations to calculate the average bulk temperature of the subchannel and the surface temperature distribution of fuel rods. It is interesting to predict the detailed velocity and temperature distributions by solving the basic differential equations of the turbulent flow and energy. The " $k-\epsilon$ " turbulence model and the anisotropic eddy viscosity are the most advanced and widely used approaches for the calculation of turbulent heat and momentum transport in bare rod bundles.<sup>1</sup> Numerous anisotropic factor distributions,  $\psi$ , are proposed to take care of the pronounced anisotropic character within the subchannel. For this study, 11 distributions (see Table I) are adopted to calculate the axial velocity distribution, turbulent kinetic energy, and wall shear stress,  $\tau_w$ . After comparison with experimental data, the distribution

$$\psi = 30 \exp[-(3y/\delta)^2] + 1,$$

TABLE I

IDIV	$\psi$	Ref.
1	$0.7 + \frac{0.35}{1.0167 - Z}$	3
2	$\frac{1}{1.05 - Z}$	3
3	$\frac{1}{1.025 - Z}$	3
4	$\frac{1}{1.00625 - Z}$	3
5	$30 \exp[-(3y/\delta)^2] + 1$	3
6	$50 \exp[-(3y/\delta)^2] + 2$	3
7	$1.5 \times 4.79 \exp[0.99(0.4 - y/\delta)]$	3
8	$2.0\{y[1 - \exp(-0.018R_t)]\}$	2
9	$0.21\{y[0.25 + 0.66 \sin[\pi(y/\delta - 0.25)/0.55]]\}$	
10	$40 \exp[-(3.6y/\delta)^2] + 1$	Present work
11	$60 \exp[-(4.0y/\delta)^2] + 1.5$	Present work
	$30 \exp[-(4.0y/\delta)^2] + 1.5$	Present work
	$Z = 1 - y/\delta$	